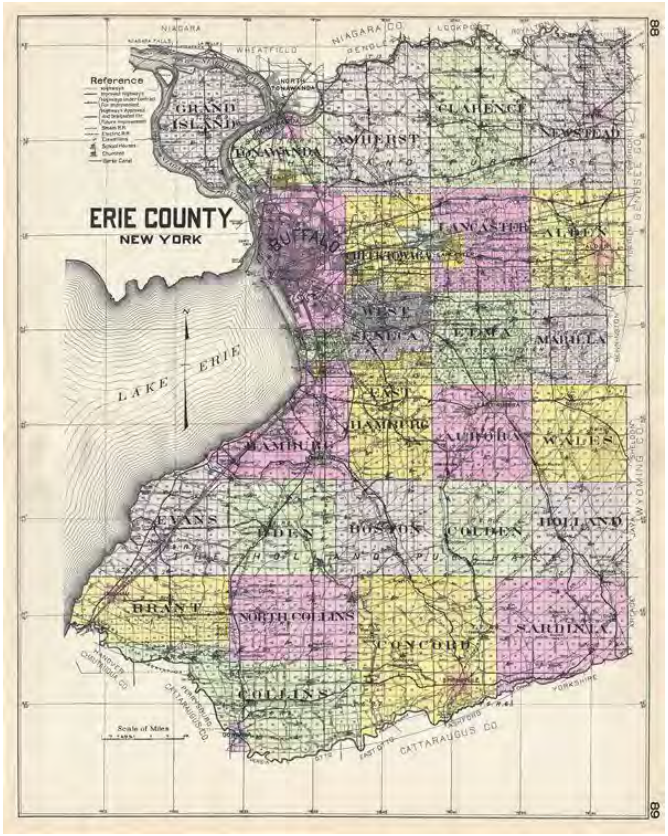
# Erie County Climate Vulnerability Assessment

## March 2023




**This project has been funded in part by the Climate Smart Community Grant Program, Title 15 of the Environmental Protection Fund through the NYS Department of Environmental Conservation.**

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*This document is a compilation of separately issued reports.  Within the reports are page numberings specific to the individual reports.*

August 12, 2022

# Erie County Climate Vulnerability Assessment: Executive Summary

**This project has been funded in part by the Climate Smart Community Grant Program, Title 15 of the Environmental Protection Fund through the NYS Department of Environmental Conservation**

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# ACKNOWLEDGEMENTS


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# INTRODUCTION

## Erie County's Climate is Changing

The Western NY region is already experiencing changing climate conditions. Some of the most noticeable changes are increasing temperatures and changing precipitation patterns[1]. Climate projections suggest that these trends will continue, especially under the most severe greenhouse gas emission scenarios[2]. These changing conditions present significant risks to Erie County and its residents. Particularly concerning are the disproportionate impacts that are expected for vulnerable populations (e.g., elderly, youth, and disadvantaged communities[3]). Some of the major implications that are expected include, but are not limited to, the following:

- Increased temperatures and more heat waves
- Enhanced intensity of both floods and drought
- Longer growing seasons, but changes in what is able to be effectively grown
- More variability in lake levels and increased shoreline erosion
- Warmer lake temperatures that exacerbate algal blooms, leading to polluted water
- Amplified threats to human health (e.g., reduced air quality, risk of disease-carrying insects, and extreme temperatures)

To contextualize these implications and integrate them into planning for Erie County and its residents, a Climate Vulnerability Assessment (CVA) for Erie County has been completed.

## What is a Climate Vulnerability Assessment?

Climate change can have significant impacts on local, regional, and national development efforts. To mitigate these impacts and promote more climate resilience in Erie County, the Department of Environment and Planning partnered with the University at Buffalo to conduct a Climate Vulnerability Assessment, which identifies some of the County's key climate threats and hazards, assesses how sensitive the County is to these threats, as well as the current capacity to handle these hazards at the County level. The results can inform strategic planning and other initiatives to reduce the impact of future events.

## Why is a Climate Vulnerability Assessment important?

Assessing and understanding Erie County's climate threats and impacts is essential for the County to prosper economically, socially, and environmentally. It is also critical for enabling the County to remain a safe, livable, and vibrant place to live and visit. This assessment seeks to

[1] Great Lakes Regional Integrates Sciences and Assessments Center (GLISA)(2021). 2021 Annual Report. Available: https://glisa.umich.edu/publication/2021-annual-report/

[2] New York State Energy Research and Development Authority (2014). Climate Change in New York State: Updated Climate Projections RepReport. Available: https://www.nyserda.ny.gov/-/media/Project/Nyserda/Files/Publications/Research/Environmental/ClimAID/2014-ClimAid-Report.pdf

[3] New York State Climate Act: Disadvantaged Communities Criteria. Available: https://climate.ny.gov/Our-Climate-Act/Disadvantaged-Communities-Criteria

inform strategic planning and future initiatives aimed at creating a more resilient and sustainable region.

## CLIMATE VULNERABILITY ASSESSMENT FRAMEWORK

The guiding framework used to complete the CVA for Erie County, breaks the assessment down into three major components: 1) exposure, 2) sensitivity, and 3) adaptive capacity, all three of which together determine the region's vulnerability to particular climate hazards and threats (as illustrated in Figure 1). *Exposure* identifies key climate threats and hazards pertinent to Erie County; *sensitivity* is the degree to which the region is affected by its exposure to identified threats and hazards; and *adaptive capacity* is the ability of the County to develop resilience and adjust to the threats and hazards it may face. These three aspects combine to inform climate vulnerability. For example, a highly vulnerable system would be a situation where a region is likely to experience many climate threats, the sensitivity to those threats is high, and adaptive capacity is considered low. Alternatively, if exposure to threats is relatively low, sensitivity is low and adaptive capacity is high, the region would have an overall low vulnerability. It is important to note that all three components are interlinked since increasing adaptive capacity to a particular hazard will likely reduce the region's sensitivity as well. The major sections of this executive summary will summarize each phase of this assessment, first exposure, then sensitivity, followed by adaptive capacity, and finally ending with overall vulnerability and next steps for Erie County, NY.

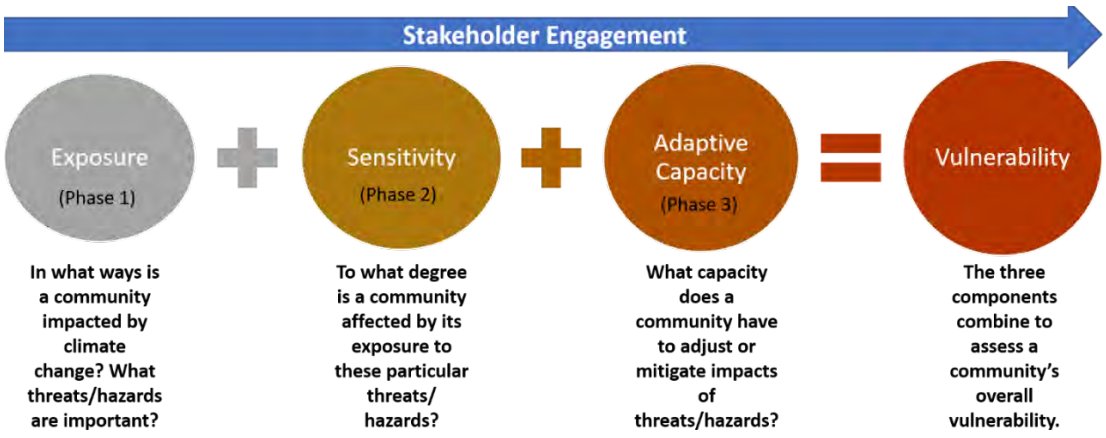



*Figure 1. Guiding framework to assess climate vulnerability for Erie County.*

### Stakeholder Engagement

The Erie County CVA emphasized input from both internal and external stakeholders. Internally, the project team benefited from guidance and feedback from the Erie County Green Team[4], an interdepartmental working group that focuses on County initiatives related to sustainability and climate topics. Externally, the project received feedback and guidance from the County's climate change advisory committee, known as the Community Climate Change Task Force

[4] Erie County Green Team. See https://www2.erie.gov/environment/index.php?q=feature/erie-county-green-team

(C3TF)[5]. The C3TF is a group of about two dozen stakeholders from a variety of sectors, including higher education, municipalities, community-based organizations, not-got-profits, utilities, transportation, as well as youth representatives, which meet monthly to discuss current programs that relate to climate change mitigation and adaptation. The C3TF is a committee of Erie County's Environmental Management Council (EMC), and was formed in 2019 to address County-wide greenhouse gas emissions. Each month of the project, the C3TF received updates on project progress and when major milestones or deliverables were developed, the task force provided valuable feedback to the project team.

# EXPOSURE: IDENTIFYING KEY CLIMATE HAZARDS & THREATS

While there are many climate-related hazards that Erie County may face, some hazards are more impactful and/or are more readily addressed by Erie County than others. Therefore, the focus of this initial phase of the CVA allowed the project team and stakeholders to refine a broad list of potential hazards to a short list of key hazards to focus the remainder of the assessment. Below is a summary of methods and outputs of this initial phase of assessment, please refer to the full *Climate Hazards Summary Report*[6] for more details.

## Methods

The process of identifying climate threats to Erie County consisted of a thorough literature review of existing climate-related guidance documents for the region, climate-related reports, and published scientific literature. A complete list of references is provided in the *Climate Hazards Summary Report*[6]. The broad list of potential threats under consideration for further assessment was then refined, focusing on threats that particularly impact Erie County's jurisdictional responsibilities, which will ultimately enable the County to take meaningful steps toward addressing vulnerabilities to these threats in future projects. These choices were reviewed and confirmed by both our internal and external stakeholders.

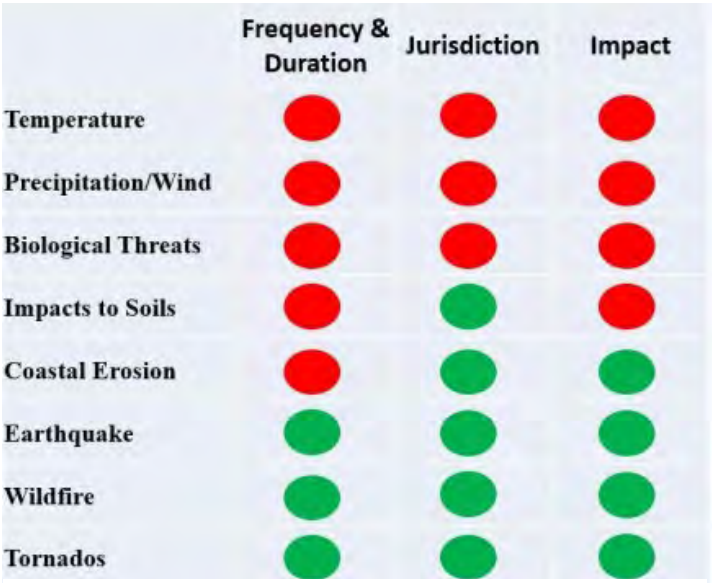



*Figure 2. Threat assessment of hazards for Erie County, NY. The color of the circles indicates the importance of the threat by category; green circles indicate lower priority and red indicates higher priority threats. The top three categories are the focus of this Climate Vulnerability Assessment.*

[5] Erie County Community Climate Change Task Force. See https://www3.erie.gov/climateaction/what-ecca
[6] Erie County Climate Vulnerability Assessment: Climate Hazards Summary Report (2020). Available: https://bit.ly/3bv8yxH

### Outputs

Based on the literature review and stakeholder input, three hazard categories were selected to investigate further: 1) temperature (extreme heat), 2) precipitation (local and downstream flooding), 3) wind (shifting wind patterns and thunderstorm winds), and 4) Biological threats (focusing on invasive species and vector-borne disease primarily). The threat categories with high expected frequency and/or duration, those that have high relevance to Erie County's jurisdictions and operations, as well as those that could potentially cause very costly or widespread impacts were included in the assessment. Our reasoning for focusing on these particular hazard categories is illustrated in figure 2. For a summary description of each threat category please refer to the *Climate Hazards Summary Report*[6].

Also, please note that the climate sensitivity assessment also includes a mobility analysis of Erie County residents during an emergency situation. Here we assess travel times to hospitals and cooling centers across the County. Although not focused on a particular hazard type, this assessment is important for understanding accessibility challenges to County resources and services, especially for our most vulnerable populations.

## SENSITIVITY: ASSESSING POTENTIAL EFFECTS OF HAZARDS

### Methods

For many of the hazards identified in the initial 'exposure' phase of the project, we spatially mapped available data related to each climate hazard, using a variety of resolutions, scales, and data sources. To be able to integrate this information, we standardized the hazard sensitivity data into a range of -1 to +1. In other words, we transform the data to have a mean of zero (average for the County) and a standard deviation of 1. Sensitivities closer to +1 indicate the most sensitive areas (or areas of highest concern), whereas sensitivities closer to -1 indicate the least sensitive areas for each hazard threat (or areas of least concern). This is a technique commonly used to integrate different types of data into a single index that is more easily compared as well as spatially mapped. A consistent color classification scheme was also employed across threats, where average values for the County are shown in green, below average values are indicated in yellow hues, and above average are indicated in pink and purple shades. With the exception of the section on wind and vector-borne diseases (which uses different methods, described below), all of the sensitivity information is visualized in this way.

### Outputs

The outputs for the sensitivity phase consist mainly of spatial data in the form of maps, except for sensitivities related to wind, which is a literature review and interview-based methodology. For the purpose of brevity, here we summarize the key findings of our sensitivity results for

each hazard. For more background information about each hazard, methodology, more detailed findings, and full-page maps, please see the full *Sensitivity Analysis Report*[7].

## Sensitivity to Extreme Heat

Sensitivity to extreme heat is a major concern for Erie County. It is predicted that the region will experience more frequent and intense heat waves in the future (Luber, 2008). Where the County has greater experience in addressing extreme cold and lake effect snowfall, vulnerability to heat waves and elevated temperatures may be particularly problematic for residents as well as infrastructure not accustomed to high temperatures.

To assess sensitivity to extreme heat, we considered landscape factors including tree canopy, proximity to water sources, the prevalence of paved surfaces, and industrial parcels. We also considered socio-demographic factors related to economic, social, physiological, and mobility factors of County residents. When both the landscape and socio-economic factors are considered, the overall results (Figure 3) indicate that urban areas of the County (predominately located in and around the City of Buffalo) are the most highly sensitive, compared to much lower sensitivities found in rural areas. The most sensitive locations are, in general, characterized by a high percentage of economically and mobility-sensitive populations and have a relatively low percentage of tree cover, more paved surfaces, and a high number of industrial parcels and/or truck terminals (that have a warming effect on surrounding areas).

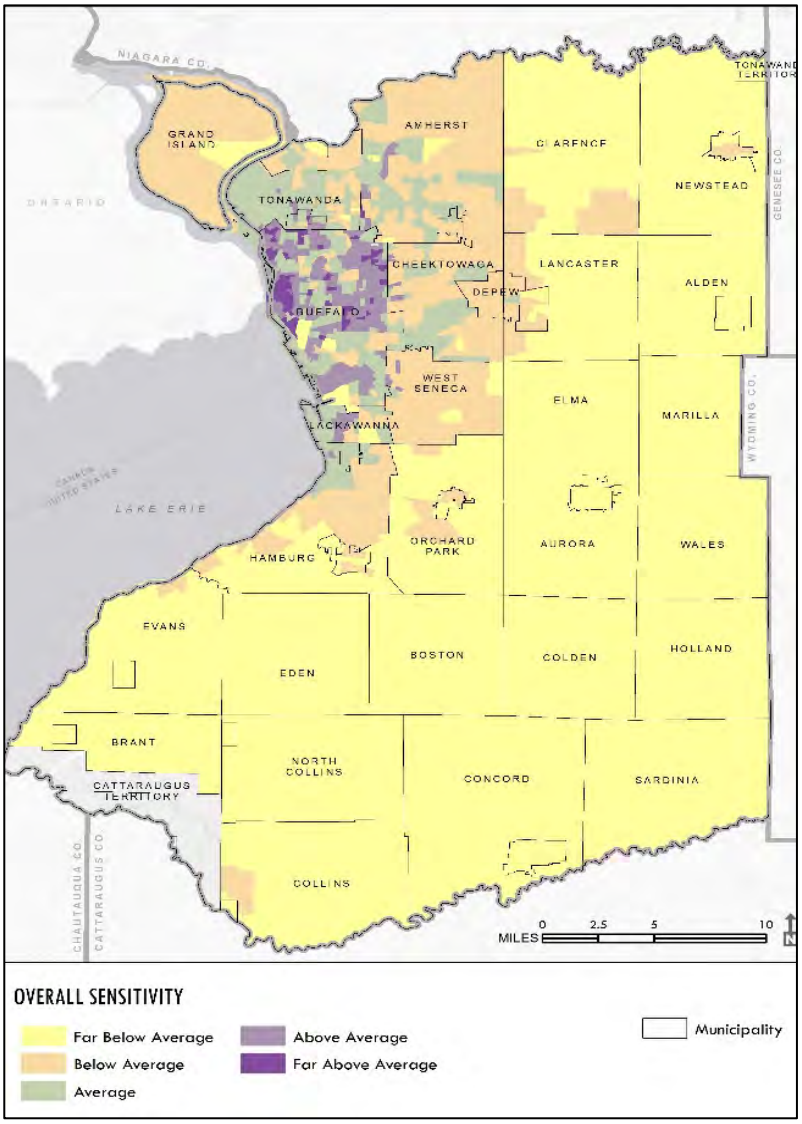



*Figure 3. Overall sensitivity to extreme heat, including both landscape and socio-demographic factors.*

[7] Placeholder for sensitivity report

## Sensitivity to Flooding

Patterns in precipitation are changing as a result of the impacts of climate change, and this has resulted in greater frequencies of extreme rainfall events (Easterling et al, 2017). These events exacerbate issues such as flooding and runoff, which impact Erie County's property and operations (County-owned roads, bridges, and stormwater infrastructure, for example) as well as private property and risks injury or death to the general public. Assessing where these impacts will be most severe will allow the County to proactively work to mitigate them and/or increase their adaptive capacity to ensure that the impacts are minimal and the risk to public health is minor.

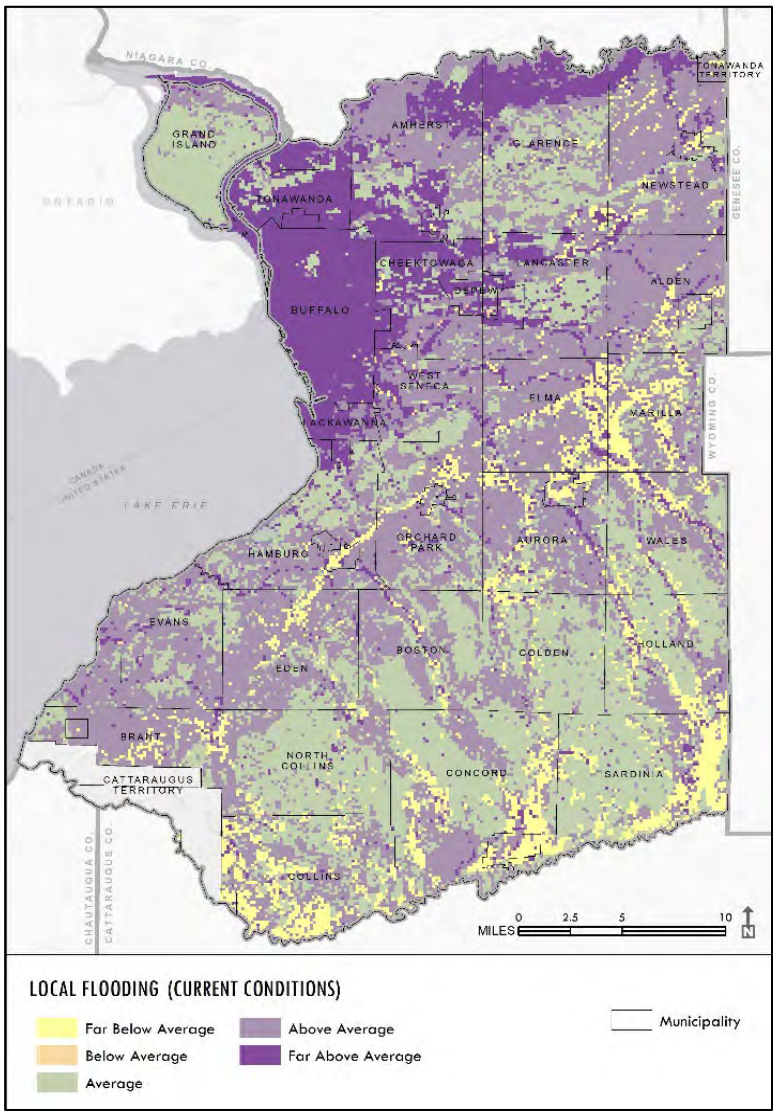



*Figure 4. Sensitivity to local flooding based on the capacity of soils to infiltrate water and FEMA's 100-year flood risk areas.*

Sensitivity to flooding was analyzed in ArcMap GIS to provide a relative measure of overall sensitivity from both local or on-site flooding and downstream flooding. Exposure to on-site flooding was assessed using soil characteristic data from the Natural Resource Conservation Service's (NRCS) GIS soil metadata. Exposure to downstream flooding was assessed by creating a topographical wetness index (TWI) derived from elevation data. The Federal Emergency Management Agency's (FEMA) Special Flood Hazard Areas (SFHA) were also included in both the local and downstream analysis, as this provided a special emphasis on areas already considered at risk of flooding.

Results of the local and downstream flooding maps (Figure 4 and 5, respectively) differ greatly in resulting sensitivities. While the local flooding map (which is determined based on the capacity of soils to infiltrate water and includes FEMA's Special Flood Hazard Areas) shows large regions of urban areas (in and around the City of Buffalo), as well as areas along the northern border of the County with the highest sensitivities, but also above

average sensitivities located throughout the central and southern areas of the County as well. Note that in the full *Sensitivity Report*[7] a complimentary map is provided that shows potential opportunities (e.g., through green infrastructure) to enhance the capacity of soils to infiltrate water more effectively across the County to reduce runoff and local flooding. The downstream flooding map suggests that while most of the County is characterized by far below-average sensitivities, there are areas, located mostly in the northern part of the County (mostly along waterways) that are highly sensitive to downstream flooding, based on factors related to landscape elevation and slope in addition to FEMA's 100-year flood risk areas. It is important to note that stormwater infrastructure is not factored into either of these analyses.

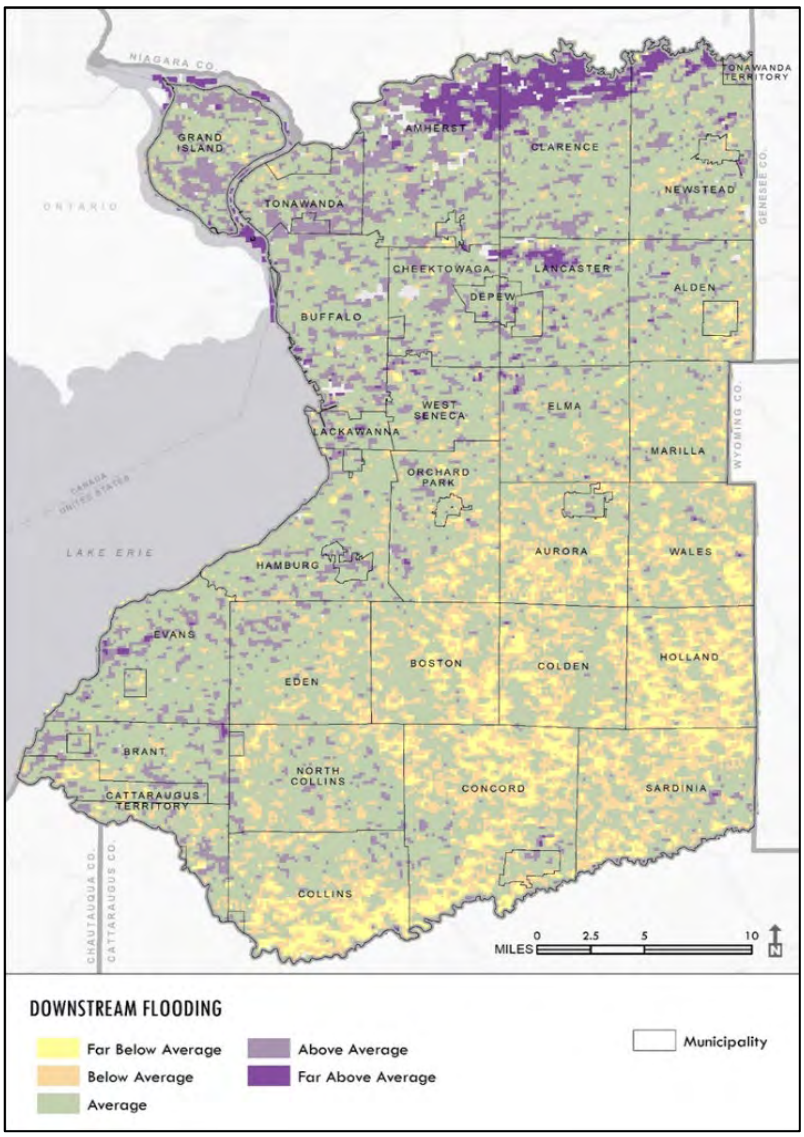



*Figure 5. Sensitivity to downstream flooding based on Topographical Wetness Index and FEMA's 100-year flood risk.*

## Sensitivity to Wind

Through a literature review and interviews with climate experts, the sensitivity to wind assessment focuses on changes in wind speed, wind direction, and seasonality of wind events observed and projected for Western NY.

Across North America, increased wind speeds are projected to occur particularly in the winter and summer months as the climate warms[8]. Higher wind speeds could mean increased damage to buildings, infrastructure, agriculture, power lines, and forestry. More specifically, a local study shows a strong increasing trend (21.4 events per decade) in the occurrence of strong thunderstorm winds (thunderstorm winds are defined as winds arising from convection,

[8] Eichelberger, S., McCaa, J., Nijssen, B., & Wood, A. (2008). Climate change effects on wind speed. *North American Windpower*, *7*, 68-72.
Jeong, D. I., & Sushama, L. (2019). Projected changes to mean and extreme surface wind speeds for North America based on regional climate model simulations. *Atmosphere*, *10*(9), 497.

occurring within 30 minutes of observed or detected lightning, with speeds of at least 58 mph, or winds of any speed producing a fatality, injury, or damage)[9]. These increasing wind speeds and more frequent wind events are already impacting the County's trees and forests. Many trees have been infested by the invasive beetle species known as the emerald ash borer, resulting in unhealthy, weakened trees that are more likely to be damaged during wind events.

Wind direction is also changing. Based on observed wind speed and direction data for our region[10] we see both increasing wind speeds and directional shifts. Erie County, because of its latitude, has prevailing winds from the southwest. However, we could experience more northeasterly winds as the climate changes. This potential change will come with stronger low-pressure systems that are characterized by winds circulating in a counterclockwise direction, resulting in winds generally from the northeast. Because the winds are stronger, we will get odd-direction storms more frequently (Levan, 2021). This shift in direction, in combination with stronger wind speeds, increases the likelihood of wind damage, especially for trees that are relatively unaccustomed to strong winds from these odd-direction storms.

In terms of seasonality, our region may experience a slight increase in the number of winter storms (due to an expected northerly shift of the jetstream) and associated high wind events. More off-season storms are also expected, which can be detrimental to trees and infrastructure. Snowstorms occurring in late Spring or early Fall, for example, can be particularly damaging. In regards to trees, once leaves on trees are budding in spring or still remaining on the trees in the fall, the weight of the snow will make trees more susceptible to being knocked down by the wind, increasing the likelihood of power outages in addition to bringing trees down. We are also expected to see a summertime increase in the strength of the lake breeze coming from Lake Erie (due to enhanced temperature differences between the lake and land), which could be beneficial for helping to cool the region during the summer months.

## Sensitivity to Biological Threats

As the climate changes, so do the ecosystems and habitats in our region. These changes in habitat suitability can lead to changes in the geographic range of many species. Vector-borne diseases (VBD), invasive species, and other biological threats may become more prevalent or have a greater impact should the region's climate become more suitable for them (Brownstein et al., 2005). For example, diseases spread by mosquitoes and ticks as well as invasive species may become more prevalent where they already occur and/or become established in new areas. Other biological threats, such as outbreaks of toxic cyanobacteria blooms ("Harmful Algal Blooms" or HABs) in Lake Erie, are also exacerbated by water temperature increases driven by climate change and are a regional concern[11]

[9] Vermette, S. (2017). Weathering Change in WNY: Climatic Trend Analysis (1965-2016). Available: https://bit.ly/3QlbWKs

[10] National Oceanic and Atmospheric Administration (NOAA), National Centers for Environmental Information. 2020. Storm Events Database.

[11] Griffith, A. W., & Gobler, C. J. (2020). Harmful algal blooms: A climate change co-stressor in marine and freshwater ecosystems. Harmful Algae, 91, 101590.

In order to assess the risk that biological threats pose, a GIS-based tool called the Risk-Assessment Mapping Program (RAMP), created by the Fish and Wildlife Service (USFWS) was utilized. The RAMP tool incorporates the known environmental variables that are present in a given species' native geographic range and applies it to a new geographic area under warming scenarios, in a map-based visualization (Sanders et al., 2018). The USFWS RAMP program's outputs include a series of maps to visualize changing habitat suitability in the future for a range of target species for Erie County.

Although thirteen species were visualized using the RAMP tool to understand the County's sensitivity to invasive species and VBDs, in this summary report we show the results for two disease-carrying ticks, the Asian Longhorned Tick (an invasive species, new to the area) and the Deer Tick (considered a native species). The results are fairly representative of the outputs generated across species types. For more detailed results, see the full Sensitivity Report[7]. Results indicate a general trend in the change of habitat suitability for native versus invasive species analyzed. Native species, such as the Deer Tick, saw a decline in habitat suitability over time (see Figure 6). Invasive species, such as the Asian Longhorned Tick, saw an increase in habitat suitability from the current to 2050 time interval, and a decline in habitat suitability in the 2050-2070 time interval (see Figure 7). This suggests that the issues that Erie County may face in terms of VBDs will likely be dynamic and change over time as climate conditions change, with new species/diseases moving in and out of the area.

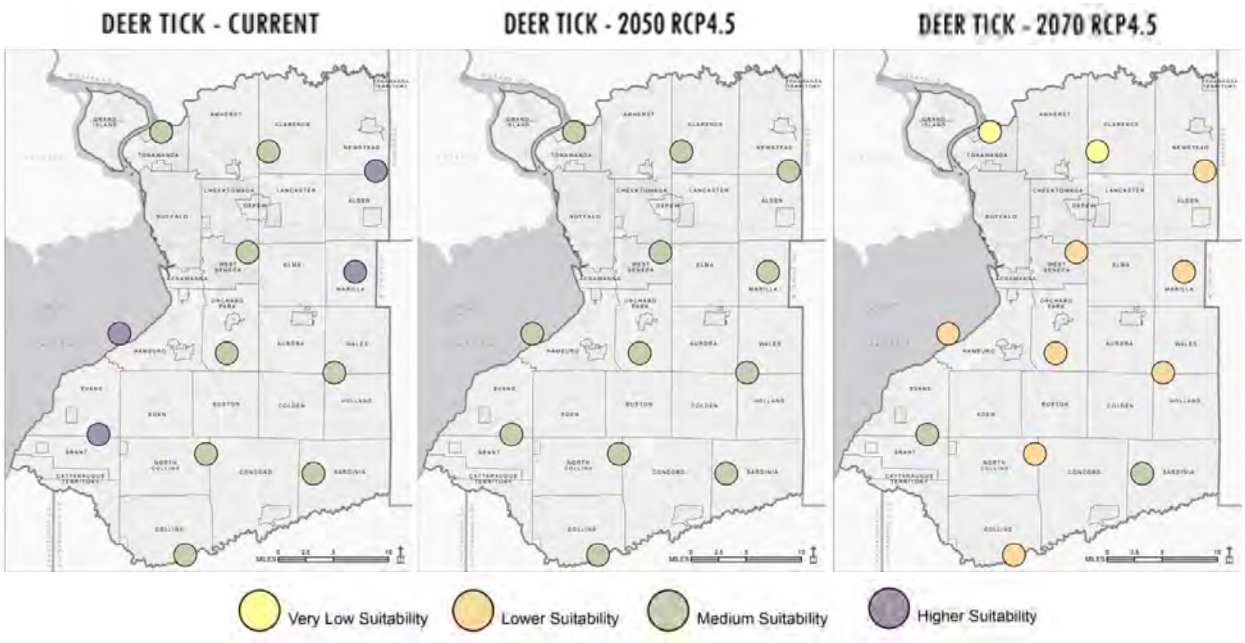



*Figure 6. Habitat suitability changes for the native Deer Tick for current and future warming conditions in Erie County. Results indicate less favorable conditions for this particular native species in the future, as the climate warms.*

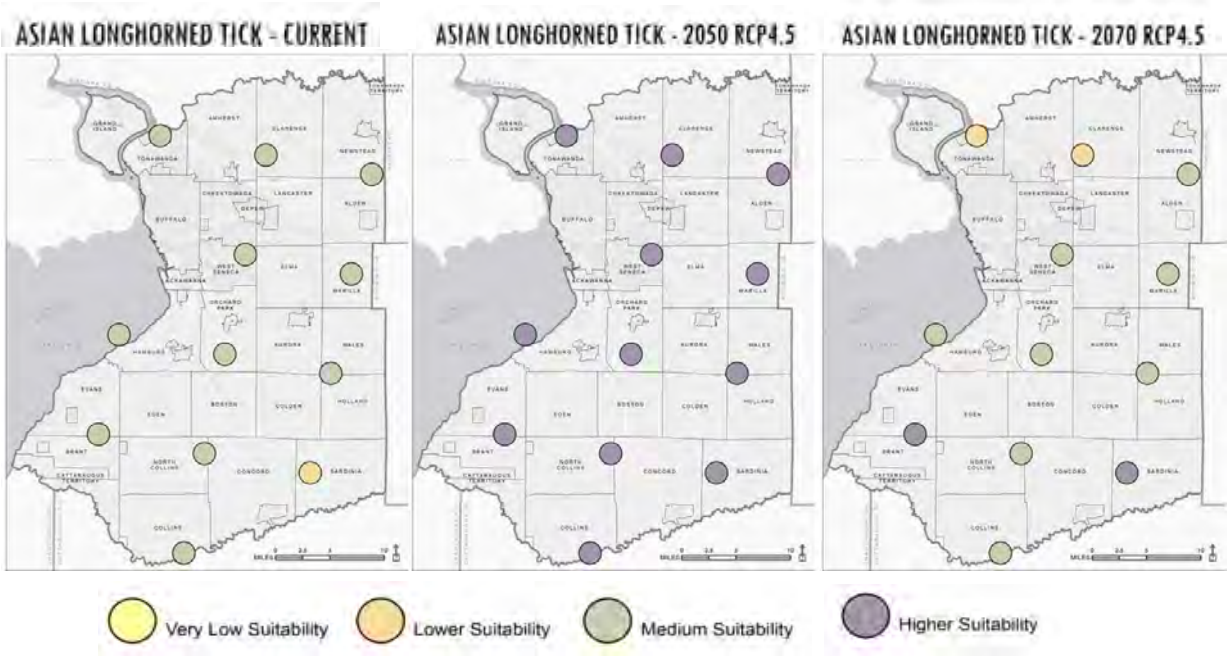



*Figure 7. Habitat suitability changes for the invasive Asian Longhorned tick for both current and future warming conditions in Erie County. Results suggest more favorable conditions for this invasive species during mid-century, with declining suitabili*

## Sensitivity with Respect to Mobility and Accessibility

Levels of mobility (how far a person can travel in a given amount of time) and levels of accessibility (the number of transportation services a person can reach in that given amount of time) vary across space and socioeconomic demographics (Lee et al., 2018). A key concern for the County is the potential lack of access to care during emergency situations, especially for less mobile or disadvantaged populations that are considered more vulnerable to climate hazards.

In this analysis, mobility and accessibility were estimated for 24 hospital emergency departments (EDs) across Western New York, and 37 County library cooling shelters (CSs). While EDs are considered critical service providers in all types of hazards, CSs are particularly important for providing services during extreme heat events. To account for the presence of vulnerable populations across the County, measures of social vulnerability were incorporated, based on data from the US Census Bureau and Centers for Disease Control and Prevention (CDC). Although walking and public transport times were also explored in the assessment, here we only show results for driving. See more methodological details and results in the full Sensitivity Report[7]. In Figure 8 and 9, driving times (derived from Google Maps) from the geographic center of County census tracks to the closest ED, as well as the nearest CS are shown, relative to each census tract's reported social vulnerability. For example, areas indicating far above average values (purple hues) indicate long driving times for more vulnerable populations. For the most vulnerable census tracts in the County, the average minimum travel time to a hospital ED is approximately 24 minutes, while only 7 minutes to a

CS. Note that driving times do not account for traffic, construction, or other types of delays that one might encounter during an emergency, including unsafe road conditions.

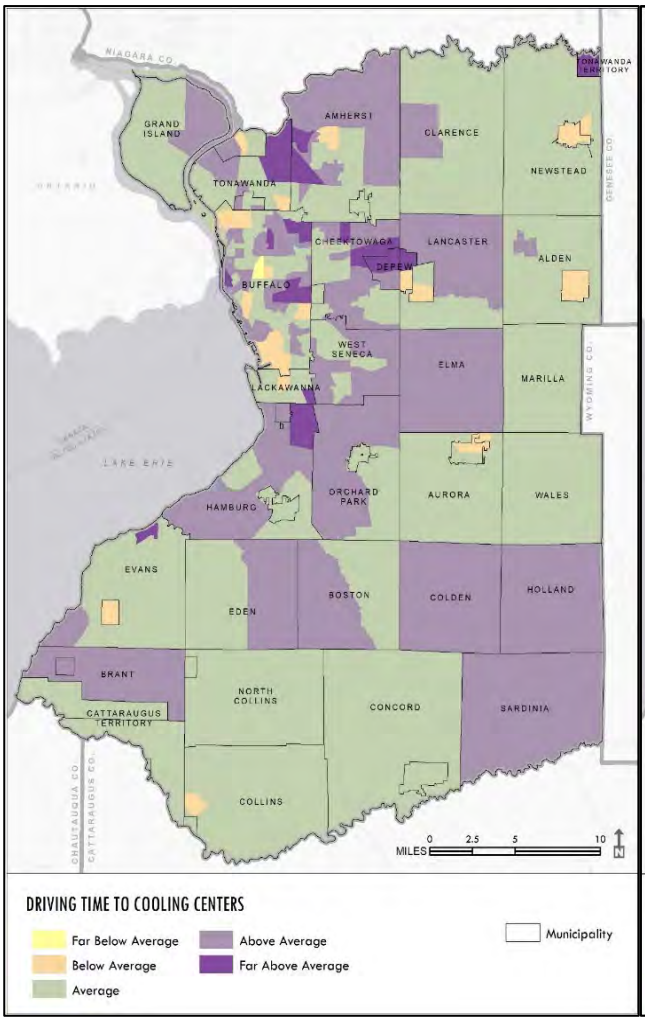



*Figure 8. Minimum driving times to County cooling shelters relative to social vulnerability.*

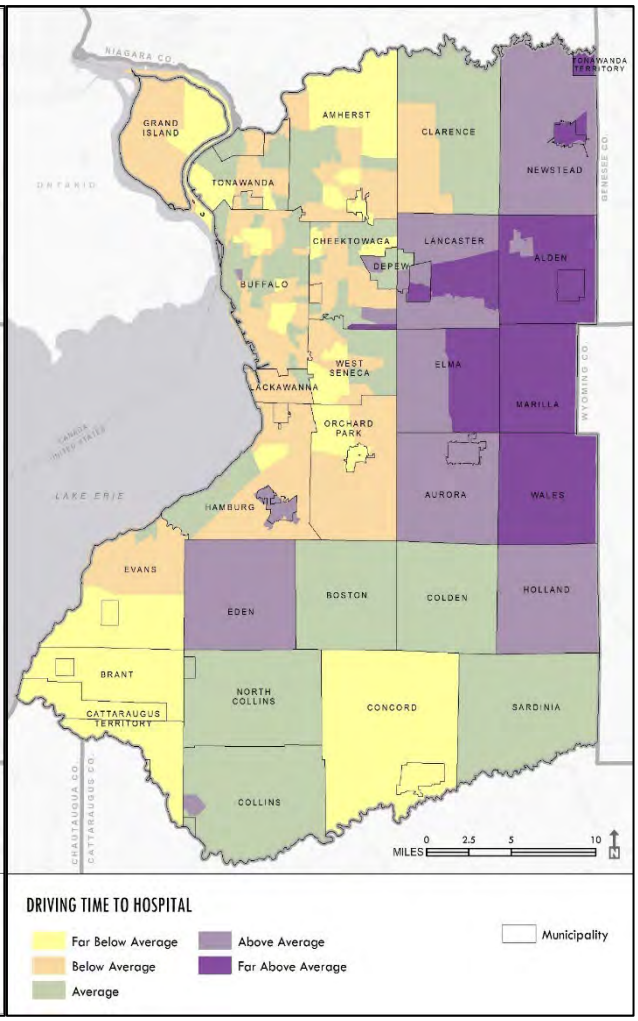



*Figure 9. Minimum driving times to hospital emergency departments relative to social vulnerability.*

## ADAPTIVE CAPACITY: GAGING COUNTY PREPAREDNESS

In this third and final phase of the CVA, the adaptive capacity of Erie County is evaluated in the context of the climate-related hazards identified in the first phase, and the results of the sensitivity analysis completed in the second phase. Adaptive capacity refers to the ability of the County to adapt or adjust to climate hazards and risks. This is an important component of the CVA process, providing a qualitative assessment of where the County is in terms of being prepared for increasing climate-related risks.

### Methods

Representatives from relevant Erie County departments were interviewed and asked to respond to questions about current practices and planning related to the climate sensitivities identified in the Sensitivity Analysis Report[7]. Each interview was conducted virtually (during the

COVID-19 pandemic) and most lasted about an hour. These sessions often included several County representatives at once, as appropriate based on overlapping responsibilities. Each meeting was recorded and meeting notes were shared and reviewed with County representatives. Table 1 outlines the specific Erie County departments, as well as units and divisions that were interviewed as appropriate, as well as the date of the meeting, and finally the County system(s) of focus in each meeting.

*Table 1. Interviews conducted with County staff to assess adaptive capacity*

| Department | Office/Division | Date of Meeting | Focal System(s) |
|---|---|---|---|
| **Environment and Planning** | Geographic Information Systems | Several meetings throughout Project | All Systems |
| **Environment and Planning** | Watershed Management | Several meetings throughout Project | Natural Systems |
| **Environment and Planning** | Stormwater Management | Several meetings throughout Project | Physical Infrastructure; Natural Systems |
| **City of Buffalo** | Buffalo Sewer Authority | April 14, 2021 | Physical Infrastructure |
| **Environment and Planning** | Sewerage Management | April 21, 2021 | Physical Infrastructure |
| **Parks, Recreation and Forestry** | | April 28, 2021 | Natural Systems |
| **Homeland Security and Emergency Services** | | June 30, 2021 | Human Systems; Emergency Services |
| **Health** | Environmental Health | June 30, 2021 | Human Systems |
| **Social Services** | | July 6, 2021 | Human Systems; Emergency Services |
| **Senior Services** | | July 6, 2021 | Human Systems; Emergency Services |
| **Public Works** | | September 21, 2021 | Physical Infrastructure |

## Outputs

In the full *Adaptive Capacity Report*[12] results from each interview are provided in detailed narratives, organized by each hazard type (temperature, precipitation, wind, biological threats, and mobility/accessibility) according to the department/system of focus. Here we provide a summary in Table 2 below (also included in the full report) that highlights only the major issues discussed by each department during interview sessions, according to each threat type and department/division interviewed. The final "Adaptive Capacity" column indicates existing adaptive capacities (activities already being done or being planned) identified through the conducted interviews according to the four phases of emergency management, described below. Blank cells in the final column suggest where there may be significant opportunities to improve the capacity of Erie County to respond to climate-related impacts.

- *Mitigation:* Proactive measures that are undertaken to remove or reduce the risk that the climate hazards in question pose to Erie County.
- *Preparation:* Actions that enhance the capacity of Erie County and allied organizations to address an ongoing emergency as well as the aftermath or damage from that emergency.

[12] Placeholder for Adaptive Capacity Report info

- *Response:* Methods to reduce loss of life/personal injury and damage to property that is takes place in real-time, such as emergency response.
- *Recovery:* Reconstruction efforts that are essential to returning to normal life, or ideally enhancing the quality of life after an emergency.

*Table 2. Summary table of major issues and existing adaptive capacities discussed during interview sessions, organized by threat type and department/system of focus.*

| Temperature | | |
|---|---|---|
| **Department** | **Issues** | **Adaptive Capacity** |
| **DEP Geographic Information Systems** | Spatial and temporal patterns of temperature-related hazards and the vulnerable communities that are sensitive to extreme heat | *Preparation*: Assist in data provision, mapping |
| **Sewerage Management** | High temperatures cause increased mechanical weathering and can result in dry sewers | |
| | Biological treatment may experience limited efficacy during extreme temperatures | |
| **Parks, Recreation & Forestry** | Employee health and safety in extreme conditions when traveling or working outdoors | *Mitigation*: Precautionary policies to ensure risk is minimized |
| **Homeland Security & Emergency Services** | Increased duration, intensity, and frequency of extreme heat events | *Response:* Coordination with Erie County Library system to provide cooling centers and other forms of shelter during extreme events |
| **Health** | Health impacts of extreme heat, particularly for most vulnerable populations | *Preparation*: Public health bulletins warning the public of extreme events |
| | Extreme heat can result in increased atmospheric ozone, degrading air quality. This can be a health concern for some vulnerable communities | *Preparation*: Public health bulletins warning the public of extreme events |
| **Social Services** | Vulnerable communities lack access to cooling units for their homes, which may exacerbate health conditions during heat waves | *Mitigation:* HEAP provides air conditioners through programs that fund purchase and installation of cooling units. |
| **Senior Services** | Elderly residents of the county are particularly sensitive to heat-related impacts, while at the same time lack mobility. | *Preparation*: Senior alert programs via phone call and text message to increase awareness of potential issues related to extreme heat. |
| **Public Works** | Control of climate in County-owned buildings is necessary for the health and wellbeing of employees, yet can be expensive and resource-intensive | *Preparation:* Energy performance contracts are in place to improve efficiency and weatherization |
| | Increased risk of heat-related issues among employees, especially those working outdoors | *Mitigation*: Projects are scheduled during the coolest part of the day and employees are encouraged to drink plenty of water and take frequent breaks |
| | County-owned roadways are at risk of heat-related damage during extreme heat events | *Mitigation*: Roadways are engineered according to designs suitable for southern climates, making them resilient in the event of a heat wave. |

| Precipitation | | |
|---|---|---|
| **Department** | **Issues** | **Adaptive Capacity** |
| **DEP Geographic Information Systems** | Spatial and temporal patterns of temperature-related hazards and the vulnerable communities that are sensitive to this issue | *Preparation:* Assist in data provision, mapping |
| **Sewerage Management** | More frequent or intense precipitation events increases the likelihood of flooded sewers | *Response:* The City of Buffalo has capacity to store stormwater in un-used sewer pipes, reducing the potential for flood sewers. |
| | Influx of sediment/debris during heavy rains or floods may result in clogged systems | *Mitigation:* Installation of green infrastructure that reduces the amount of sediment influx |
| **Parks, Recreation & Forestry** | Flooding of County-owned land from excess rain or seiche events. This includes public parks and forests, as well as beaches | *Mitigation:* Engineered responses that are more resilient to flood damage |
| **Homeland Security & Emergency Services** | Flooding of homes and basements during heavy precipitation events | *Response:* Coordinate response with local fire departments |
| | Lack of tracking areas where localized and large-scale flooding frequently takes place | |
| **Health** | Drinking water quality may become impacted as pollutant-laden floodwater enters homes and/or well heads where drinking water is sourced | *Mitigation:* Engineering to protect some water supplies |
| **Social Services** | Flooding disproportionately impacts vulnerable communities, which may require support financially to recover | *Recovery:* Post-flood impact recovery |
| | Seniors frequently cancel flood insurance when their home mortgages are paid off and they are no longer required to hold insurance | *Recovery:* Post-flood impact recovery |
| | Snowstorms may create barriers when accessing critical or emergency services. | |
| **Public Works** | Ensuring buildings and roadways are accessible during heavy snowfall events is a major priority | *Response:* Snow removal plans are detailed and well developed. |
| | Potential for flooding of bridges and roadways during heavy precipitation events or other flooding events | *Preparation:* Bridges are all designed to be higher than the FEMA-designated "100-year flood, and roadways in floodplains are all engineered to account for flooding when sited in floodplain areas. |

| Wind | | |
|---|---|---|
| **Department** | **Issues** | **Adaptive Capacity** |
| **DEP Geographic Information Systems** | Spatial temporal patterns of wind-related hazards and the vulnerable communities that are sensitive to this issue | *Preparation:* Assist in data provision, mapping |
| **Sewerage Management** | Reliability of the electrical grid is a concern in the event of extreme winds that topple trees and can cause power outages | *Mitigation:* Back-up generators |
| | High winds off of Lake Erie can lead to seiche events that subsequently push water into effluent discharge systems, causing sewer backups | |
| **Parks, Recreation &Forestry** | Forest health is declining as invasive species weaken and kill trees. This issue combined with a windstorm, can cause trees to topple | *Mitigation:* Proactive removal of hazard trees |
| | Changes in prevailing winds can result in more frequent and intense nor'easter storms. This also places wind in directions that are opposite to a tree's natural strengths – increasing the odds of downed trees | *Response:* Removal of fallen trees in Parks-owned areas and facilities. |
| **Homeland Security & Emergency Services** | Large-scale storms can create multiple areas of power outages, downed lines, trees, and other unsafe conditions | *Response:* Coordinate to restore of safe conditions and critical service |
| **Social Services** | Hazard trees are expensive to remove and present a danger to public safety. Wind-related tree damage present financial burdens to the socioeconomically disadvantaged | |
| **Senior Services** | Seniors are more likely to own their homes and live off of a fixed retirement income. As such, they may not be required to hold homeowner's insurance and would not be able to afford the removal of hazardous trees or recovery from a fallen tree | |
| **Public Works** | Trees on County-owned roads or properties may be knocked over by powerful winds | *Response*: DPW has staff in place to address downed trees in these areas |

| Biological Threats | | |
|---|---|---|
| **Department** | **Issues** | **Adaptive Capacity** |
| **DEP Geographic Information Systems** | Spatial and temporal patterns of biological hazards and the vulnerable communities that are sensitive to this issue | *Preparation:* Assist in data provision, mapping |
| **Sewerage Management** | Drought conditions can leave isolated pools in sewer systems. These pools can develop bacterial growths resulting in septic conditions in sewers | |
| **Parks, Recreation and Forestry** | County employees that work outdoors may be exposed to vector-borne diseases from ticks and other vectors | *Mitigation:* Precautionary policies to ensure risk is minimized for employees and visitors |
| | Invasive species proliferation in County-owned parks and forests diminishes the resilience of these landscapes to the impacts of climate change | |
| **Homeland Security & Emergency Services** | Transport and storage of hazardous materials may be impacted by a climate-related disaster, resulting in spills or other environmental release | *Mitigation:* Planning efforts and regular updates to these plans (i.e. Multi-Jurisdictional Hazard Mitigation Plans) |
| **Health** | Increase in the prevalence and distribution of certain vector-borne diseases that are associated with changing habitat suitability | *Preparation:* Public health mandates and public service messaging |
| | Lack of tracking prevalence and distribution of vector-borne diseases that may be exacerbated by the impacts of climate change | |
| **Social Services** | Vector-borne diseases can lead to indirect issues such as evictions, loss of work, increased child care costs, and other financial hardships for vulnerable communities | *Recovery:* Assistance to vulnerable populations (i.e. SNAP benefits, child daycare programs etc.) |
| **Senior Services** | Seniors are particularly vulnerable to biological threats due to underlying health issues, and potentially limited mobility | *Mitigation:* Senior wellness programs to encourage seniors to get fit and stay healthy to proactively enhance wellbeing |
| **Public Works** | Climate change may result in instances of degraded air quality through increases in ozone and elevated levels of allergens | *Mitigation*: Building retrofits of County-owned structures may improve the heating and cooling and associated air filtration systems |
| | Invasive species that can result in human-health impacts may be found on County-managed right-of-ways | |

| Accessibility & Mobility | | |
|---|---|---|
| **Department** | **Issues** | **Adaptive Capacity** |
| **DEP Geographic Information Systems** | Geospatial data to analyze emergency services networks for mapping and analysis | *Preparation:* Assist in data provision, mapping |
| **Sewerage Management** | Clogged and backed-up sewer systems may coincide with flood emergencies; Addressing clogs and backups during and after a flood event may become problematic | |
| **Parks, Recreation & Forestry** | Provision of emergency services to those working and recreating in County-owned parks and forests | *Response:* respond to emergency service calls during an emergency event. |
| **Homeland Security & Emergency Services** | Proactive planning to reduce the severity and extent of an emergency | *Preparation:* Hazard mitigation planning |
| | Emergency response that is highly coordinated and efficient so as to be as effective as possible | *Response:* Coordination across the County of all relevant first responders during an emergency |
| **Health** | Provision of clear and current directives and announcements so that the public is aware of the situation and the opportunities for help | *Preparation:* Public service messaging |
| **Social Services** | Accessibility to services during and after emergency/extreme events (many can find transport to County services, but lack local access in their community) | |
| **Senior Services** | Mobility of seniors to services during and after emergency/extreme events | |
| **Public Works** | County-owned structures are used for various essential services to the people that the County serves, and associated roadways are critical to accessing these services | |

## OVERALL VULNERABILITY: KEY ISSUES AND NEXT STEPS

In general, the County can expect increases in the frequency and severity of heat waves, flooding, and storms with damaging winds. Changes in wind direction and seasonality of storms are also potential threats. Projected climate change in the region is also likely to reduce habitat suitability for a variety of native species while improving conditions for existing and new invasive species. Exposure to vector-borne diseases from both native and invasive species will therefore continue to change over time as habitat suitability shifts for particular species types in the future. Finally, accessibility (in terms of minimum driving times) to area hospital emergency departments is relatively low for rural communities, whereas access to County cooling shelters is more uniform. Table 3 summarizes particular areas of vulnerability for Erie County to climate change that this assessment has identified and potential opportunities to mitigate this vulnerability in the future.

*Table 3. Summary of major vulnerabilities and potential opportunities according to threat type.*

| *Threat* | *Vulnerabilities* | *Opportunities* |
|---|---|---|
| *Increase in the frequency and intensity of heat waves* | • Stress on the power grid due to higher cooling demand<br>• Increased health impacts, especially for vulnerable populations (e.g., elderly, youth, pregnant women)<br>• Old housing stock and lack of access or affordability challenges to air conditioning for most vulnerable | • Increase communication and coordination with electric utilities<br>• Enhance outreach and awareness about heat vulnerability and ways to avoid impacts<br>• Develop a heat emergency plan for County<br>• Create a system to check on the most vulnerable during a heat wave |
| *Increase in frequency and severity of flooding* | • More frequent local flooding, including County land, homes, and roadways<br>• Increased debris in sewer systems<br>• Reduced drinking water quality during flooding events | • Invest in green infrastructure projects to improve infiltration capacity, retention, and stormwater management<br>• Map location of past flooding hotspots<br>• Avoid or reduce development in flood-risk areas |
| *Increase in wind damage* | • More power outages<br>• Reduced tree health and more tree damage<br>• Financial burden and increased safety risk for workers | • Increase power backup system capacity (mobile generators, micro-grids, etc.)<br>• Consider wind-resistant trees in tree-planting initiatives<br>• Financial support for proactive tree removal |
| *Changing habitat suitability for species/diseases* | • Increased exposure and health impacts of County employees and residents to Vector Borne Disease | • Increased monitoring of changing species and health risks<br>• Preparation and training for County employees<br>• Information and outreach to increase awareness and reduce the impacts of disease-carrying species |
| *Accessibility and Mobility Challenges for Vulnerable Populations* | • Access to critical lifeline services during and after extreme events/emergencies, especially for the most vulnerable | • Identifying local community shelters in the most vulnerable communities<br>• Increasing access to public transportation services, especially in rural communities |

## Next Steps

Based on this assessment, as well as input and feedback from our stakeholders and the public, key topics will be focused on for mitigation and adaptation planning, including but limited to the following:

- ### Developing an Emergency Heat Plan, funded by New York State:
  This project is planned to commence in Spring of 2023 and will build upon the extreme heat-related analysis in this assessment to develop a locally informed plan for mitigating the effects of, and responding to, heat wave conditions. This project will also build upon current programs to check on the most vulnerable during a heat wave.

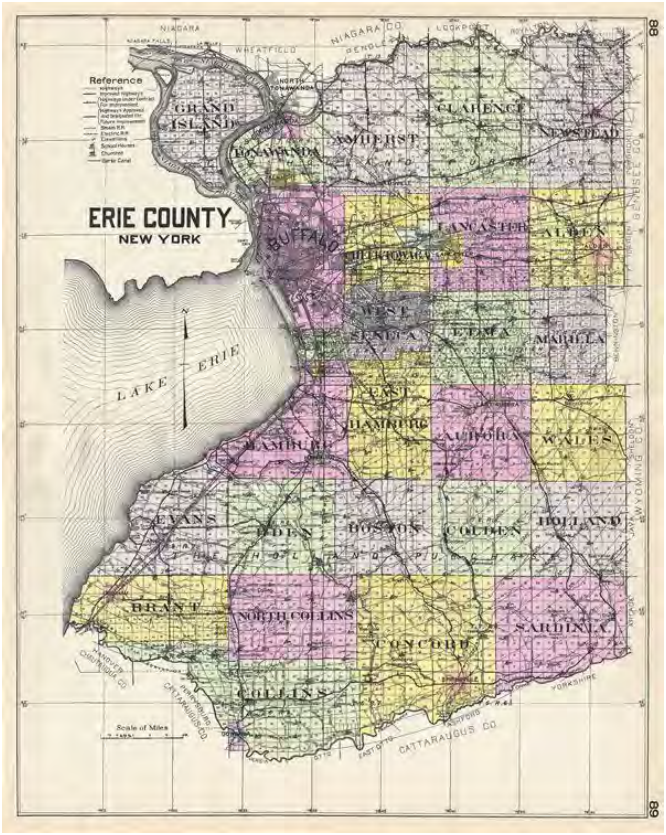
- ### Erie County Climate Action Planning:
  The main goal of this ongoing initiative is to develop an equity-centered Community Climate Action Plan, to identify actions we can take to reduce greenhouse gas emissions, and help the community adapt to our changing climate. See www.erie.gov/climateaction.

- ### Erie County Low Income Program for Sustainable Energy (ECLIPSE):
  This program is working to create a community-scale program to provide integrated energy services for Low- to Moderate-Income (LMI) households. It will establish an Energy Services Company to purchase energy in bulk for as many as 60,000 Home Energy Assistance Program (HEAP) recipients in Erie County.

# Erie County Climate Vulnerability Assessment

# Climate Hazards Summary Report

**August 16, 2020**

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**Cover page: The image shows a historic map of Erie County from 1912 (Image Credit: Everts, 1912). This project takes into account peer-reviewed climate projections and literature, existing data, and maps in order to assess Erie County's Vulnerability to changes in the dynamics of physical, chemical and biological processes due to climate change across the region.**

**This project has been funded in part by the Climate Smart Community Grant Program, Title 15 of the Environmental Protection Fund through the NYS Department of Environmental Conservation.**

**Abstract**

Erie County, NY is in the process of developing a Climate Vulnerability Assessment (CVA) of its jurisdictional responsibilities. The overall objective is to assess the climate related hazards most pertinent to Erie County, identify gaps in the County's capacity to mitigate and address the identified threats, as well as show where the County is doing well in climate preparedness to allocate resources more efficiently. In an important first step, the particular climate hazards and threats that the assessment will focus on need to be identified. While there may be multiple climate-related hazards that Erie County may face, some hazards are more impactful and/or are more readily addressed by Erie Count than others. A literature review identified hazards related to temperature (air quality, extreme heat etc.), precipitation (flooding, ice jams and water quality issues from pollutants associated with agricultural runoff/sewer overflows and erosion-based nutrient injections etc.), wind (coastal erosion, property/infrastructure damage), vector-borne diseases (malaria, Lyme's disease etc.), and invasive species/Harmful Algal Blooms (changes in species' distribution, increased incidence of occurrence etc.) as the primary focus areas for the CVA process. These hazards will be incorporated into the next steps in the vulnerability framework, which include spatially mapping these threats, performing a sensitivity analysis to identify the most sensitive populations, infrastructure and other sectors; and evaluating the adaptive capacity of Erie County to respond and recover from these threats.

**Executive Summary**

With the impacts of global climate change already becoming evident locally and across the globe (Erie County, 2019a; Environmental Law & Policy Center, 2019; Rosenzweig et al, 2011), it is the responsibility of governments and communities to work proactively to prevent, mitigate, and offset the coming impacts. The government of Erie County, NY has been awarded funds through the New York State Department of Environmental Conservation's Climate Smart Communities program (NYS, 2019) to conduct a Climate Vulnerability Assessment of its operations. Erie County has contracted a team at the University at Buffalo (UB) to conduct this assessment. This team includes faculty from the Departments of Environment and Sustainability as well as Geography, and a doctoral student also from the Geography Department. In addition, staff at Erie County's Department of Environment and Planning are overseeing and coordinating this effort.

First, a literature review has been conducted. The review included climate hazards, as well as issues of social vulnerability and resilience. Based on the literature review and input from internal stakeholders at Erie County and external stakeholders such as the Erie County Community Climate Change Task Force (C3TF), several focus hazards were selected. Selected hazards aligned with previous guidance documents (Erie County, 2019a; Erie County 2019b; URS, 2015; BNW, 2014 etc.) as well as in consideration of what Erie County as a governmental entity can feasibly influence under its jurisdiction. Selected focus hazards include temperature, precipitation, vector-borne diseases, and invasive species/Harmful Algal Blooms. Each hazard will be analyzed to identify the projected impacts that the changing climate will bring with respect to that specific threat. In most cases, the hazards will be geospatially analyzed in order to identify the geographic and temporal scale of the threat. Hazards not analyzed geospatially will be assessed through additional literature review to ensure all pertinent information is reflected in the final Climate Vulnerability Assessment.

Once the climate hazards have been investigated and spatially mapped, they will be cross referenced with Erie County's sensitive populations, infrastructure, and ecosystems under the County's jurisdiction in what is called sensitivity analysis. Sensitivity analysis identifies the extent to which vulnerable populations and infrastructure are potentially impacted by their exposure. In this case, that exposure is in reference to climate-related hazards (City of Rochester, 2018, Colburn et al, 2016; Kumar et al, 2016; Shen, Fen & Peng, 2016). The final step is to evaluate the County's adaptive capacity to climate change-related impacts. Adaptive capacity is the innate resilience of social institutions such as county governance to impacts, both over the short and long term. This resilience is due to proactive planning and/or the production of innovative responses from government and partners both prior to and after a disaster/impact (Gupta, et al., 2010). Collectively, this information will be incorporated into the final report that will conclude the Climate Vulnerability Assessment for Erie County, NY.

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**INTRODUCTION**

***Erie County:*** Erie County, NY, sits entirely within the Lake Erie-Niagara River watershed (BNW, 2014) and consists of 44 municipalities – 25 towns, 16 villages, and 3 cities (Erie County, 2019a). Geographically, the County consists of about 1,277 square miles, 17.5% of that is open water; and there are 77 miles of shoreline between Lake Erie and the Niagara River (URS, 2015). As the 8th most populous county in New York, Erie County government manages extensive infrastructure, including sewers, roadways, and buildings. The County manages over 1,100 miles of sewers, 6 Water Resource Recovery Facilities (WRRF), 5 Excess Flow Management Facilities, and over 90 pumping stations (Erie County, 2019a). Collectively, more than 16 billion gallons of sewage passes through the County's jurisdiction, with 10 billion gallons directly treated and 6 billion passed through to another municipality's WRRFs (Erie County, 2019a). The County manages a substantial portfolio of buildings (more than 220) and fleet vehicles (1,195) (Erie County, 2019a). Additionally, with 1,187 centerline miles of roadways and 290 bridges, the County has the largest system of county-owned roadways in the State (Erie County, 2019a). Collectively, this amounts to a significant responsibility for the County, all of which is subject to a variety of climate-related impacts. Erie County's Department of Environment and Planning (EC DEP) has been proactively working to reduce, mitigate and offset its internal operations GHG emissions and climate impact, as described in its "Climate Action & Sustainability Plan" (Erie County, 2019a).

In addition to the responsibilities related to infrastructure, Erie County government has important roles for emergency, social and health services, and is the leading provider of services for vulnerable populations. Erie County oversees multiple departments relevant to these services, including Departments of Homeland Security and Emergency Services, Health, Labor Relations, Mental Health, Senior Services, Social Services, and Veterans Services, Commission on the Status of Women, and Offices for Consumer Protection, Medicaid Inspector General, People with Disabilities, and Public Advocacy. With almost 25% of the County's population of minority status, 1 in 5 people in the county considered "vulnerable" (populations that are more likely to experience negative impacts from a given hazard, such as those that are below 5 years of age and above 65 years of age, as defined in the Multijurisdictional Natural Hazard Mitigation Plan Update) (URS, 2015), a 7% foreign-born population, and a 14.9% poverty rate (Data USA, 2020), the County has both critical relationships with and understanding of vulnerable populations, and therefore has a unique role in addressing new threats posed by climate change.

***Global Climate Change****:* Rising greenhouse gas emissions are resulting in unprecedented global environmental change (Environmental Law & Policy Center, 2019, Rosenzweig et al, 2011), including changes in temperature and precipitation (Climate Connect, 2020; IPCC, 2013). These climatic changes have been induced by rampant human emissions of greenhouse gases such as carbon dioxide. These emissions result from the combustion of fossil fuels and other human activities. Although greenhouse gases are necessary to make Earth habitable, the increased concentration of these gases in our atmosphere traps a greater amount of heat than what would occur naturally, leading to increases in average temperature across the globe and a variety of other changes in climate trends. **While human civilization has existed for about 10,000 years, and our species, *Homo sapiens,* has existed for about 300,000 years, under our current trajectory temperatures on earth may increase to those that have not been seen for 20 million years** (**Figure 1).**

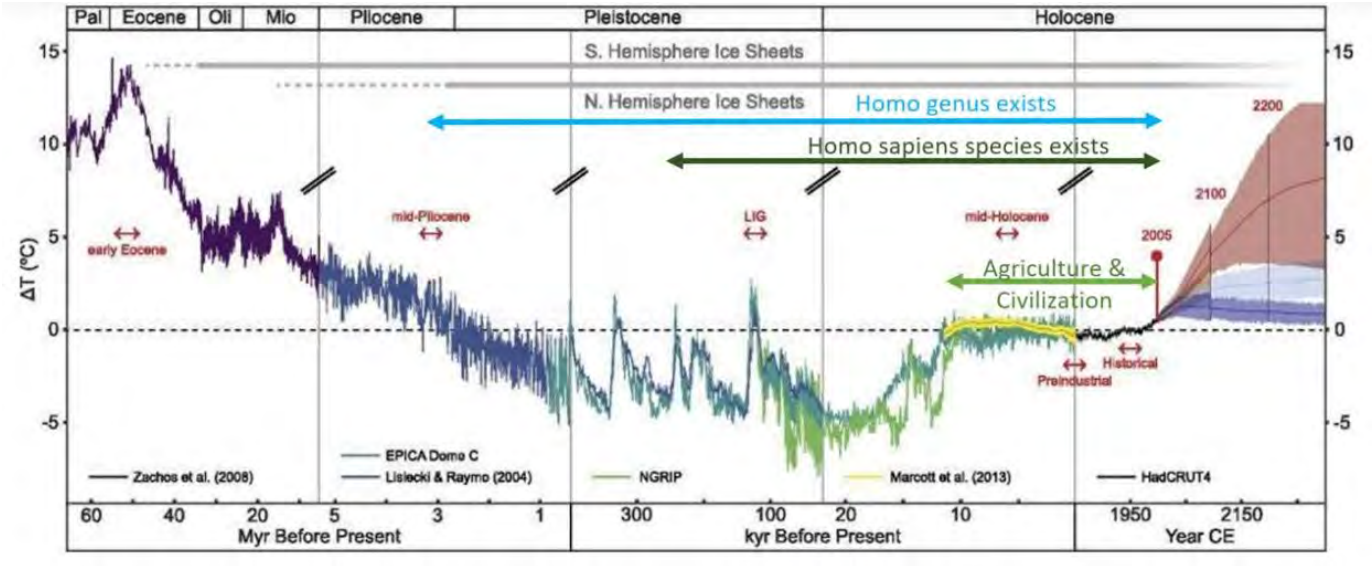


**Figure 1: Trends in temperature over the past 65 million years, and projected trends in temperature over the next 200 years.**

This includes shifts in the climatic zones that plants and wildlife have evolved with and are adapted to, as shown by **Figure 2** and **Figure 3**. In **Figure 2**, the growing zones mapped by the Arbor Day Foundation show a comparison between the years 1990 and 2015, clearly showing a change in the delineated growing zones. In this analysis, the growing zones that are suited for cold-loving plants have been shifting northward as average temperatures rise. In Parker and Abatzoglou, 2016; future projections were mapped, and this additional analysis further illustrated the northwards shift of climatic growing zones (**Figure 3**). For more background information on climate science, please refer to the Climate Health Connect's "Climate Change 101: Climate Science Basics" report (https://climatehealthconnect.org/wp-content/uploads/2016/09/Climate101.pdf) (Climate Health Connect, 2020).

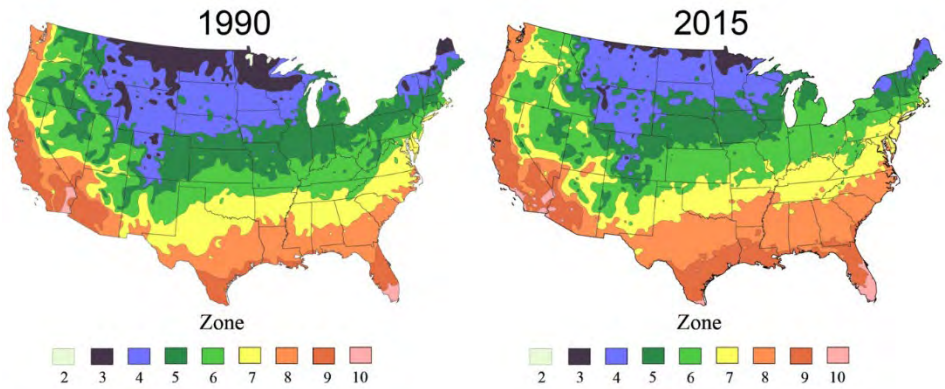


**Figure 2: Arbor Day Foundation comparison of temporal changes in growing zones from 1990 to 2015. (Arbor Day Foundation, 2020)**

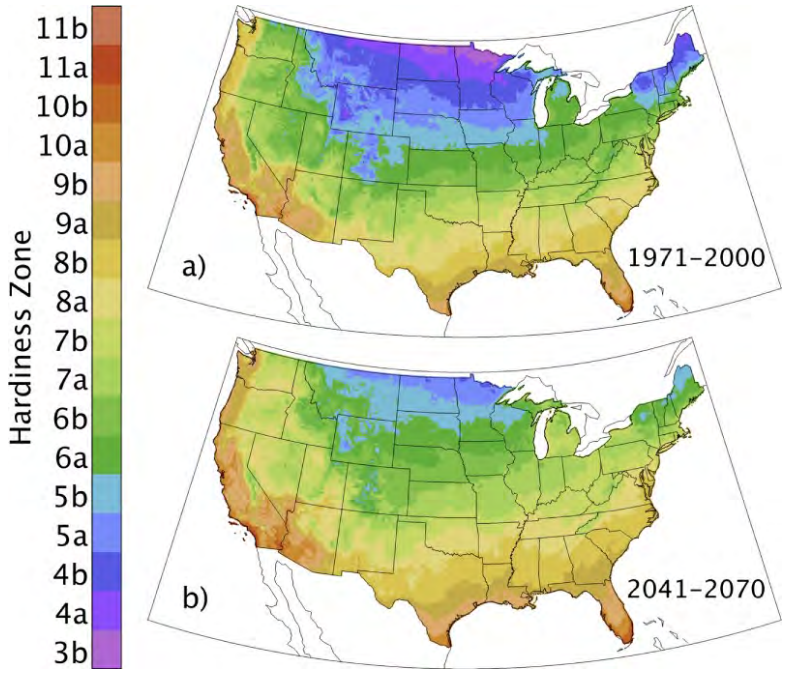


**Figure 3: Future projections showing continued northward shift of colder hardiness zones (Parker and Abatzoglou, 2016)**

***Climate Change in Western NY:*** Human-made emissions of carbon dioxide and other greenhouse gases are causing warming that is not typical of the historical record. These emissions are likely to result in negative impacts to the western New York region. Increases in average annual temperature, frequency of extreme heat and precipitation events, and alterations of habitat suitability will all bring potentially negative changes to the region. For a detailed information on climate change science and how climate change may impact New York State specifically, refer to "Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation in New York State" (Rosenzweig et al, 2011). Data showing historical atmospheric concentration of carbon dioxide (**Figure 4**) (Our World in Data, 2020), and an increase in Erie County's historically observed versus projected temperature (**Figure 5**) (US Climate Resilience Toolkit, 2020) help to visualize these changes. Even under emissions scenarios that assume humans greatly reduce GHG emissions, the challenge to Erie County to protect life and property in our community, and especially to protect vulnerable populations, is significant.

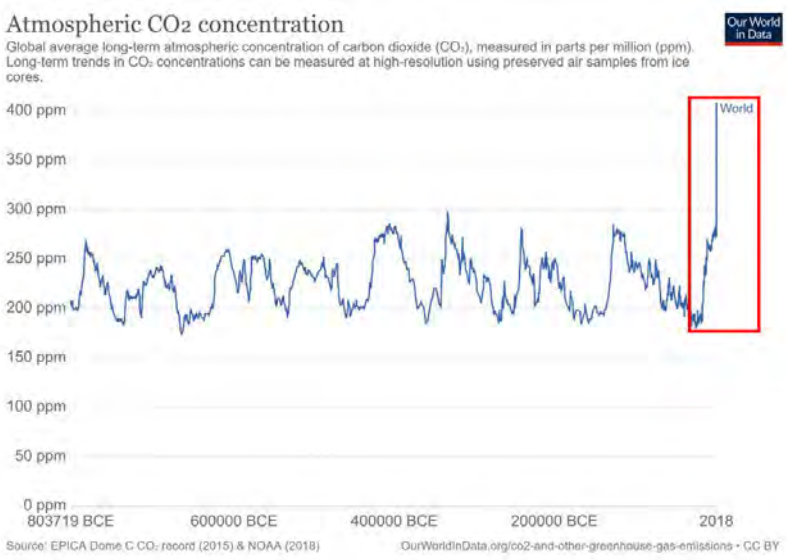


**Figure 4: Chart showing measured atmospheric concentration of carbon dioxide over past 800,000+ years. Note nonlinearity of recent increase in concentration outlined in red box (Our World in Data, 2020).**

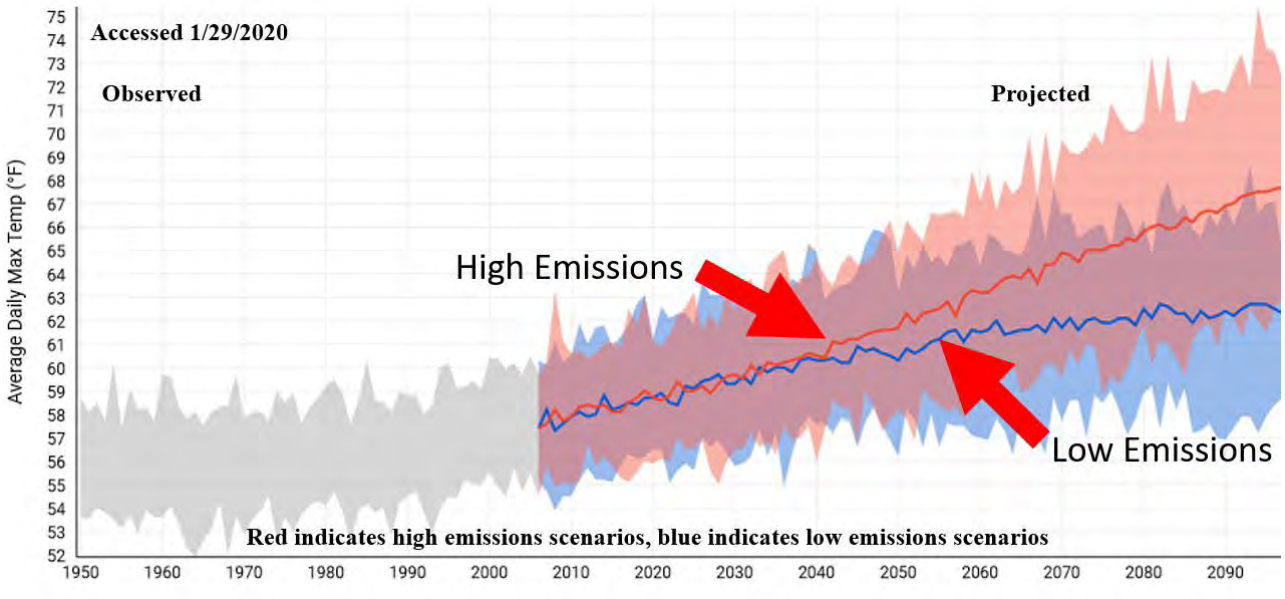


**Figure 5: Observed and projected average daily maximum temperature for Erie County, NY (1950 – 2100). Low emissions scenario is shown in blue and high emissions scenario is shown in red (US Climate Resilience Toolkit, 2020).**

***Climate Change and Extreme Weather Events:*** While no single weather event is standalone evidence of a changing climate, longer-term trends in frequency and intensity of extreme events inform potential climate change impacts. Trends in temperature change impact the hydrological cycle and can lead to extended periods of drought intermingled with extreme precipitation. For instance, elevated temperatures reduce winter snowpack, which reduces soil moisture, potentially leading to drought conditions (Frumhoff et al, 2007). It may be counterintuitive, but these same changes can also lead to extremes in precipitation, and New York State has seen an increase in extreme precipitation events in recent years (Figure 4) (New York State, 2014). Extreme snowfall is projected to increase in the northeast US as well, something that may be particularly relevant to the Erie County region given the proximity to Lake Erie. As ice cover on the Great Lakes diminishes, the warmer water makes it more likely to drive lake-effect snow, resulting in periods of extreme snowfall. This is evident in current trends in lake-effect snowfall around the Great Lakes basin (Easterling et al, 2017). These extremes take place as warmer air drives moisture off of waterbodies and mixes in the atmosphere, ultimately producing precipitation. Our changing climate can release a vast amount of moisture in a short period of time, especially if the right atmospheric conditions exist (Environmental Law and Policy Center, 2019; Rosenzweig 2011).

***Extreme Weather Events in Western New York:*** New York state is no stranger to extreme events, including flooding, snowstorms, extreme heat and high wind events. Some important past extreme weather events in our area include:

- **The 2009 historic flooding in the Village of Gowanda.** Flooding of Thatcher Brook occurred when extreme precipitation from the collision of two storms dropped a massive amount of water on the Cattaraugus Creek watershed. The flooding left one dead, destroyed the Village hospital and resulted in $1-2 million in damages to the community where at least 25% of the homes in the Village of Gowanda were impacted (Olean Times Herald, 2020; Szabo et al, 2010).

- **The November 2014 winter storm.** A lake effect storm, given the code name Knife by local governments and known colloquially as “Snowvember”, hit the greater Buffalo region and lasted from November 17 to 19. Nearly 7 feet of snow fell in this time on a large portion of the County, resulting in stranded commuters, property damage, and the loss of 13 lives (National Weather Service, 2020) (**Figure 6**).

- **A record-breaking heat wave in July, 2020.** During this heat wave, WNY temperatures soared into the 90+ degree range for multiple consecutive days, breaking weather records for Buffalo, NY for both duration of these temperatures as well as the hottest day on record for July 9$^{th}$ at 98 degrees Fahrenheit. This record was the 2$^{nd}$ hottest of any day in Buffalo as well (Buffalo News, 2020).

- **A July 16, 2020 tornado.** A severe storm resulted in a tornado touching down in Chautauqua County, NY. This tornado destroyed a family barn, causing hundreds of thousands of dollars of damage to the Dewettville property (WIVB4, 2020). Extreme winds associated with thunderstorms have been increasing in Erie County, a potential link to climate-related changes (Vermette, 2017).

**Figure 6: Image of the November 2014 winter storm "Wall of Snow" approaching Buffalo in 2014 (NOAA, 2014)**

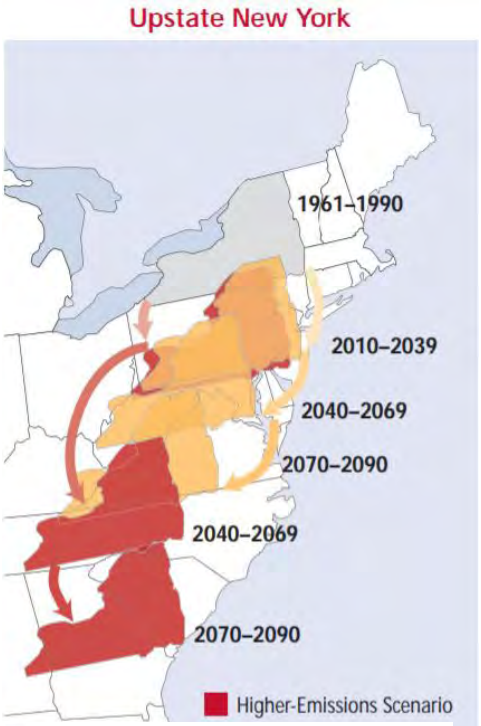


**Figure 7: Graphical depiction of NY's "Migrating Climate" (Frumhoff et al, 2007)**

As our climate shifts, and potentially "migrates", western NY is predicted to experience more extreme weather events, including possible extremes not historically witnessed before **(Figure 7**). Under certain emissions scenarios, New York State's climate may change to resemble the climates that are typically experienced in the southeast United States. This potentially means longer summers and shorter winters. Given the extremes already experienced in recent years, in a warming world these events are expected to occur more frequently, with increased severity and duration. Extremes in temperature (**Figure 8**) (Frumhoff et al, 2007) and precipitation (**Figure 9**) (New York State, 2014) are often cited as common hazards we may face. However, these changes in temperature and precipitation can lead to other, less-direct threats that may be less obvious.

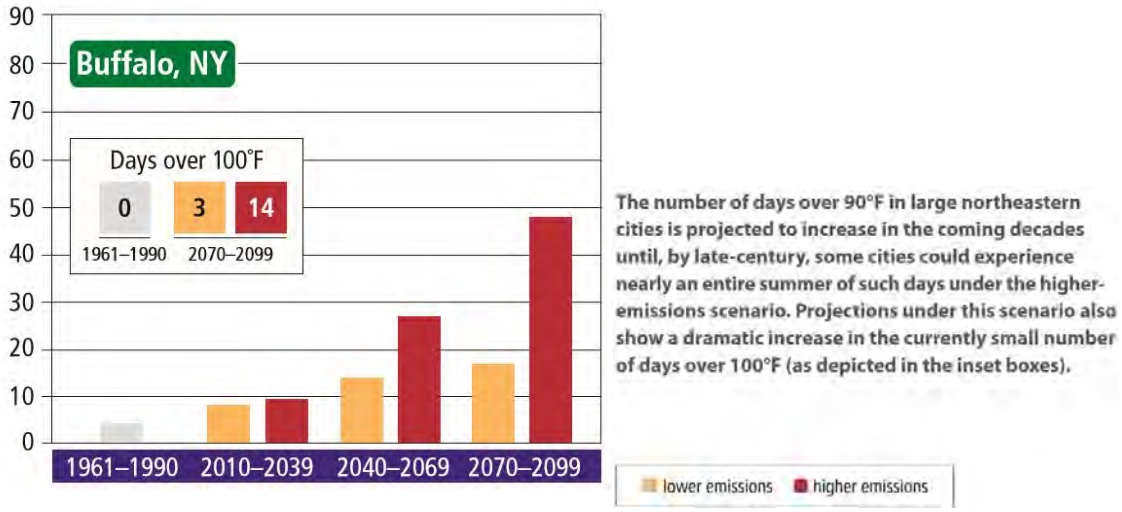


**Figure 8: Extreme heat projections (days over 100°F) for Buffalo, NY (Frumhoff et al, 2007).**

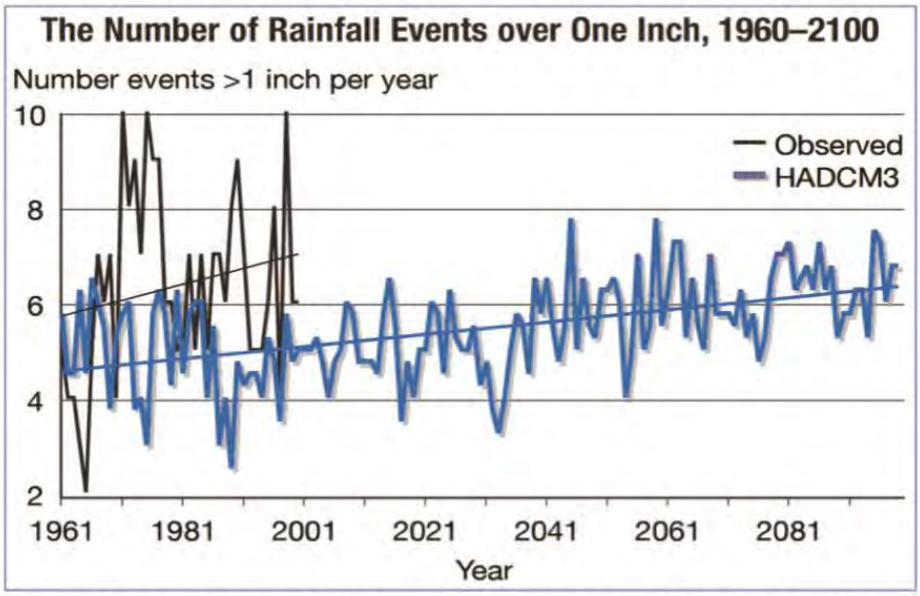


Figure 4. The observed number of rainfall events exceeding one inch from 1960 to 2000 in New York is shown by the black line, and the projected number of such events, using the HadCM3 global climate model, is show by the blue line. These results are broadly consistent with those of the other 15 global climate models used by ClimAID for a high greenhouse gas emission scenario.

**Figure 9: Extreme precipitation projections for New York State (New York State, 2014)**

In western New York and beyond, the simultaneous convergence of multiple climate change impacts could lead to synergistic effects that amplify the already dangerous changes we may face (Climate Central, 2020). For example, increased incidence of extreme precipitation events can lead to erosion of streambanks. This erosion results in direct loss of arable soil in agricultural land and potential damage to public property. Additionally, the soil lost from riparian zones causes sedimentation in waterways, and

eventual deposition into lakes. This increase in turbidity negatively impacts aquatic ecological communities and delivers nutrients in the form of phosphorous and nitrogen (naturally present in soils) that can cause excessive growth of aquatic macrophytes and harmful algal blooms (HABs). These algal blooms can cause toxic effects on wildlife and pets, as well as humans, and are a major cause for concern in NYS and abroad (New York State, 2019). Harmful algal blooms are also linked to increases in temperature, so climate-related increases in water temperature are a contributing factor in HAB extent, severity, and duration. This combination of extremes in precipitation and increases in temperature may elevate the extent and severity of HABs, impacting water quality for wildlife as well as drinking water supplies (Griffith and Gobler, 2019; Gobler, 2019). Understanding these impacts on municipal governments is critical to ensuring that impacts to public health and safety, damage to infrastructure, and environmental impacts are all kept to a minimum.

***The Climate Vulnerability Assessment:*** Recently, the Erie County Department of Environment and Planning received funding from the New York State Department of Environmental Conservation to conduct a Climate Vulnerability Assessment (CVA) under the State's "Climate Smart Communities" program (New York State, 2018; New York State, 2020). This summary report on Erie County's Climate Vulnerability Assessment (CVA) will aid Erie County in determining climate vulnerability, social vulnerability, and adaptive capacity as it relates to the areas that are under County jurisdiction. Identifying the County's strengths and weaknesses will help guide decision making and planning efforts to prevent or mitigate the impacts that climate change may bring. This assessment will investigate the direct impacts of anticipated climate hazards on Erie County. Additionally, the issues related to climate migration, environmental justice and vulnerabilities to western NY's supply chains will also be incorporated into the assessment. Each are briefly described below.

The Erie County region has recently been described as a potential "climate oasis" (Aldia Environmental, 2020; NBC News, 2020). In general, this is due to the region's proximity to immense freshwater resources found in the Great Lakes and relative mild temperatures that may provide greater ecosystem and economic resilience compared to other regions. However, the issue is complex. The Great Lakes are a massive resource of freshwater, but they are not unlimited. Indeed, these resources have already been strained for decades due to pollution and human development (Environmental Law & Policy Center, 2019), and the additional stressor of climate change may further exacerbate the problem. Combine the existing degradation of these resources with an influx of "climate refugees" or "climate immigrants" from more severely impacted regions, and the resources may not be as rich as once thought. Also, potential changes in temperature across the region are likely to cause negative impacts for residents. Although current residents of Erie County may be used to the frigid temperatures of the winter months, climate refugees coming from warmer locations will be less adapted to this environment. And current residents are likely less prepared for potentially warmer temperatures and more frequent heat waves that are predicted during the summer. For example, Buffalo, NY has one of the oldest housing stocks in the country and many homes lack air conditioning. This makes our region more vulnerable to increasing temperatures than southern regions, and there is also potential for unanticipated extremes beyond modeled projections as climate change progresses.

Because climate change will not affect everyone equally, issues of equity and environmental justice are critical when assessing the impacts of climate hazards. One of the issues with the notion of WNY potentially becoming a "climate oasis" is that it tends to overlook issues of historical gentrification of the cities in Erie County, and risks creating "climate gentrification" as more and more people move to this

region and property values go up. This in turn makes it more difficult for those of lower economic status to own homes and thrive in these higher cost situations. Currently, home values are rising faster in Buffalo than anywhere else in the country, including New York City (Bloomberg News, 2020). Additionally, the most vulnerable among us - the old, young, impoverished, and ethnic minority populations - have historically faced the brunt of the impacts from disasters (Andrew et al, 2008; Peek, 2008, Bolin, 2007; Fothergill & Peek, 2004; Cutter et al, 2003) and it behooves us to consider these populations and the impacts they face as we develop an assessment of Erie County's climate vulnerabilities.

Should the WNY region avoid the worst of direct climate-related impacts, there remains the risk of climate impacts elsewhere on the globe impacting the residents of Erie County, and Erie County as a governmental entity. For example, although the direct impacts of the 2012 Hurricane Sandy in New York State largely centered around the New York City area, there were disruptions in the supply chain here in western New York as a result. Additional risks in supply disruption and municipal financing may be associated with agriculture, water scarcity, and famine in other parts of the world that are far removed from WNY but may impact the region all the same. The risk that climate change has on supply chains is well known to the business community. This awareness is borne out in reports from Business for Social Responsibility, where they explicitly recommend that businesses identify and mitigate issues with climate hazards in their suppliers (Wei and Chase, 2018). Other industry-specific news articles identify climate change as one of several key drivers of potential global supply chain disruptions, listed along with COVID-19 and terrorism (MH&L, 2020). The heightened risk is a cause for concern for the shipping industry, as efforts to get the business community to understand and address these concerns shows (BSR, 2020; MIT Management, 2020). Clearly, we do not live in a vacuum and what impacts humanity elsewhere may very well impact us from thousands of miles away.

**IDENTIFYING CLIMATE THREATS TO OUR REGION**

This section of the report is focused on assessing Erie County's exposure to a variety of climate-related hazards to identify a few specific hazards that will be analyzed further in this assessment. This is the initial step in the process of developing a Climate Vulnerability Assessment (CVA) for the region. The process of identifying climate threats to Erie County consisted of a thorough literature review of existing climate-related guidance documents for the region, climate related reports, and published scientific literature. Our review of scientific publications particularly focused on literature and data that is based on future climate projections for our region, as opposed to historical data trends. This is due to increasing evidence that environmental change may bring about non-linear, and sometime unexpected alterations in climate (Our World in Data, 2020; Burke et al, 2018; Franzke, 2014; IPCC, 2013). The broad list of potential threats under consideration for further assessment were then refined, focusing on threats that particularly impact Erie County's jurisdictional responsibilities, which will ultimately enable the County to take meaningful steps toward addressing vulnerabilities to these threats in future projects.

The process of identification began with a review of four important climate mitigation guidance documents that illustrate the approaches and methods that Erie County is currently considering, employing, or planning to implement related to climate change, which offer important insights for how

the County is currently thinking about climate and its potential impacts. These documents are listed and summarized below:

- the Climate Action and Sustainability Plan (CASP) (Erie County, 2019a),
- the Multijurisdictional Natural Hazard Mitigation Plan Update (MNHMP) (URS, 2015),
- the Healthy Niagara-Niagara River Management Plan Phase I (BNW, 2014) and
- the Regional Niagara River Lake Erie Watershed Management Plan Phase II (Erie County, 2019b).

In the CASP document (Erie County, 2019a), several sections are devoted to describing and evaluating the impacts, as well as mitigation efforts, that relate to Erie County's governmental activities. The Plan consists of in-depth reviews of the County's infrastructure and associated climate-related impacts and an inventory of their carbon emissions; transportation-related emissions and how to reduce the carbon footprint of county-owned vehicles as well as employee's commutes; waste management and recycling program; County-owned buildings and energy consumption; management of County-owned lands; issues related to stormwater, flooding, and water conservation; how to leverage the County's purchasing power effectively. Finally, a detailed plan on how to achieve the GHG reduction goals outlined in the CASP is included (Erie County, 2019a).

The MNHMP (URS, 2015) describes a total of 14 goals that aim to reduce losses (economic as well as related to personal injury and property damage) from natural hazards. These three goals include these ones that are overlapping with the objectives of this study:

1. improving Best Management Practices (BMPs) to encourage development that is less prone to damage from disasters,
2. capacity building for disaster preparation and response, and
3. overall reducing damage and/or losses from a variety of natural hazards (extreme temperatures, high wind events, winter storms, erosion, flooding, ice jams, earthquakes, mass wasting or landslides, fire), damage to critical infrastructure and facilities, and damage from human activities.

To support these goals, the MNHMP (URS, 2015) detailed a considerable list of actions that may be used (the value and appropriateness of the action depends on local conditions) to achieve the goals outlined above.

The Healthy Niagara – Niagara River Watershed Management Plan Phase 1 (BNW, 2014) and Regional Niagara River Lake Erie Watershed Management Plan Phase 2 (Erie County, 2019b) were authored by a collaborative effort between the Erie County Department of Environment and Planning, Buffalo Niagara Riverkeeper and the Lake Erie Watershed Protection Alliance (LEWPA). They are a treasure trove of information on the myriad natural features in the region and the threats that they face. The Plans also provide an analysis and assessment of these threats, that culminate in 25 Key Findings, as well as subsequent recommendations. The full list of recommendations can be viewed at www.erie.gov/wmp, and relevant examples are outlined in the next section.

These documents are thorough and exhaustive in nature, representing the County's concerted effort to understand and assess the natural history of the region, mitigate or lessen the impacts that the County may have on the environment, and plan for climate-related disasters.

In addition to the four documents mentioned above, many other resources were reviewed as part of our literature review including articles, reports and other documents that focus on a portfolio of potential

threats to our region. These include biophysical threats such as temperature (heat-related mortality and disease, air quality degradation), precipitation (ice jams, flooding, erosion, runoff, snowfall), wind (seiche events, lakeshore flooding and erosion, treefalls), vector-borne diseases (Lyme Disease, Malaria), invasive species (zebra mussel, hemlock woolly adelgid), harmful algal blooms (HABs). Social and economic threats were also assessed via literature on social vulnerability to disasters (risk to minority communities/the economically disadvantaged, children, and the elderly), and impacts to regional and local economies (such as changes to the quality and length of the winter recreation season). Guidance documents such as the Great Lakes Climate Change Report (Environmental Law & Policy Center, 2019), New York State Climate Hazards Profile (Tuzzo et al, 2018), One Region Forward (University at Buffalo Regional Institute, 2014), ClimAID (Rosenzweig et al, 2011), Cleveland, Ohio Climate Hazard and Social Vulnerability Assessment (Esselman et al, 2018), Erie County Natural Resources Inventory (Erie County, 2020), LiveWell Erie (Erie County, 2019c), Initiatives for a Smart Economy 2.0, Focus on Inclusion (Erie County, 2017), Western New York Regional Sustainability Plan (Regional Planning Consortium, 2013), and Resilient Buffalo Niagara (Grover et al, 2014) among others, were also reviewed.

Existing guidance on the topic found in the MNHMP (URS, 2015) highlights multiple hazards that the region may face. These hazards are linked as well as unrelated to climate change; and include natural hazards such as winter storms, earthquakes, severe storms, ice storm events, tornados, landslides, wildfires, ice jams, floods, extreme temperatures, and wave action; as well as man-made hazards such as terrorism, hazardous materials (fixed sites and transit of), fire, transportation accidents, structural collapse, explosions, oil spills, and epidemics (URS, 2015).

An additional concept utilized in the threat assessment process can be found in the PEOPLES Resilience Framework (Renschler et al., 2010; Renschler, 2013; Renschler, 2015; Cimellaro et al., 2016). The PEOPLES Framework features seven interrelated dimensions, across a variety of scales, that are useful for taking a holistic approach towards assessing a system's resilience and sustainability in the face of disruption. The seven dimensions and a brief description of each are provided in **Figure 10** below (Renschler, et al., 2010). This concept was developed by Dr. Chris Renschler from the University at Buffalo, in conjunction with other scientists as funded by the National Institute of Standards and Technology's Engineering Laboratory (Renschler et al., 2010). The PEOPLES Resilience Framework has been shown to be very useful in assessing the functionality of a given system based on perturbations from events such as climate-related natural disasters that change the functionality of services an individual, a neighborhood or a county relies on. Utilizing the PEOPLES Resilience Framework is therefore inclusive and comprehensive in nature and makes sure that the investigators and users of the method take into account a wide range of stakeholder interests and ask relevant questions. This is especially important as our assessment seeks to consider the unequal impacts of climate threats on underrepresented communities in our region.

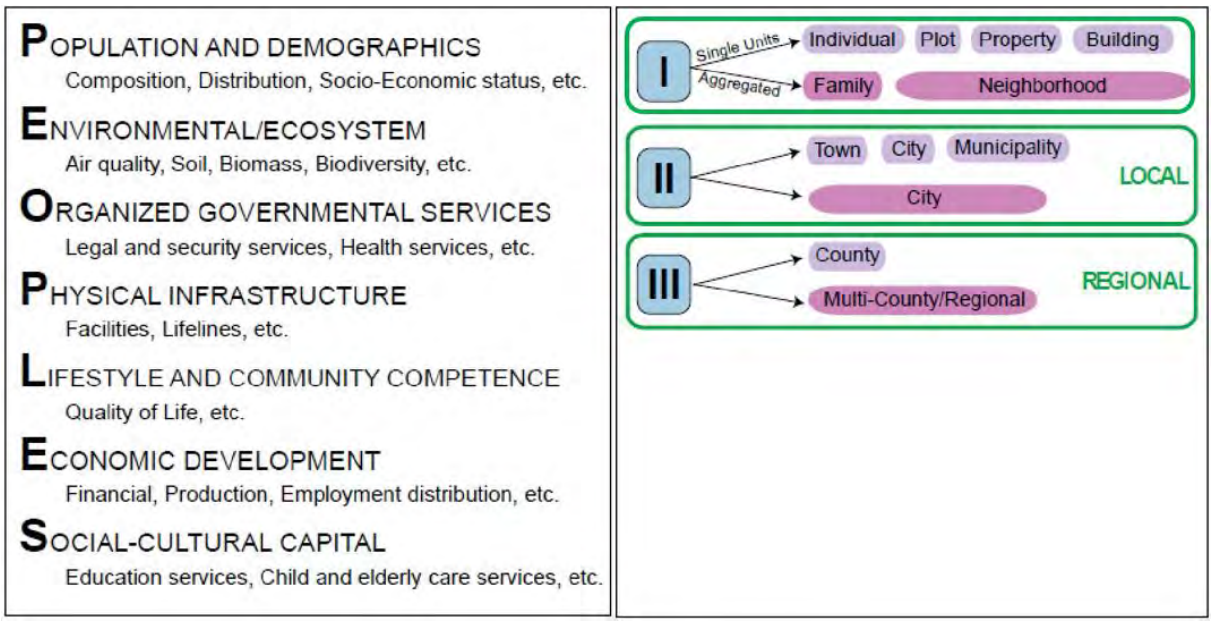


**Figure 10: PEOPLES Resilience Framework (Renschler, et al., 2020)**

Using the PEOPLES framework to guide our thinking, the CVA team reviewed the potential threats that had been previously identified in the literature. This process is illustrated in **Figure 11**, where the hazards related to changes in temperature and precipitation in the region are compared with the variable scales and dimensions of the PEOPLES Framework. In this example, climate hazards are shown to differentially impact populations based at the individual, neighborhood, business, and municipal (Erie County) level. The threats under consideration were further refined based on the likely frequency and duration of the threat's occurrence and impact, the jurisdictional ability of Erie County to impact the threat, and the overall impact that the threat has on the County (**Figure 11, Figure 12**).

| | Vulnerable Populations | Temperature Effects | Precipitation Effects |
|---|---|---|---|
|  | **Individuals,** disadvantaged and low income populations (P E O P L E S) | Impact to health and finances from air quality impacts and utility costs | Risk to individual health from flooding or heavy snow |
|  | **Neighborhoods,** disadvantaged and low income populations, proximity to risk areas (P E O P L E S) | Disadvantaged neighborhoods lack access to warming/cooling stations | Disadvantaged neighborhoods lack disaster preparedness and are slow to recover |
|  | **Businesses,** large shopping centers, small shops, home businesses (P E O P L E S) | Cost of heating and cooling | Damage to physical infrastructure of businesses |
|  | **Erie County,** jurisdictional responsibilities – roads, sewers, social support network (P E O P L E S) | Extremes in temperature impact County infrastructure, stress budget, and social services | Flooding and snow can impact sewer infrastructure, social services |

**Figure 11: Consideration of populations vulnerable to two climate-related impacts with the various dimensions of the PEOPLES Resiliency Framework**

**RESULTS**

Based on our review, five hazard categories were selected to investigate further, pending stakeholder review and County confirmation. These categories are:

1. temperature (extreme heat/cold),
2. precipitation (extreme precipitation events and flooding),
3. wind,
4. vector-borne disease (VBD), and
5. invasive species & Harmful Algae Blooms (HAB).

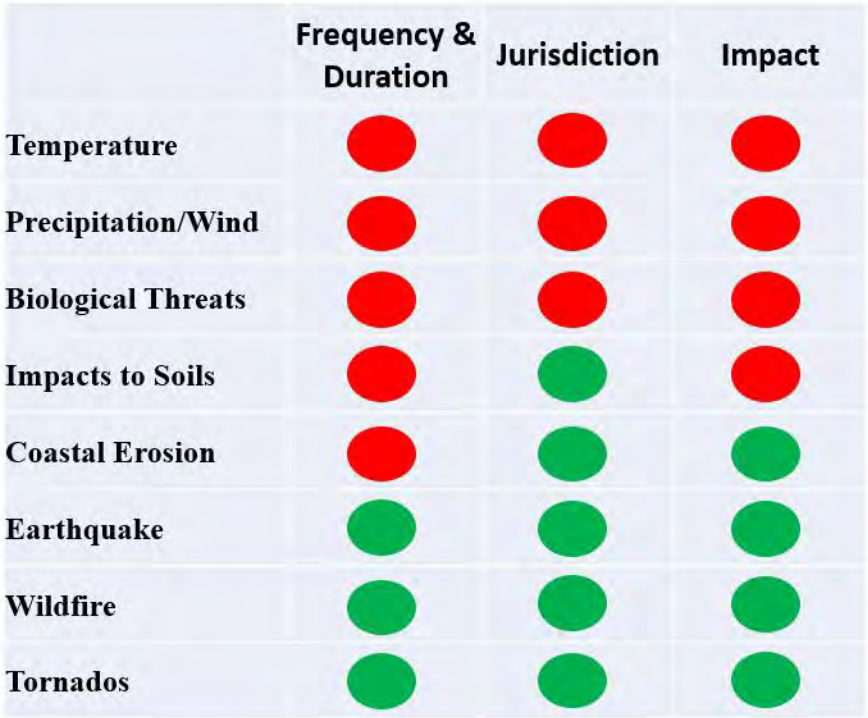


**Figure 12: Matrix created using MJHR-identified threats to aid in selecting focus threats for the CVA process. In this decision-making process, green = lower and red = higher.**

***Note that certain threats may include multiple subcategories: extreme heat or extreme cold, air quality impacts (temperature); extreme rain events, windstorms associated with thunderstorm events, prolonged drought, or snowstorms (precipitation); and vector-borne diseases, invasive species, and harmful algal blooms (biological threats). While coastal erosion, earthquakes, wildfire and tornados may have impacts, these impacts are of low frequency, localized and are outside the scope of this study.**

The hazards were chosen based on the potential frequency and duration of an event in that category, its relevance to Erie County jurisdiction, as well as the severity of potential impacts of the event (**Figure 12)**. For example, while earthquakes have occurred in the region, they are uncommon and rarely result in

major damage; while flooding does occur with greater frequency and can result in major damage (as described above, regarding Gowanda in 2009). Each of the 5 chosen categories, as they relate to Erie County are briefly described below.

**Temperature** analysis of the northeast US, western New York, and the Greater Buffalo and Erie County region all point to an upward trend for average temperature. Since 1990, vegetative growing zones have shifted northward and the trend is projected to continue (**Figure 2 & Figure 3**) (Parker and Abatzoglou, 2016; Arbor Day Foundation, 2015; Frumhoff et al, 2007). While increases in temperature and carbon dioxide may increase plant productivity in some instances, overall the increase in temperature is expected to negatively impact crop yields and health of livestock, and may also result in an increase in pressure on agriculture from noxious weeds and insect pests (Walthall et al, 2013). Observed and projected changes in average daily maximum temperature modeled by the US Climate Resilience Toolkit (toolkit.climate.gov/) have an upward trend, whether the low emissions scenario or high emissions scenario is considered (**Figure 4**) (US Climate Resilience Toolkit, 2020). In Buffalo, NY, temperature extremes such as the number of days over 100 degrees Fahrenheit are expected to increase from 0 to between 3 and 14 days (**Figure 8**) (Frumhoff et al, 2007). Climate-related changes in temperature may also impact the formation and break up of ice jams (Das et al, 2017). Ice jams occur when ice builds up in a waterway, damming the water behind the buildup. This in turn creates a dangerous situation, as a substantial volume of water may accrue behind the ice jam and a melting event can release that water creating a flash flood (URS, 2015). Wind can be a contributing factor to development of ice jams. Changes in temperature can also negatively impact air quality when extreme heat events create high levels of ozone. This can be a public health concern in regions not previously experienced in dealing with such events (**Figure 8, Figure 12, Figure 14**) (APHA, 2020; Hamstead et al., 2018; Jacob and Winner, 2009).

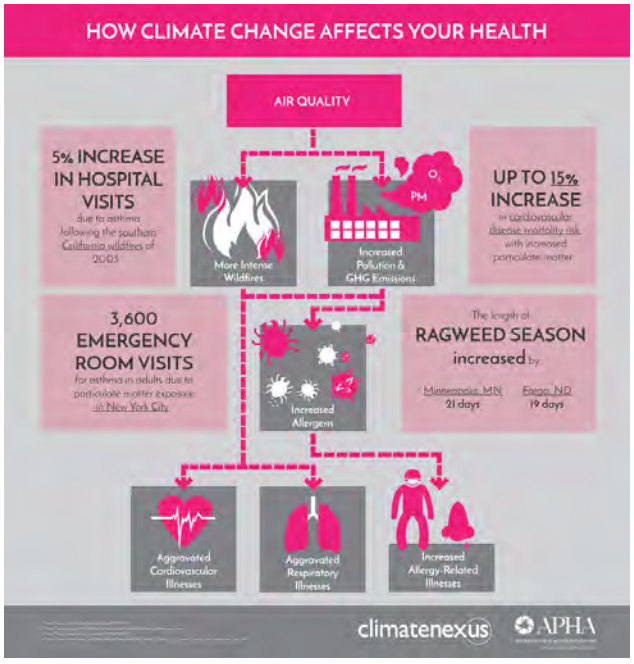

**Figure 13: How air quality degradation (from wildfires, allergens, temperature etc.) attributed to climate change can impact your health (APHA, 2020)**

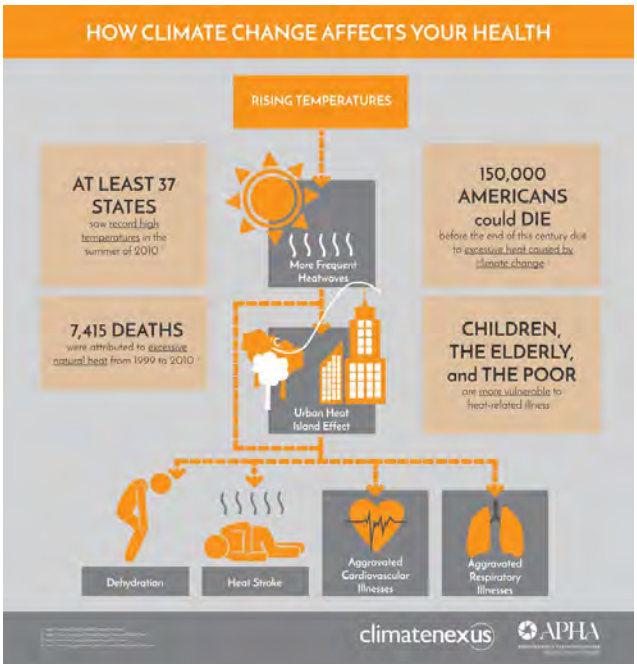


**Figure 14: How climate change-related changes to temperature affect your health (APHA, 2020).**

**Precipitation** patterns have changed in New York State. The number of rainfall events that produce precipitation in excess of 1 inch have increased over the past 50 years and the events that produced more than 2 inches of precipitation has had the highest frequency in the past 10 years, this is expected to increase further over the next several decades (**Figure 9**) (Frankson et al, 2017; NYS Environmental Protection Bureau, 2014). Annual precipitation is expected to increase by 5-15% in the region, with less precipitation in winter and spring and more precipitation in fall and summer (Easterling, et. al., 2017). Snowfall will also be impacted. While the overall amount of winter precipitation isn't expected to decline, the timing and intensity of storms may change. Erie County is expected to see a decrease in precipitation overall in December, winter storms are projected to produce more rain than snow, and when it does snow the intensity of snowfall may be more severe with short durations of heavy snow (Notaro & Lorenz, 2013). Heavier, more intense, precipitation can lead to increased physical and chemical weathering (Chapin et. al., 2002). Physical weathering will take place from increases in freeze-thaw or wet-dry events, which creates and widens physical cracks in substrates such as bedrock, concrete, and pavement. Additionally, heavy rain can lead to saturated soils and splash effects that may exacerbate erosion. Increases in precipitation may also exacerbate chemical weathering through elevated acidity stemming from the dissolution of carbon dioxide in rainwater – creating a weak, albeit still acidic, carbonic acid. These impacts combined with increases in temperature can also lead to higher rates in chemical reactions which in turn increases chemical weathering. Alterations in precipitation patterns may negatively impact the agricultural community in Erie County. As variability increases, more arid conditions may reduce crop yields and extremes in precipitation may increase rates of erosion and directly lead to loss of prime farm soils (Walthall et al, 2013). Precipitation can also interact with wind. Over the past 20 years, there has been a significant increase in wind associated with thunderstorms (**Figure 15**), illustrating the interrelated impacts that climate change may bring (Vermette, 2017). From

the Erie County perspective, these potential changes can mean challenges in managing stormwater flow, excess inputs to sewer lines (and associated overages of flow that release untreated wastewater into waterways), and damage to infrastructure from physical weathering, chemical weathering, and storm damage. Vulnerable populations may be more at risk through low-income residences located in a floodplain, or through a lack of ability to recover from the financial aspect of flood damage.

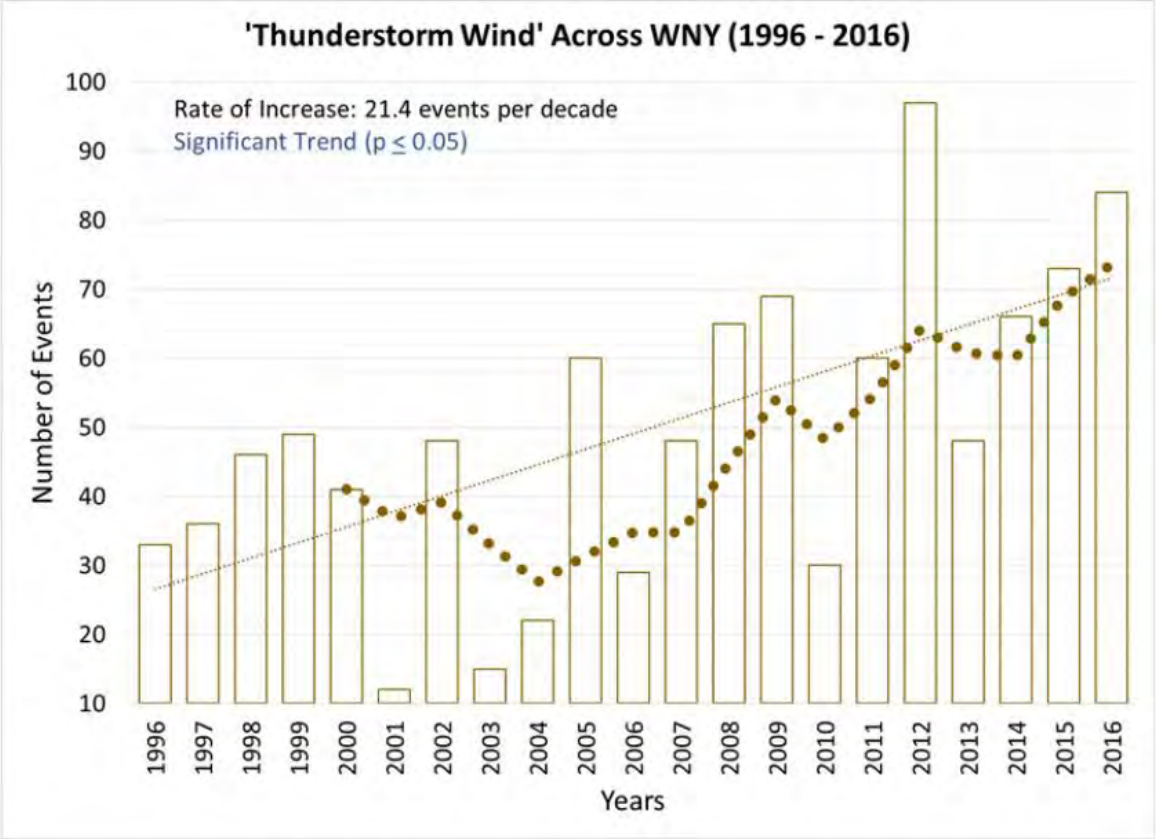


**Figure 15: Frequency of thunderstorm wind events reported for WNY (1996-2016) (Vermette, 2017).** Data for this chart was obtained from NOAA's Storm Events Database. Here, 'thunderstorm winds' are defined as winds arising from convection (occurring within 30 minutes of observed or detected lightning) with speeds of at least 58 mph, or winds of any speed producing a fatality, injury, or damage).

**Wind**, according to the MJHR (2015 the entirety of Erie County within an "extreme wind hazard area", and that historically this hazard has cost the region millions in property damage and crop failure (URS, 2015). Additional literature on the topic suggests that climate change may have profound impacts on wind currents surrounding large bodies of water like Lake Erie (Desai et al, 2009), as well as an increase in annual-mean wind speed values in the future (Eichelberger et al, 2008). This may also lead to changes in ice jam formation and break up while the Lake still has ice formation in the winter, although more modeling is needed to assess this factor (Das et al, 2017). Increases in extreme wind events can exacerbate the damage that has historically been done when these events occur (such as ice jams), leading to additional property damage, crop failure, and potentially wind-related erosion. In regard to extreme wind events such as tornados, western NY has not had the number of events that other regions

of the country have. However, a review of the tornado occurrences between 1950 and 2020 indicates that these storms are increasing in frequency – at least over the long term. The period spanning 1950 to 1990 had 8 tornado events, while the period between 1990 and 2020 had 14. Extreme wind can also lead to lakeshore flooding from seiche events, which for Lake Erie are waves resulting from oscillations in lake levels due to atmospheric events. In the Great Lakes, this is largely due to a rapid alteration of barometric pressure gradients resulting in higher wind speeds (URS, 2015). A review of the last 20 years of data indicates that a seiche event occurs on average once every year, with property damage occurring in 11 of those 20 events (NOAA, 2020). In the CVA process, wind will be incorporated into both temperature and precipitation-related analyses, as it is a key factor in both extreme temperature and precipitation (e.g., thunderstorms, **Figure 15**) related events.

**Vector-borne diseases (VBD)**, such as those related to mosquitos and ticks, can be influenced by changes in climate which can lead to changes in habitat suitability for organisms involved (Brownstein et al., 2005). Alterations in average temperature and rates of precipitation can lead to the ability of these organisms to expand their geographic range and can also lead to changes in their behavior (Tuzzo et al, 2018; Gubler et al., 2001). Overall, this can lead to an increase in tick-borne and mosquito-borne disease in Erie County (APHA, 2020). Expansion of the range of the Asian tiger mosquito (*Aedes albopictus*), a species associated with multiple diseases (chikungunya, dengue, West Nile virus etc.) may occur in the Erie County region over the next several decades (Rochlin et al., 2013; Alto & Juliano, 2001), and research on ticks point towards a range of biogeographical factors associated with population increases (Khatchikian et al., 2013).

**Invasive species** refers to any organism that is found outside of its natural range, and that causes negative impacts to ecological relationships, human economies and public health (WNY PRSIM, 2020). This issue is increasingly recognized as a serious threat, and the same alterations of climate and habitat that may result in range expansions in VBDs pose the same risks regarding invasive species (Tuzzo et al, 2018), which in turn translates to an exacerbated level of negative impact to terrestrial and aquatic ecosystems (Hellman et al, 2008; Rahel and Olden, 2008; Mainka and Howard, 2010). Harmful Algal Blooms (HABs) occur when certain species of aquatic life, such as cyanobacteria, proliferate above their background population levels in freshwater systems such as Lake Erie. These species of cyanobacteria, and others, may create harmful levels of microcystin toxins and other compounds, which can be harmful to human health, pets, and wildlife (NYSDEC, 2019). This issue may also become exacerbated from the impacts of climate change (**Figure 16**) (Griffith and Gobler, 2020; Gobler, 2019).

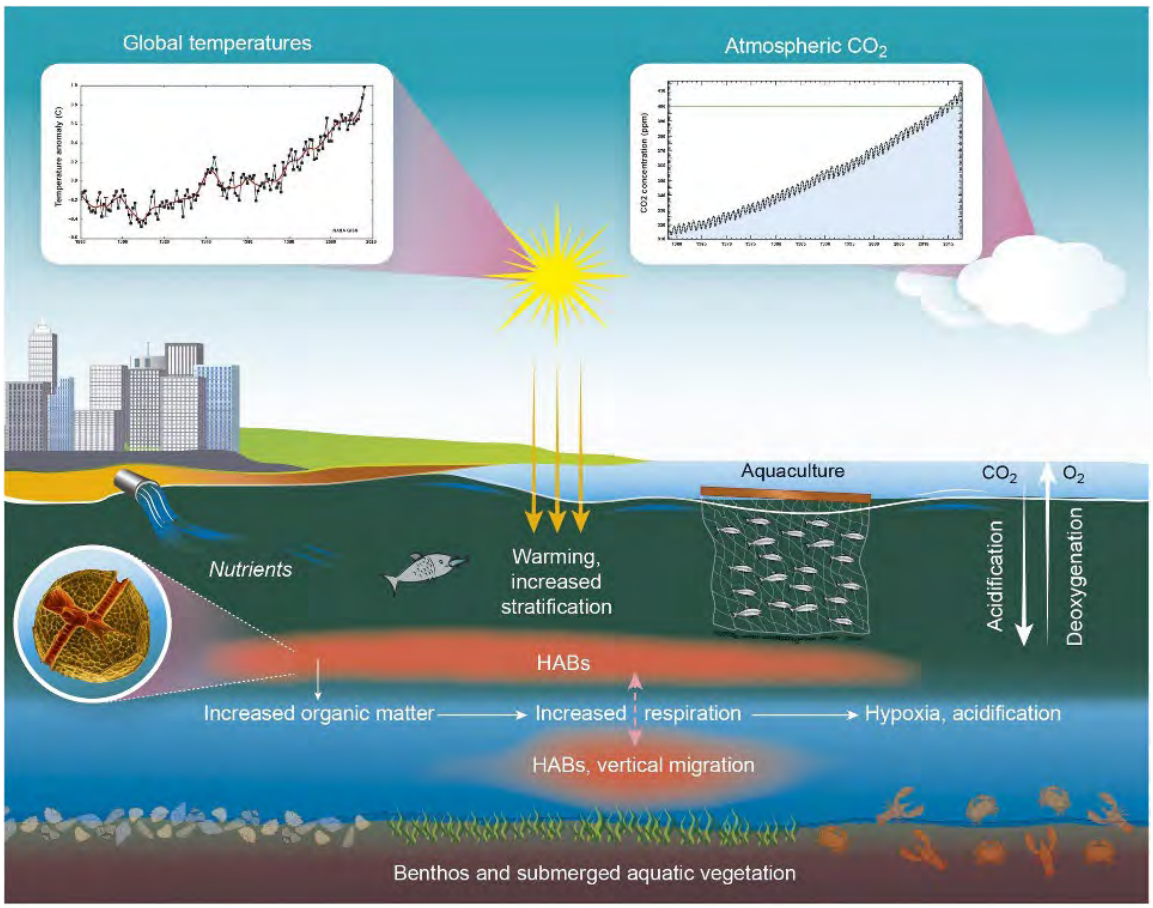


**Figure 16: Interaction between climate change impacts and HABs as temperature, carbon dioxide, and nutrients (exacerbated by extremes in precipitation) synergistically react with each other to elevate the frequency, duration, and severity of HABs (Griffith and Gobler, 2020).**

**NEXT STEPS**

The hazards outlined above are not the only threats Erie County may face that are related to climate change. This summary of the Climate Vulnerability Assessment (CVA) for Erie County lists some of the main threats and should be considered as a starting point in analyzing where and to what extent certain hazards may impact the County across time and space. The next step of the CVA includes geospatial analysis of the identified threats, and of what populations and infrastructure are most sensitive to their impacts. This analysis will include the use of the CDC Social Vulnerability Index, which uses a variety of social factors at the census tract level (i.e., economic data and data regarding education, family characteristics, housing, language ability, ethnicity, and vehicle access) to depict the social vulnerability of communities to disasters. The final step will be to assess the adaptive capacity of the County government to be able to address and recover from the identified threats. Currently, University of Buffalo is developing geographic information systems-based (GIS) methodologies to analyze and spatially map these hazards.

Building on previous work by Hamstead et al. (2018) our team is updating a local thermal vulnerability assessment to identify hotspots within the County that are particularly vulnerable to extreme heat and cold conditions. Also, a flood hazard index (FHI) is being developed that compiles metrics from several data sources and creates a numerical index of flood risk that can be spatially mapped to identify areas of concern (Forkuo, 2011; Sanyal & Lu, 2005). The methods used in this study are adapted from these and other literature (Kabenge et al., 2017; Kazakis et al., 2015; Bapalu & Sinha, 2005;), and will include parameters such as elevation/slope, land cover and land use, FEMA-designated flood zones, population density, and tax map parcel density; as well as factoring in climate scenarios produced by the Environmental Protection Agency across two return periods (EPA, 2020). This index is in the process of being improved upon and validated.

To assess the threat of expanded range and subsequent impact from vector-borne diseases and invasive species, this project is investigating the utility of a mapping application created by the United States Fish and Wildlife Service (USFWS). The program is called the "Risk Assessment Mapping Program" (RAMP), and is an application used in ESRI's ArcMap GIS to map invasive species in conjunction with range shifts attributed to climate change (Sanders et al, 2018). In a proof-of-concept phase, this program will be used to assess the potential range expansion of an invasive, disease-causing species of mosquito. The Asian tiger mosquito (*Aedes albopictus*) has been linked to diseases such as chikungunya and West Nile (WNV) and has the potential to spread from southern New York to western New York (Rochlin et al, 2013). If appropriate, RAMP will be used to analyze species of ticks, HABs and certain invasive species (to be decided upon pending appropriate utility of the RAMP program).

Collectively, these various indices and geospatial analyses will be incorporated into the CVA process so that they can be cross referenced with existing Erie County services to identify where the most sensitive populations and infrastructure are located, who the most sensitive populations are (again, to incorporate climate equity in our analysis), what specific hazard(s) may impact them, and the extent of the anticipated impact. This data is then used to inform the assessment of Erie County's adaptive capacity to respond to these hazards. Finally, a set of recommendations for mitigation measures, future planning needs, and other information will be included in the final CVA report, which is projected to be released in early to mid-spring, 2021.

**REFERENCES**

Aldia Environment. "Why Buffalo is the best U.S. city for climate refugees". Accessed July 17, 2020. https://aldianews.com/articles/cultura/environment/why-buffalo-best-us-city-climate-refugees/57108

Alto, Barry & Juliano, Steven. 2001. Precipitation and Temperature Effects on Populations of Aedes albopictus (Diptera: Culicidae): Implications for Range Expansion. Journal of medical entomology. 38. 646-56. 10.1603/0022-2585-38.5.646.

American Public Health Association (APHA). "How Climate Change Affects Your Health". Accessed 2 February, 2020. https://www.apha.org/news-and-media/multimedia/infographics/how-climate-change-affects-your-health

Andrew MK, Mitnitski AB, Rockwood K. 2008. Social Vulnerability, Frailty and Mortality in Elderly People. PLoS ONE 3(5): e2232. https://doi.org/10.1371/journal.pone.0002232

Arbor Day Foundation. Accessed February 1, 2020. arborday.org/media/map_change.cfm

Bapalu, G.V., & Sinha, R.. 2005. GIS in Flood Hazard Mapping: a case study of Kosi River Basin, India.. 10.13140/RG.2.1.1492.2720.

Bloomberg News. "Will Buffalo Become a Climate Change Haven?". Accessed July 17, 2020. https://www.bloomberg.com/news/articles/2019-12-05/the-consequences-of-being-a-climate-refuge-city

Bolin B. 2007 Race, Class, Ethnicity, and Disaster Vulnerability. In: Handbook of Disaster Research. Handbooks of Sociology and Social Research. Springer, New York, NY

Brownstein, J. S., Holford, T. R., & Fish, D. 2005. Effect of Climate Change on Lyme Disease Risk in North America. EcoHealth, 2(1), 38–46. doi:10.1007/s10393-004-0139-x

Buffalo News. "Getting warmer: Heat wave breaks records, but another is coming". Accessed July 19, 2020. https://buffalonews.com/news/getting-warmer-heat-wave-breaks-records-but-another-is-coming/article_2313d09a-c1f1-11ea-aca5-87e81529a160.html

Buffalo Niagara Riverkeeper. 2014. Healthy Niagara – Niagara River Watershed Management Plan.

Burke, KD & Williams, JW & Chandler, MA & Haywood, AM & Lunt, Dale & Otto-Bliesner, BL. 2018. Pliocene and Eocene provide best analogs for near-future climates. Proceedings of the National Academy of Sciences. 115. 10.1073/pnas.1809600115.

Business for Social Responsibility (BSR). "Why Climate Resilience and Supply Chains Go Hand in Hand". Accessed July 17, 2020. https://www.bsr.org/en/our-insights/blog-view/climate-change-supply-chains-go-hand-in-hand

Chapin, F. S., Matson, P. A., & Mooney, H. A. 2002. Principles of terrestrial ecosystem ecology. New York: Springer.

Cimellaro, G. & Renschler, Chris & Reinhorn, Andrei & Arendt, Lucy. 2016. PEOPLES: A Framework for Evaluating Resilience. Journal of Structural Engineering. 142. 04016063. 10.1061/(ASCE)ST.1943-541X.0001514.

City of Rochester. 2018. Climate Vulnerability Assessment Report

Climate Central. Accessed May 27, 2020. https://medialibrary.climatecentral.org/resources/local-climate-hazard-pile-up-2019

Climate Health Connect. “Climate Change 101: Climate Science Basics”. Accessed July 29, 2020. https://climatehealthconnect.org/wp-content/uploads/2016/09/Climate101.pdf

Colburn, Lisa & Jepson, Michael & Weng, Changhua & Seara, Tarsila & Weiss, Jeremy & Hare, Jon. 2016. Indicators of climate change and social vulnerability in fishing dependent communities along the Eastern and Gulf Coasts of the United States. Marine Policy. 74. 10.1016/j.marpol.2016.04.030.

Cutter, Susan & Boruff, Bryan & Shirley, W.. 2003. Social Vulnerability to Environmental Hazards. Social Science Quarterly. 84. 242-261. 10.1111/1540-6237.8402002.

Das, Apurba & Rokaya, Prabin & Lindenschmidt, Karl-Erich. 2017. Assessing the impacts of climate change on ice jams along the Athabasca River at Fort McMurray, Alberta, Canada.

Data USA. “Erie County”. Accessed July 29, 2020. https://datausa.io/profile/geo/erie-county-ny

Desai, Ankur & Austin, Jay & Bennington, Val & Mckinley, Galen. 2009. Stronger winds over a large lake in response to weakening air-to-lake temperature gradient. Nature Geoscience. 2. 10.1038/ngeo693.

Easterling, D.R., K.E. Kunkel, J.R. Arnold, T. Knutson, A.N. LeGrande, L.R. Leung, R.S. Vose, D.E. Waliser, and M.F. Wehner, 2017: Precipitation change in the United States. In: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 207-230, doi: 10.7930/J0H993CC.

Eichelberger, S. & Mccaa, James & Nijssen, Bart & Wood, A.. 2008. Climate change effects on wind speed. NAm Wind. 7. 68-72.

Environmental Law & Policy Center. 2019. An Assessment of the Impacts of Climate Change on the Great Lakes.

Erie County. 2020. Natural Resources Inventory. Accessed August 6, 2020. https://www2.erie.gov/gis/index.php?q=check-out-our-natural-resource-inventory-story-map

Erie County. 2019a. Erie County Climate Action and Sustainability Plan, Internal Operations. Erie County - Department of Environment and Planning Report No. 1 Contract No. 57240

Erie County. 2019b. Regional Niagara River Lake Erie Watershed Management Plan Phase 2. Erie County – Department of Environment and Planning. http://www2.erie.gov/environment/sites/www2.erie.gov.environment/files/uploads/pdfs/ECS_WMP%20FINAL.pdf

Erie County.2019c. LiveWell Erie. September, 2019. https://www2.erie.gov/livewellerie/sites/www2.erie.gov.livewellerie/files/uploads/pdfs/September%20Live%20Well%20Vision%20Updated%20for%20Kelly%202.pdf

Erie County, 2017. Initiatives for a Smart Economy 2.0, Focus on Inclusion. https://www2.erie.gov/environment/sites/www2.erie.gov.environment/files/uploads/pdfs/Initiatives%20For%20Smart%20Economy%202.0.pdf

Esselman, R., Stults, M., Reilly, B.C., Mosher, K., Rajkovich, N.B. 2017. Climate Hazard and Social Vulnerability Assessment – Cleveland, Ohio.

Frankson, K. Kunkel, S. Champion, B. Stewart, W. Sweet, and A. T. DeGaetano, 2017. New York State Climate Summary. NOAA Technical Report NESDIS 149-NY, 4 pp.

Franzke, Christian. 2014. Warming trends: Nonlinear climate change. Nature Climate Change. 4. 423-424. 10.1038/nclimate2245.

Fothergill, Alice. 2004. Poverty and Disasters in the United States: A Review of Recent Sociological Findings. Natural Hazards. 32. 89-110. 10.1023/B:NHAZ.0000026792.76181.d9.

Forkuo, Eric Kwabena. 2011. Flood Hazard Mapping using Aster Image data with GIS. Int J Geomat Geosci. 1.

Frumhoff, P.C., J.J. McCarthy, J.M. Melillo, S.C. Moser, and D.J. Wuebbles. 2007. Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions. Synthesis report of the Northeast Climate Impacts Assessment (NECIA). Cambridge, MA: Union of Concerned Scientists (UCS)

Kabenge, Martin & Elaru, Joshua & Wang, Hongtao & Li, Fengting. 2017. Characterizing flood hazard risk in data-scarce areas, using a remote sensing and GIS-based flood hazard index. Natural Hazards. 1-19. 10.1007/s11069-017-3024-y.

Kazakis, Nerantzis & Kougias, Ioannis & Patsialis, Thomas. 2015. Assessment of flood hazard areas at a regional scale using an index-based approach and Analytical Hierarchy Process: Application in Rhodope–Evros region, Greece. Science of The Total Environment. 538. 555–563. 10.1016/j.scitotenv.2015.08.055.

Kumar, Parveen & Geneletti, Davide & Nagendra, Harini. 2016. Spatial assessment of climate change vulnerability at city scale: A study in Bangalore, India. Land Use Policy. 58. 514-532. 10.1016/j.landusepol.2016.08.018.

Gobler, Christopher. 2019. Climate Change and Harmful Algal Blooms: Insights and perspective. Harmful Algae. 91. 101731. 10.1016/j.hal.2019.101731.

Griffith, Andrew & Gobler, Christopher. 2020. Harmful algal blooms: A climate change co-stressor in marine and freshwater ecosystems. Harmful Algae. 91. 10.1016/j.hal.2019.03.008.

Grover, Himanshu, Margaret Smith, Yanjia Cao and Yi Yang. 2014.Resilient Buffalo Niagara: Strategies to Respond to Climate Change. University at Buffalo Regional Institute, State University of New York at Buffalo, School of Architecture and Planning.

Gubler, D. J., Reiter, P., Ebi, K. L., Yap, W., Nasci, R., & Patz, J. A. 2001. Climate variability and change in the United States: potential impacts on vector- and rodent-borne diseases. Environmental health perspectives, 109 Suppl 2(Suppl 2), 223–233. doi:10.1289/ehp.109-1240669

Gupta, Joyeeta & Termeer, C.J.A.M. & Klostermann, Judith & Meijerink, S. & Brink, & den, van & Jong, Pieter & Nooteboom, Sibout & Bergsma, Emmy. 2010. The Adaptive Capacity Wheel: A Method to Assess the Inherent Characteristics of Institutions to Enable the Adaptive Capacity of Society. Environmental Science and Policy 13 2010 6. 13. 10.1016/j.envsci.2010.05.006.

Hamstead, Zoe & Farmer, Carson & McPhearson, Timon. 2018. Landscape-Based Extreme Heat Vulnerability Assessment. Journal of Extreme Events. 1850018. 10.1142/S2345737618500185.

Hellmann, Jessica & Byers, James & Bierwagen, Britta & Dukes, Jeffrey. 2008. Five Potential Consequences of Climate Change for Invasive Species. Conservation biology: the journal of the Society for Conservation Biology. 22. 534-43. 10.1111/j.1523-1739.2008.00951.x.

IPCC, & Stocker, Thomas & Qin, Dawei & Plattner, Gian-Kasper & Tignor, M. & Allen, S.K. & Boschung, J. & Nauels, Alexander & Xia, Y. & Bex, V. & Midgley, P.M.. 2013. The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Climate Change 2013.

Jacob, Daniel J., and Darrel A. Winner. 2009 Effect of climate change on air quality. Atmospheric Environment 43(1): 51-63.

Khatchikian, Camilo & Prusinski, Melissa & Stone, Melissa & Backenson, Bryon & Wang, Ing-Nang & Levy, Michael & Brisson, Dustin. 2012. Geographical and environmental factors driving the increase in the Lyme disease vector Ixodes scapularis. Ecosphere (Washington, D.C). 3. 10.1890/ES12-00134.1.

Mainka, Susan & Howard, Geoffrey. 2010. Climate change and invasive species: Double jeopardy. Integrative zoology. 5. 102-11. 10.1111/j.1749-4877.2010.00193.x.

Material Handling & Logistics (MH&L). "Climate Change Among Key Drivers of Global Supply Chain Disruption". Accessed July 17, 2020. https://www.mhlnews.com/global-supply-chain/article/21126860/climate-change-among-key-drivers-of-global-supply-chain-disruption

MIT Management. "Supply chain resilience in the era of climate change". Accessed July 17, 2020. https://mitsloan.mit.edu/ideas-made-to-matter/supply-chain-resilience-era-climate-change

National Oceanic and Atmospheric Administration (NOAA), National Centers for Environmental Information. Storm Events Database. Accessed July 19, 2020. https://www.ncdc.noaa.gov/stormevents/listevents.jsp?eventType=%28C%29+Tornado&beginDate_mm=04&beginDate_dd=01&beginDate_yyyy=1950&endDate_mm=04&endDate_dd=30&endDate_yyyy=2020&county=ERIE%3A29&hailfilter=0.00&tornfilter=0&windfilter=000&sort=DT&submitbutton=Search&statefips=36%2CNEW+YORK; https://www.ncdc.noaa.gov/stormevents/listevents.jsp?eventType=%28Z%29+Seiche&beginDate_mm=04&beginDate_dd=01&beginDate_yyyy=1950&endDate_mm=04&endDate_dd=30&endDate_yyyy=2020&county=ERIE%3A29&hailfilter=0.00&tornfilter=0&windfilter=000&sort=DT&submitbutton=Search&statefips=36%2CNEW+YORK

National Oceanic and Atmospheric Administration (NOAA). 2014. Photo Library. Accessed July 20, 2020. https://www.flickr.com/photos/noaaphotolib/27940598775/in/photolist-4yiQF6-4ynTes-4yiABk-4yiH4a-4ynS2J-rs5Y21-5pviTW-aA7s3h-Jz1SzD/

National Weather Service. Lake Effect Summary: November 17-19, 2014. https://www.weather.gov/buf/lake1415_stormb.html

NBC News. "Move to Buffalo? With Earth warming, northern cities could become oases." Accessed July 17, 2020. https://www.nbcnews.com/science/environment/buffalo-oasis-scientists-say-warmer-earth-could-make-colder-cities-n1113711

New York State. "Climate Smart Communities." Accessed 11 May, 2020. https://climatesmart.ny.gov/

New York State. 2018. Regional Economic Development Councils Awards.

New York State Attorney General Eric T. Schneiderman, Environmental Protection Bureau. 2014. Current and Future Trends in Extreme Rainfall Across New York State.

New York State Department of Environmental Conservation (NYSDEC). 2019. Harmful Algal Blooms (HABS) Program Guide.

Notaro, M., D. Lorenz, C. Hoving, and M. Schummer, 2014. Twenty-First-Century Projections of Snowfall and Winter Severity across Central-Eastern North America. J. Climate,27,6526–6550,https://doi.org/10.1175/JCLI-D-13-00520.1

Olean Times Herald. Accessed July 19, 2020. https://www.oleantimesherald.com/news/village-of-gowanda-decimated-by-storm-flooding/article_b47e417d-da25-5c06-b38f-70e577975009.html

Our World in Data. Accessed February 1, 2020. ourworldindata.org/co2-and-other-greenhouse-gas-emissions

Parker, Lauren & Abatzoglou, John. 2016. Projected changes in cold hardiness zones and suitable overwinter ranges of perennial crops over the United States. Environmental Research Letters. 11. 10.1088/1748-9326/11/3/034001.

Peek, Lori. 2008. Children and Disasters: Understanding Vulnerability, Developing Capacities, and Promoting Resilience — An Introduction. Children, Youth and Environments, 18(1), 1-29. Retrieved from http://www.jstor.org/stable/10.7721/chilyoutenvi.18.1.0001

Rahel, Frank & Olden, Julian. 2008. Assessing the Effects of Climate Change on Aquatic Invasive Species. Conservation biology : the journal of the Society for Conservation Biology. 22. 521-33. 10.1111/j.1523-1739.2008.00950.x.

Regional Planning Consortium. 2013. Western New York Regional Sustainability Plan.

Renschler, Chris. 2015. The PEOPLES Resilience Framework – An Integrated Quantitative Measure and Modeling of Sustainable Development and Disaster Risk Reduction.

Renschler, Chris & Reinhorn, Andrei & Arendt, Lucy & Cimellaro, G.. 2011. THE P.E.O.P.L.E.S. RESILIENCE FRAMEWORK: A CONCEPTUAL APPROACH TO QUANTIFY COMMUNITY RESILIENCE. 10.13140/RG.2.1.3355.1767.

Renschler, Chris & Frazier, Amy & Arendt, Lucy & Cimellaro, G. & Reinhorn, Andrei & Bruneau, M.. 2010. Developing the peoples resilience framework for defining and measuring disaster resilience at the community scale. Proceedings of the 9th US National and 10th Canadian Conference on Earthquake Engineering. 25-29.

Rochlin I, Ninivaggi DV, Hutchinson ML, Farajollahi A. 2013. Climate Change and Range Expansion of the Asian Tiger Mosquito (Aedes albopictus) in Northeastern USA: Implications for Public Health Practitioners. PLoS ONE 8(4): e60874. https://doi.org/10.1371/journal.pone.0060874

Rosenzweig, C., W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol, P. Grabhorn (Eds.). 2011. Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation. Technical Report. New York State Energy Research and Development Authority (NYSERDA), Albany, New York. www.nyserda.ny.gov

Sanders, S., C. Castiglione, and M. Hoff. 2018. Risk Assessment Mapping Program: RAMP, version 3.1. U.S. Fish and Wildlife Service.

Sanyal, Joy & Lu, X.X.. 2005. Remote sensing and GIS-based flood vulnerability assessment of human settlements: A case study of Gangetic West Bengal, India. Hydrological Processes. 19. 3699 - 3716. 10.1002/hyp.5852.

Shen, Suwan & Feng, Xi & Peng, Zhong-Ren. 2016. A framework to analyze vulnerability of critical infrastructure to climate change: the case of a coastal community in Florida. Natural Hazards. 10.1007/s11069-016-2442-6.

Szabo, C.O., Coon, W.F., and Niziol, T.A., 2010, Flash floods of August 10, 2009, in the Villages of Gowanda and Silver Creek, New York: U.S. Geological Survey Scientific Investigations Report 2010-5259, 23 p

Tuzzo, Michael E., Elizabeth Gilman, Nicholas B. Rajkovich, Bartholomew Roberts, Ellen Cousins, Sean Daigneault, and Stefan Cecelski. 2018. New York State Climate Hazards Profile. New York State Energy Research and Development Authority (NYSERDA), Albany, New York.

University at Buffalo Regional Institute, State University of New York at Buffalo, School of Architecture and Planning. 2014. “One Region Forward: A New Way to Plan for Buffalo Niagara”.

URS. 2015. Erie County, New York Multijurisdictional Hazard Mitigation Plan Update. Add source here

US Climate Resilience Toolkit. Accessed February 1, 2020. toolkit.climate.gov/

Vermette, S. 2017. Weathering Change in WNY: Climatic Trend Analysis (1965-2016). Report prepared for Designing to Live Sustainably (d2ls), Buffalo, NY. 14pp.

Walthall, Charles L.; Anderson, Christoper J.; Baumgard, Lance H.; Takle, Eugene; Wright-Morton, Lois; and et al. 2013. "Climate Change and Agriculture in the United States: Effects and Adaptation" 2013. Geological and Atmospheric Sciences Reports. 1.http://lib.dr.iastate.edu/ge_at_reports/

Wei, David, and Chase, Marshall. 2018. “Climate and Supply Chain: The Business Case for Action.” Report. BSR, San Francisco.

Western New York Partnership for Regional Invasive Species Management (WNY PRISM). Accessed May 10, 2020. Wnyprism.org

WIVB4. “Chautauqua County family picking up the pieces after tornado rips through their property”. Accessed July 17, 2020.

# Sensitivity Analysis Report

## Part II of Climate Vulnerability Assessment for Erie County

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*Figure 1:Flooding in the area around Hoover Beach in late 2020, Hamburg NY (WGRZ.com, 2020)*

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## Land Acknowledgement

This report is based on the geographic territory contained within the administrative boundary of Erie County, New York. The authors of this report collectively acknowledge that the region under study is situated on the ancestral territories of the Onödowága Nation of the Haudenosaunee Confederacy and the First Nations that lived there before them. The continued presence of the Onödowága on the landscape is also recognized.

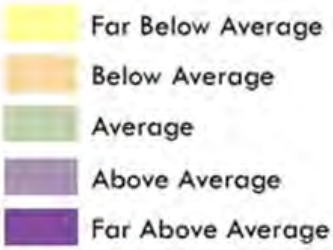
# Chapter 1. Introduction

Erie County, New York, has been proactive in planning for and working to mitigate the impacts of climate change expected for the Western New York region. Efforts to-date include the Healthy Niagara-Niagara River Management Plan Phase I (BNW, 2014), the Multijurisdictional Natural Hazard Mitigation Plan Update (MNHMP) (URS, 2015), the Climate Action and Sustainability Plan (CASP) (Erie County, 2019a), and the Regional Niagara River-Lake Erie Watershed Management Plan Phase II (Erie County, 2019b). All of these initiatives provide a strong foundation to build upon in this **Climate Vulnerability Assessment (CVA) Sensitivity Analysis Report (SAR)**. While the before mentioned documents provide planning for many aspects of climate change impact mitigation and adaptation efforts, they do not clearly identify the sensitivity of key areas of the County governance as well as its residents to climate-change related hazards, which is the focus of this SAR report. **By sensitivity, we mean the degree to which systems' functionality are affected, either adversely or beneficially, by climate change related hazards.** This sensitivity analysis is a key step in assessing County's overall vulnerability to climate change.

Studying sensitivity and its relation to overall climate vulnerability in a variety of contexts has been the subject of numerous reports in the literature and media (Aldia Environment, 2020; NBS News, 2020; Rochester, 2018; Frankson et al, 2017; New York State, 2014). Mapping sensitivity with Geographic Information Systems (GIS) is often utilized by similar studies, as it allows for analysis of these issues in a spatial and temporal context (Colburn et al, 2016; Margles et al, 2016; Kherde & Priyadarshi, 2014; Marshall et al, 2010; Andrew et al, 2008; Smit & Wandel, 2006; Cutter et al, 2003; Fothergill, 2002; Moss et al, 2001). In this manner, issues such as climate-related impacts and/or extreme events can be analyzed across time and space to identify critical zones of impact or opportunities to mitigate and lessen impacts. Thus, this project employed GIS at a variety of scales and scopes to assess the sensitivity of Erie County to the climate-related hazards of 1) extreme heat, 2) flooding, 3) wind, and 4) biological threats; and how these four types of hazards interact with access and mobility to emergency services and critical infrastructure. For a review of these specific threats, as well as the process used to determine them as priorities for our CVA, please refer to our Phase I report, entitled "Climate Hazards Summary Report" ( https://bit.ly/3coZOXP).

In this assessment, we spatially map socio-economic, landscape, and infrastructure data related to the climate hazards listed previously, using a variety of resolutions, scales and data sources. To be able to integrate this information, we standardize the hazard sensitivity data into a range of -1 to +1. In other words, we transform the data to have a mean of zero (average for the County) and a standard deviation of 1 (sensitivities closer to +1 indicate the most sensitive areas, whereas sensitivities closer to -1 indicating the least sensitive areas for each hazard threat). This is a technique commonly used to integrate different types of data into a single index that we more easily compare as well

as spatially map. We also employ a consistent color classification schemes across hazards considered, as detailed on the next page.




Maps showing sensitivity to extreme heat, flooding, and mobility factors are coded with the following sensitivity color scheme (shown to the left) and according to the following: yellow indicates far below average, orange indicates below average, green indicates average, light purple indicates above average, and dark purple indicates far above average sensitivities. With the exception of the section on vector-borne Diseases (which uses a different, scenario-based methodology), all of the sensitivity information is visualized in this way.

This assessment is the second phase of our overall Climate Vulnerability Assessment (CVA) framework, outlined below. Erie County staff were involved at each step of the process to ensure that the methods and data being used were appropriate for the needs of the County. For each particular hazard we consider three facets of sensitivity at a certain location to be analyzed: 1) sensitivity to landscape attributes (neighborhood location), 2) sensitivity to socioeconomic attributes (neighborhood economics), and 3) sensitivity in regards to mobility (neighborhood transportation infrastructure) (**Figure 2**). This framework has been adapted from literature on analyzing and mapping vulnerability, sensitivity and adaptive capacity (e.g., Kumar et al., 2016; Margles et al., 2016; and Shen et al., 2016).

Our sensitivity assessment also incorporates aspects of human systems, natural systems, and physical systems that are interconnected, but for communication purposes organized around seven dimensions of the PEOPLES Resiliency Framework (Renschler et al, 2010) (also detailed below) offering a holistic perspective of the County's climate sensitivity. Each perspective is summarized below.

Consideration of **human systems** includes how Erie County employees that are providing services especially to vulnerable populations (homeless, economically disadvantaged, minority communities, and the very young and/or old) and the vulnerable population themselves are affected by the climate hazards discussed in this report. **Natural systems** considered include parks and forests that are under the jurisdictional responsibility of the County, in addition to climate and other environmental factors (i.e., the hydrological cycle and habitat quality) involved in the various climate hazards outlined. In the context of this CVA, **physical systems** are the physical infrastructure of Erie County, including transportation infrastructure such as roadways, as well as other physical infrastructure-related items such as traffic flow, mobility, sewers and County buildings.

To analyze these systems, the CVA team interviewed multiple Erie County departments and personnel, including:

- 
- Department of Environment and Planning
    - Environmental Compliance Services Division
        - Sewers
        - Watershed Management
        - Sustainability
    - Office of Geographic Information Systems
- Department of Homeland Security and Emergency Services
- Department of Health
    - Division of Environmental Health
- Department of Social Services

## Statement on Equity and Inclusion

This report recognizes that there are concerns with racial bias and equity that magnify existing and upcoming issues related to the impacts of climate change. Examples of this can be found in the analysis of temperature-related impacts. In this report, the focus is on extreme heat, as that is a climate-related hazard that the region is generally not well-experienced in mitigating. However, this is not to say that extreme cold won't be a potential climate hazard in the future, or that there aren't vulnerable populations at risk of impact during a snow emergency. It is also likely that the extent of this hazard will differentially impact minority populations, who may see their mobility limited from unplowed roads and unshoveled sidewalks and thus their accessibility to warming centers and other critical services may be limited. Issues such as this were not addressed due to limitations in time, resources, and data. The CVA team highly recommends that future studies discuss and integrate the problem of racial bias and equity into future analyses.

## Climate Vulnerability Framework

In **Figure 2**, the overall framework for the collective assessment that will result in the final climate vulnerability analysis is outlined. As noted above, the first step in this process, assessing **Climate Exposure**, was completed in the CVA Climate Hazards Summary Report from August, 2020. Exposure in that case was how climate threats and hazards could impact the region. The climate hazards outlined in that report (extreme heat, flooding, biological threats and wind) were the foundation for the analysis in this report. Stakeholder engagement is a central component of all aspects of the process – with an internal stakeholder committee comprised of Erie County employees as well as an external stakeholder committee comprised of members of the Erie County Climate Change Task Force (C3TF) providing input and feedback on each step of the process.

**Sensitivity,** or the degree to which the County is likely be affected by the identified climate hazards, is assessed with respect to landscape elements that are present and that may lead to elevated sensitivity when climate change is considered, as well as socioeconomic issues that may exacerbate existing sensitivity to these landscape elements. We also consider sensitivity in terms of mobility or limitations in mobility that may inhibit the access to critical services in the event of climate-related emergencies and/or natural disasters.

**Adaptive Capacity,** or the ability of the County to adjust and respond to climate risks, will be qualitatively assessed through interviews and focus groups with County representatives. This assessment will include consideration for proactive measures, mitigative actions, direct response to events, and recovery from disasters. The next phase of our CVA assessment will focus on this aspect and is not part of this report.

**Vulnerability** is the resulting combination of exposure, sensitivity, and adaptive capacity. This is a relative measure of vulnerability the County is to the identified climate threats and hazards. The final phase of our project will combine results from the Exposure, Sensitivity, and Adaptive Capacity assessments to determine areas of concern and priorities for future research and planning efforts.

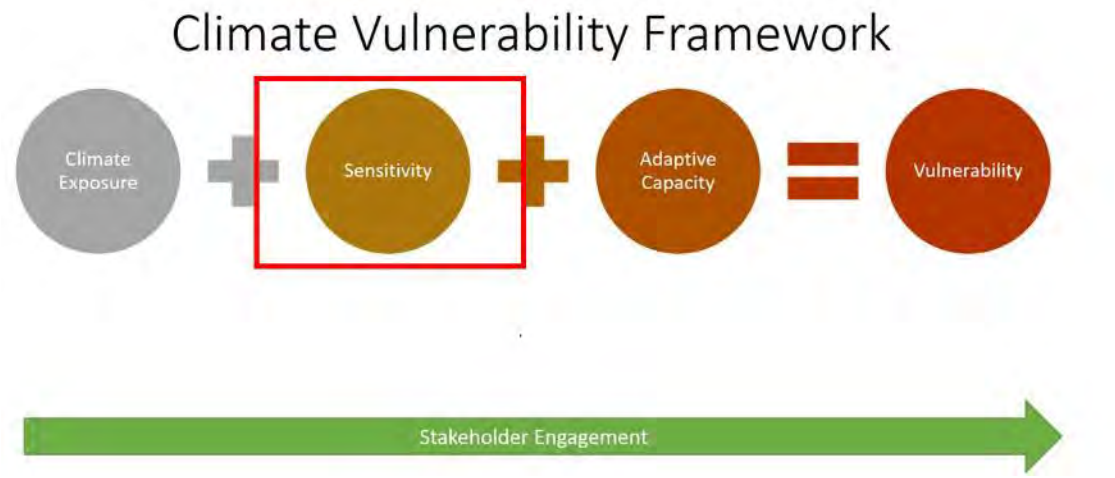



*Figure 2: Climate Vulnerability Framework employed in this CVA process with Sensitivity highlighted as the aspect of vulnerability for which this report is focused.*

## PEOPLES Resilience Framework

The PEOPLES Resiliency Framework was developed in 2010 (Renschler et al, 2010) in an effort to define and quantify community resilience to disasters. The Framework features seven interrelated dimensions, outlined below. Since the initial framework was developed it has been useful in other analyses that have contributed to the body of knowledge of sustainability and resilience studies (Cimellaro et al, 2016, Renschler, 2015, Renschler et al, 2011).

This Framework provides an integrated, holistic lens with which to approach analysis of sensitivity while integrating the results of the analysis in a useful and cohesive manner. The results of this analysis will be analyzed quantitatively as well as qualitatively in the lens of the PEOPLES Resilience Framework, as outlined in Figure 3. Each dimension is described in detail in Table 1.

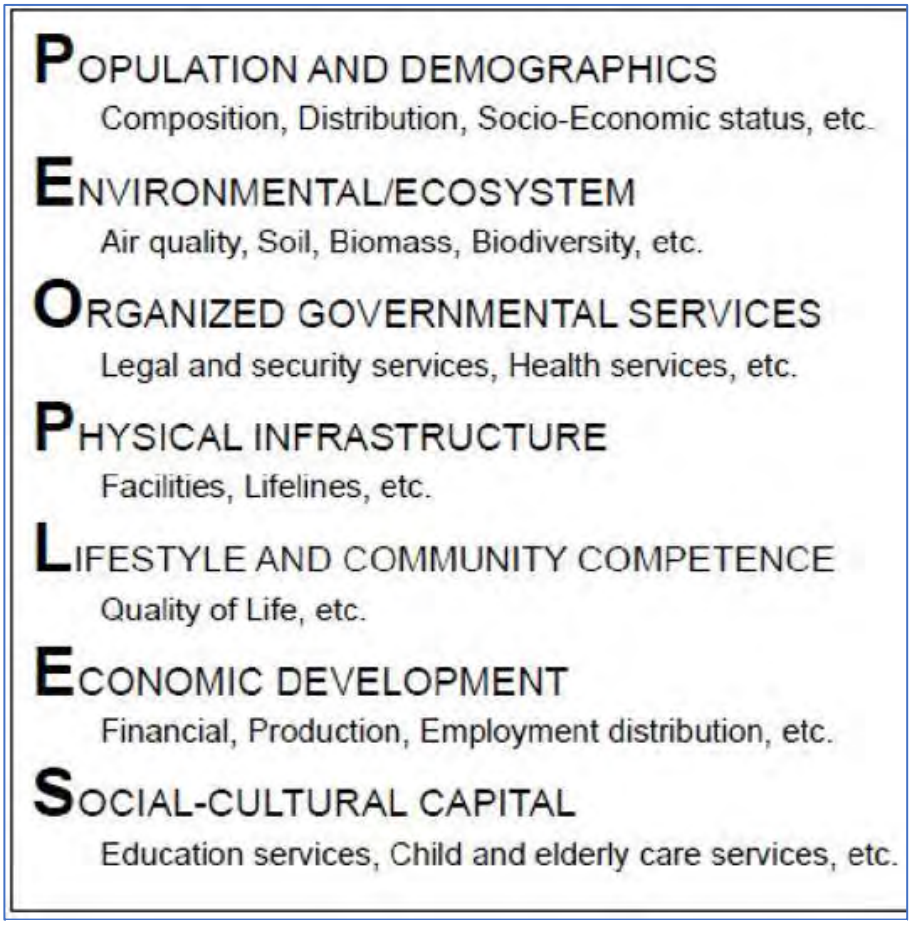



*Figure 3: PEOPLES Resiliency Framework that is used to organize and coordinate the process of analyzing and interpreting sensitivity in a holistic fashion, allowing for an integrated assessment of sensitivity across multiple frameworks and dimensions (Renschler*

*Table 1: The PEOPLES Resiliency Framework and associated seven dimensions of resiliency*

| | |
|---|---|
| **Population and Demographics**: This dimension is related to social vulnerability, which is a measure of the inability of a community to overcome impacts that the community is exposed to. | **P** |
| **Environmental/Ecosystem**: Resilience as related to ecosystem processes typically refers to the extent of environmental disturbance that a given ecosystem can withstand without resulting in a reduction of ecosystem function or significant damage to ecosystem structure. Disturbance/recovery are quantified to measure ecosystem resiliency. | **E** |
| **Organized Governmental Services**: In this dimension, organized governmental services refers to those that provide an orderly and structured response to a disaster. Such services include those provided by police, emergency response, public legal system, health dept., etc. | **O** |
| **Physical Infrastructure**: The physical infrastructure dimension includes facilities and lifelines such as housing, commercial and cultural facilities; as well as lifelines such as food supply, health care, utilities, transportation and communication networks. | **P** |
| **Lifestyle and Community Competence**: This dimension measures the impact of a disaster on a community and the post-disaster period of recovery. A community's recovery depends on the collective efforts of the community, their ability to solve problems, ingenuity, and political good will, among others. | **L** |
| **Economic Development**: Economic development refers to measurements of the community's products and services that are made in and used in the community. Both employment and financial services are included, as are subcategories such as the production and employment of an industry, and financial services. | **E** |
| **Social-Cultural Capital**: Participation in civil and community organizations, investment in the betterment and maintenance of community structure, and providing incentive for citizens to stay and/or return to the community are all attributes of the social-cultural capital a community has. | **S** |

## Overview of Sensitivity to Climate Threats in Erie County

### Extreme Heat

Sensitivity to extreme heat is a potentially major issue in the Erie County region. Where the County has greater experience in addressing extreme cold and lake effect snowfall, thermal vulnerability to heat waves and elevated temperatures may be particularly problematic for residents as well as infrastructure not accustomed to high temperatures. It is predicted that the region will experience more frequent and intense heat waves in the future (Luber, 2008).

### Flooding

Patterns in precipitation are changing as a result of the impacts of climate change, and this has resulted in greater frequencies of extreme rainfall events (Easterling et al, 2017). These events exacerbate issues such as flooding and runoff, which impact Erie County's property and operations (County-owned roads, bridges and stormwater infrastructure, for example) as well as private property and risks injury or death to the general public. Assessing where these impacts will be most severe will allow the County to proactively work to mitigate them and/or increase their adaptive capacity to ensure that the impacts are minimal and risk to public health is minor.

### Biological Threats

The changing climate is reverberating through the Earth's ecosystems, altering habitat suitability and phenology for many species (Brownstein et al., 2005). This includes those species that are involved in vector-borne disease (VBD) relationships, invasive County's e species, and native phenomena such as harmful algal blooms (HABs). As Erie County's Department of Health is the primary public health authority for the County, this issue is particularly relevant. Climate change may result in exacerbated instances of VBDs, may make the habitat in the region more suitable for new VBDs, and the same may be true for invasive species. Harmful algal blooms are a natural occurrence that stems from a native species of aquatic cyanobacteria. These cyanobacteria "bloom" under certain environmental conditions and can create potentially toxic exudates that impact water quality for public and private wells, swimmers and recreationists, as well as create a public health issue for those that come into contact with the bloom (Griffith and Gobler, 2020). The conditions that promote HABs are also conditions expected as climate change intensifies.

### Wind

Wind is closely intertwined with the hazards of temperature and precipitation, and as such may be difficult to analyze separately from these hazards. However, there has been some local work on the topic, and the results of these projects have found that high wind events have been increasing in the region, as associated with thunderstorms (Vermette, 2017). Here, we provide a summary of key issues/concerns related to wind for Western NY.

## Chapter 2: Sensitivity Analysis with Respect to Extreme Heat

Extreme heat events are often underestimated. This is especially true in areas where the climate is relatively cool throughout much of the year, such as much of the Northeastern US, where the population is not accustomed (and the infrastructure may not be well-equipped) to handle high temperatures. Extreme heat can cause heatstroke, a flare up of pre-existing conditions (specifically respiratory and circulatory diseases), or even death (Luber, 2008). Unfortunately, the number of deaths caused by extreme heat events is challenging to quantify accurately, as deaths caused by these events usually have other contributing or underlying factors, which is more likely to be reported. Deaths can also happen from complications years down the line (e.g., Arguad, 2008). This is concerning, given that climate projections for the region suggest that we will experience more frequent and intense heat waves (Luber, 2008).

It is important to note that people throughout a region do not experience heat in the same way. One's microclimate can be influenced by the surrounding landscape, including things like proximity to water systems, vegetation, as well as the built environment. Canopy cover (i.e., shading from tress) in particular has been observed to have a significant cooling effect on microclimates, especially in the short term (Chatzidimitriou, 2015). Other important factors include proximity to large roadways (Pohlman, 2009), proximity to the emissions of large trucks (Dreher, 1998), and proximity to large bodies of water (Sun, 2012). These factors combined can give a good image of the landscape's sensitivity to changes in the microclimate.

A person's socio-economic status can also change how that person experiences heat. Economic factors, like living below the poverty line or being unemployed, can affect which resources a person has to combat extreme heat events (Morrow, 1999; Cutter, 2003). This is also true of racial and ethnic minorities, as the result of decades of de jure and de facto discrimination in housing (Morrow, 1999; Cutter, 2003). Physiologically, those aged under the age of 5 and over the age of 65 are at the highest risk of being affected by extreme heat (Ngo, 2001). Social isolation, or being confined to only one's house or bed, can also be a factor making a person more sensitive to extreme heat (Bouchama, 2007). Mobility factors, like using public transport or walking or biking to work, can also make a person more vulnerable to extreme heat, especially if they don't have any other way of getting where they need to go. Finally, residential and housing factors, such as when a dwelling was built and the number of families in one household also affect sensitivity to heat; the older a building is, and the more families living inside it, the more sensitive it is to extreme heat. (Cutter, 2003). Note that the methodology used to determine sensitivity to heat builds upon previous work completed by Hamstead and colleagues on thermal vulnerability in Erie County at the University at Buffalo (see Hamstead et al. 2020 and UB Community Resilience Lab). In this section, we will investigate both the sensitivity to the landscape and the sensitivity of the population based on a variety of socio-economic factors.

## Methodology

Here we provide a summary of the methods and data used in our analysis. A more detailed methodology is provided in the Appendix.

*Heat sensitivity related to landscape* is divided into two categories: 1) heat sinks and 2) heat sources, with six sub-factors shared between them. Specific factors for each category were chosen based on available data as well as their warming or cooling effect on surrounding microclimates. Heat sinks include sub-factors that have a cooling effect, such as tree canopy cover, proximity to water sources and the prevalence of pervious (or non-paved) surfaces. The sub-factors included in the heat source category are aspects that have a warming effect, including locations of industrial parcels and truck terminals. For each category, the data for each sub-factor were averaged together across Erie County, creating an overall map of heat sources and a map of heat sinks. To create the overall landscape sensitivity map (Figure 4), the values for heat sinks were subtracted from the values of heat sources. Areas in yellow to green colors are considered less sensitive to heat than the average across the region, and the pink to purple areas are expected to be more sensitive to warmer temperatures during a heat wave.

*Table 2: Factors included in the socio-economic sensitivity assessment*

| Factors | Sub-Factors |
|---|---|
| Socio-Economic Sensitivity | |
| Economic Sensitivity | % under poverty line<br>% over 25 without a high school diploma<br>% unemployed |
| Physiological Sensitivity | % 5 years old and under<br>% 65 years old and over |
| Social Isolation | % foreign born<br>% aged 20-65 with disability status |
| Mobility-based Sensitivity | % active commuters |
| Residential + Housing Sensitivity | Median year built<br>Population density<br>% Multi-family dwellings<br>% Affordable housing |

Heat sensitivity related to socioeconomic factors was also considered in our analysis. The major categories of socioeconomic sensitivity include: economic sensitivity, physiological sensitivity, social isolation, mobility-based sensitivity, and residential and housing sensitivity, each with a variety of subfactors (see Table 2). Each sub-factor was included based on the availability of data as well as their expected influence on sensitivity to heat, justified in peer reviewed literature (Morrow, 1999; Cutter, 2003; Ngo, 2001; Bouchama, 2007).

In general, a simple average was calculated for each of the sub-factors within a category at the block group scale. After an average was found for each, the maximum and minimum averages were identified for each category to standardize the data from -1 to 1 for easier comparison. The results are shown in Figure X, with purple areas being more sensitive and yellow areas being less so. Overall sensitivity to heat was found by adding the previous landscape and socioeconomic sensitivities together. By doing this, lower numbers shown in yellow contain more heat sinks and fewer sensitive populations, while higher numbers shown in purple contain more heat sources and more sensitive populations.

## SENSITIVITY OF ERIE COUNTY TO EXTREME HEAT

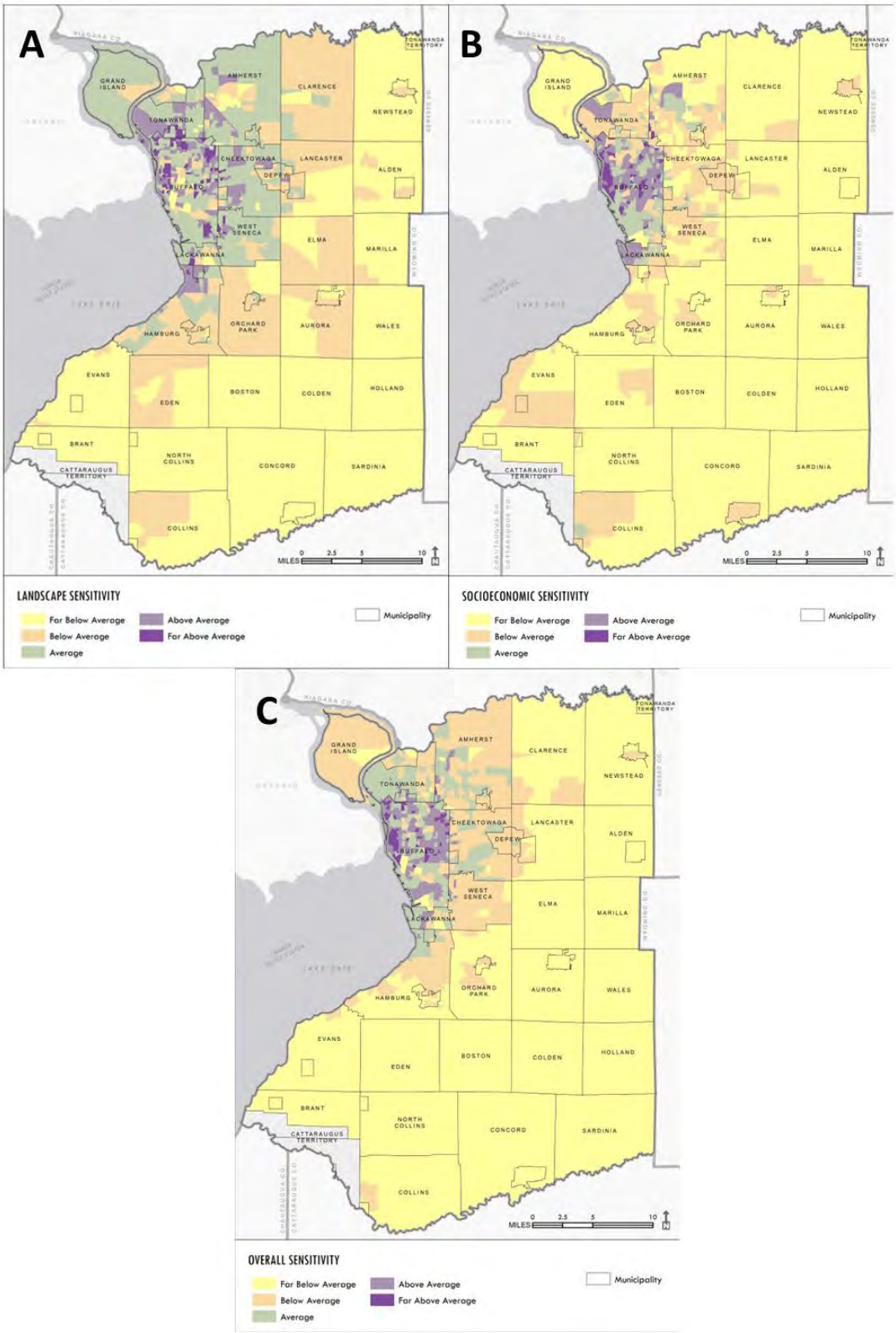



*Figure 4: Overall sensitivity to extreme heat (C) derived from landscape (A) and socioeconomic variables (B)*

| | |
|---|---|
| **Population and Demographics** living in areas with a high sensitivity are more at risk of extreme heat-related problems, even if they are not part of a particularly sensitive population due to location and landscape factors that increase exposure. Likewise, sensitive populations are more at risk, even if they are not located in an area of high exposure. And those who are both part of sensitive populations and live in areas of high exposure are the most vulnerable. | **P** |
| **Environments and Ecosystems**, like those in Erie County's parks or forests play an important role in mitigating heat. The trees and vegetation contained within help to cool the area surrounding them, and the shade they provide can be invaluable for sensitive populations during heat waves. Heat sensitivity may also be mitigated by ensuring equitable access to climate-controlled cooling shelters (County libraries) throughout the County, especially in areas considered most sensitive to heat. | **E** |
| Erie County's **Organized Governmental Services** are impacted by this information. Specifically, this information would be very valuable to EMTs and other crisis workers in the midst of an extreme heat event. These maps point out both where (on average) the people most sensitive to an extreme heat event live, where it's bound to get the warmest, and where those two factors overlap. This gives a rough idea of where resources should be allocated first, to help the most amount of people. | **O** |
| **Physical infrastructure** like roads and buildings can be negatively impacted by extreme heat, such as the reduced life of asphalt, the buckling or bending of railways, and/or the increased likelihood of power outages. Physical infrastructure also impacts the microclimates surrounding it, with roadways and industrial parcels in particular acting as heat sources, and with buildings and asphalt in general contributing to the urban heat island effect. | **P** |
| Even without an extreme heat event, areas that have a highly sensitive landscape are more likely to be warmer during the summer, decreasing the quality of the Lifestyle **and Community Competence** of those living within those areas. This would be, of course, exacerbated by an extreme heat event, but even normal summer days would be warmer and more uncomfortable in areas of high exposure (such as inland urban areas without much vegetation). | **L** |
| An extreme heat event can impact both personal, corporate, and county **Economic Development**. For example, cooling costs can increase during a heat wave, placing additional financial stress on low-income households. Jobs that have to be completed outdoors will either need to be put on hold during the heat event or the times that these jobs can be completed will need to be shifted. Negative impacts to physical infrastructure will also increase maintenance and replacement costs. | **E** |
| **Social-Cultural Capital** may be impacted during an extreme heat event, where any outdoor events or activities may need more emergency personnel to attend in the case of a heat-related injury. Proper precautions, including putting up tents or moving indoors, will also have to be taken, placing additional financial strains on event hosts. | **S** |

*Table 3: Sensitivity to Extreme Heat as interpreted through the PEOPLES Resiliency Framework*

## Overall Sensitivity to Heat and Case Studies

Looking at the results of the overall sensitivity to heat, we can determine the block groups that are the most and least sensitive to an extreme heat event, relative to other areas in the County. Our findings indicate that one of the block groups with the lowest sensitivity to heat is Marilla, NY. This makes sense because the block group is filled with forests and grasslands, which have a significant cooling influence on the area's microclimate. The socio-economic sensitivity in the Marilla block group is also low (although many other block groups have lower sensitivities). Because this block group has the lowest landscape sensitivity by quite a large margin, these combine to create a low overall sensitivity to heat.

We find that the most highly sensitive block group to heat is in the City of Buffalo's Broadway-Fillmore neighborhood. This block group is residential and has the highest percentage of economic and mobility-based sensitive populations (i.e., impoverished and relatively immobile) in the County. The rest of the socio-economic factors are also relatively high compared to other areas. In terms of the landscape, this block group is located in an area with a large net heat source due to its very high number of industrial parcels and low percentage of canopy cover and pervious surfaces. This means that during a heat wave this area would expect to be relatively warmer than other areas. These sensitivities combine to create a high overall sensitivity to heat.

One limitation of this analysis is that only some important factors related to heat sensitivity were taken into consideration based on available data and resources. For example, we did not have access to data for the County related to other important factors including crime, health, and weatherization efforts to date, particularly for socio-economic sensitivity. We were also not able to include wind and moisture data for landscape sensitivity. There are also variations in patterns of temperature based on seasonality and other microclimate factors, including wind and moisture. For example, extreme heat is typically an issue of concern mainly during the summer months, however above average temperatures occurring in other parts of the year may have differentiating implications for the County. Also, while the overall sensitivity results emphasize certain areas of the County as being more sensitive than others, this does not mean to imply that residents in areas with below average sensitivity do not or will not experience climate-related impacts associated with extreme heat. The micro-scale factors that play an important role in how an individual may experience heat are beyond the scope of this report. However, this is an important limitation of our work that must be considered when interpreting and communicating the results. Additional scenarios that were not considered involve power disruption during heat waves. In a setting where electrical demand is high to power air conditioners, power disruption may exacerbate the impacts that a heat wave may have (i.e., reduced air quality, increased risk of heat-related sickness and/or death – see the CVA Climate Hazards Summary Report for more information).

## Chapter 3: Sensitivity Analysis with Respect to Flooding

Precipitation patterns in Western NY are changing. Extreme rainfall events are becoming more common in NY (New York State, 2014), and this trend is expected to continue (Easterling, et. al., 2017; Frankson et al, 2017). The combination of an increase in intensity of rainfall, as well as an increase in frequency of heavy rainfall events, will result in a variety of changes to rates of erosion, as well as physical weathering, chemical weathering, and nutrient cycling (Chapin et al., 2002). To aid Erie County in identifying high priority areas in its jurisdiction that may be impacted by climate-related floods, we analyzed runoff generation potential across the County from both a local and a downstream perspective. Local flooding issues include ponding of water on roadways and on landscapes with a relatively flat profile, creating issues with flooding in certain neighborhoods that are more sensitivity to this type of flooding than others. Downstream flooding includes considerable runoff during heavy rain events that take floodwater from steeper landscapes down into low lying areas. Both aspects of flooding are important to consider, as they present different challenges to Erie County and private homeowners. For example, identifying areas prone to local flooding can help target flood mitigation measures such as creating dikes and berms to prevent damage; while identifying areas prone to problematic runoff aids in targeting preventative measures (such as green infrastructure) that work to enhance infiltration of stormwater before it runs off of the landscape to create flooding issues off-site.

Sensitivity to flooding was analyzed in ArcMap GIS to provide a relative measure of overall sensitivity from both perspectives. Exposure to on-site flooding was assessed using hydrologic soil group data extracted from the Natural Resource Conservation Service's (NRCS) GIS soil metadata. Exposure to downstream flooding was assessed by creating a topographical wetness index (TWI) derived from elevation data. The Federal Emergency Management Agency's (FEMA) Special Flood Hazard Areas (SFHA) were also included in both the local and downstream analysis, as this provided special emphasis on areas already considered at-risk of flooding. More specific methods for our flooding sensitivity analysis are described in the Appendix C.

In this assessment, the impacts that infrastructure (such as culverts and stormwater systems) may have in regards to flooding were not part of the analysis. The County-level scale of the data unavoidably overlooks fine-scale elements of flooding, and the geographical data used is not current to 2020-2021 time period. These issues are due to incomplete or missing data, as well as capacity and funding in the project. There were also limitations when considering these impacts across time and space, similar to extreme heat. The extent and duration of floods can depend on a variety of factors – including the saturation of the soil, season, and topography. While topography and some data on soils were included, not all factors (i.e. depth of snowpack during a spring thaw) were able to be assessed. There are also issues that differentially impact rural and agricultural areas – such as flood-related impacts on the functionality of drinking wells and septic systems and nutrient-laden runoff from agricultural fields that degrade water quality.

## Methodology - Local Flooding:

The local, or on-site, flooding analysis included data on soils as well as maps of the "100-year" flood zones (or Special Flood Hazard Areas - SFHA) as mapped by FEMA. Information on the infiltration and runoff potential of soils was mapped using the USDA-NRCS Hydrologic Soil Group (HSG) units. The HSG units included A, B, C, D*, D, and U designations, as outlined in Table 4 below. The units were ranked, with soils possessing greater infiltration capabilities given a negative ranking as they would infiltrate storm water and slow runoff; and soils possessing little infiltration capabilities given a positive rating as they would poorly infiltrate storm water and increase runoff. This dataset was combined with FEMA's SFHA data to assess the extent of local flooding potential.

For comparison, maps showing both the current conditions (with D* soils ranked as +0.75), and the potential changes that would be achieved if soils in certain areas were altered to improve drainage (with D* soils ranked accordingly as A, B, or C soils) are included in the figures below. It should be noted that while there are potential improvements in drainage as well as reductions in risk of flooding not all locations are appropriate for these mitigations. Some areas should be altered to retain water, not drain it; and others may have similar constraints on modifications.

*Table 4: Hydrologic Soil Groups*

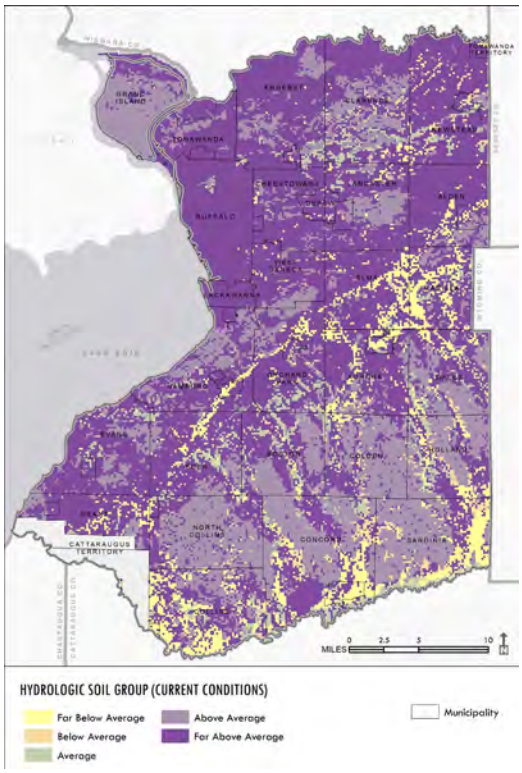
| Group | Properties | Rank |
|---|---|---|
| A | Rapid Infiltration | -0.75 |
| B | Weak Infiltration | -0.5 |
| C | Low Infiltration | +0.25 |
| **D*** | Undrained A-B-C Soils | +0.75 |
| D | Very Little Infiltration | +0.75 |
| U | Compacted Urban | +0.8 |

## Methodology - Downstream Flooding:

Downstream, or off-site, flooding analysis included data on elevation that was manipulated in GIS software to calculate a Topographic Wetness Index (TWI) and also included FEMA's SFHA data as well. The TWI was created using slope (% grade of the landscape), flow accumulation of runoff, and flow direction of runoff – all derived from a Digital Elevation Model produced by the United States Geological Survey (USGS). The TWI data was broken down into 5 numerical ranks and reclassified to create an identical ranking system as shown above for the HSG data.

The results allow for a visual assessment of locations in Erie County that have greater potential to see local flooding and ponding as well as where flood runoff is originating from during extreme rain events. This provides Erie County with the opportunity to proactively mitigate these issues.

**HYDROLOGIC SOIL GROUP UNITS OF ERIE COUNTY AND FLOODING MITIGATION**




This map shows current conditions of Hydrologic soil group units and their relative capacity to allow the infiltration of water. Note that this map does not reflect stormwater management infrastructure that may be in place – only the physical capacity of the soil to allow water to infiltrate.

This map shows opportunities to enhance soils to allow for further infiltration above the baseline physical properties of a given HSG unit. Again, existing stormwater infrastructure is not factored in to this analysis. However, it is clear that there are many opportunities for green infrastructure development that will increase infiltration and reduce runoff.

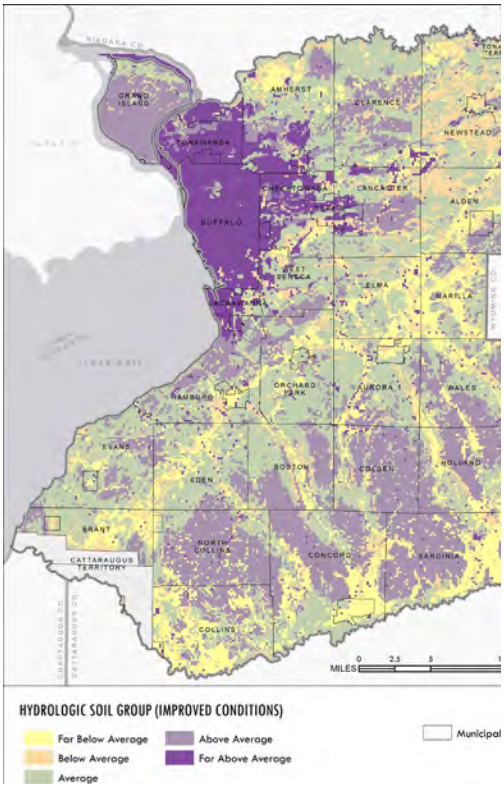
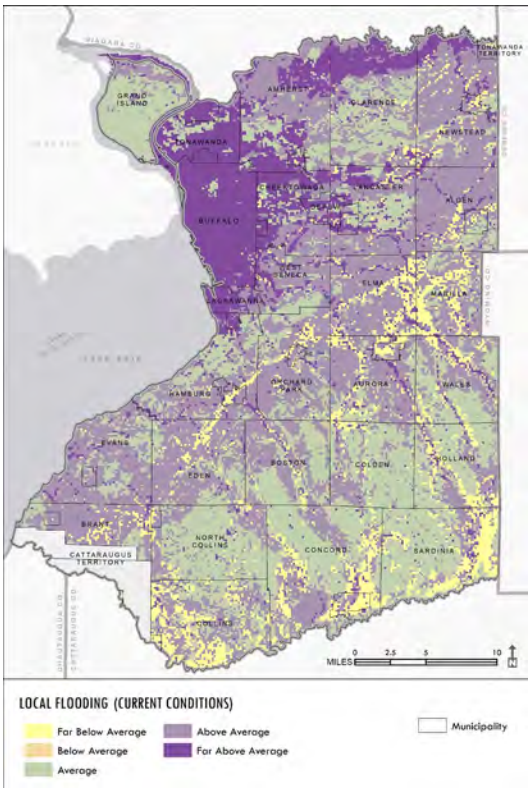



*Figure 5: Infiltration capacity of soils (current versus improved drainage conditions)*

**SENSITIVITY OF ERIE COUNTY TO FLOODING BASED ON LOCAL PONDING**




Sensitivity to Local Flooding includes infiltration capacity of soils in conjunction with 100-year flood risk. Purple represents areas that have a higher potential for ponding during heavy rain events. This map includes current conditions of drainage.

Sensitivity to Local Flooding with altered soil conditions to improve drainage. Note that there is a substantial difference in potential for flooding when drainage is improved. While there are large areas of opportunity for improvement, there may be many limitations in carrying out mitigation projects, as not all of these regions are appropriate to drain.

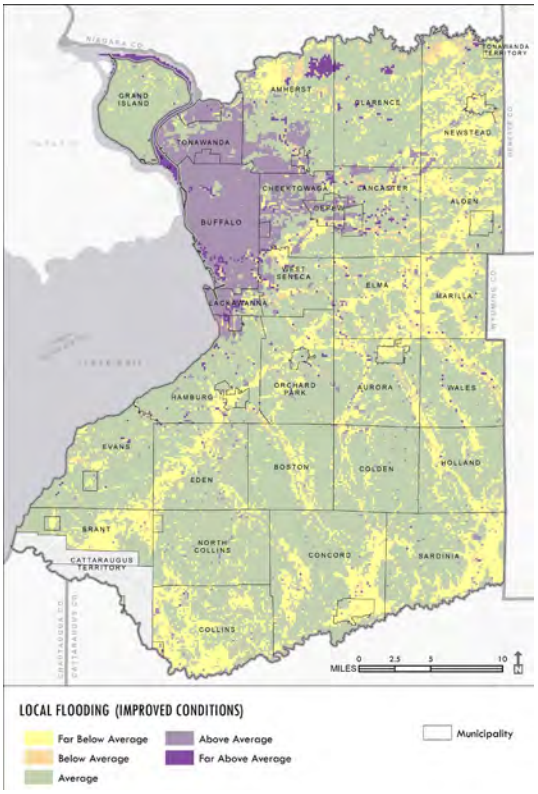



*Figure 6: Sensitivity to local flooding (current versus improved drainage conditions)*

**SENSITIVITY OF ERIE COUNTY TO FLOODING BASED ON SOURCES OF RUNOFF AND FLOODING DOWNSTREAM**

Analysis of Sensitivity to Downstream Flooding includes combination of a Topographic Wetness Index in conjunction with 100-year flood risk. Purple areas are areas that have a higher potential to release floodwater downstream.

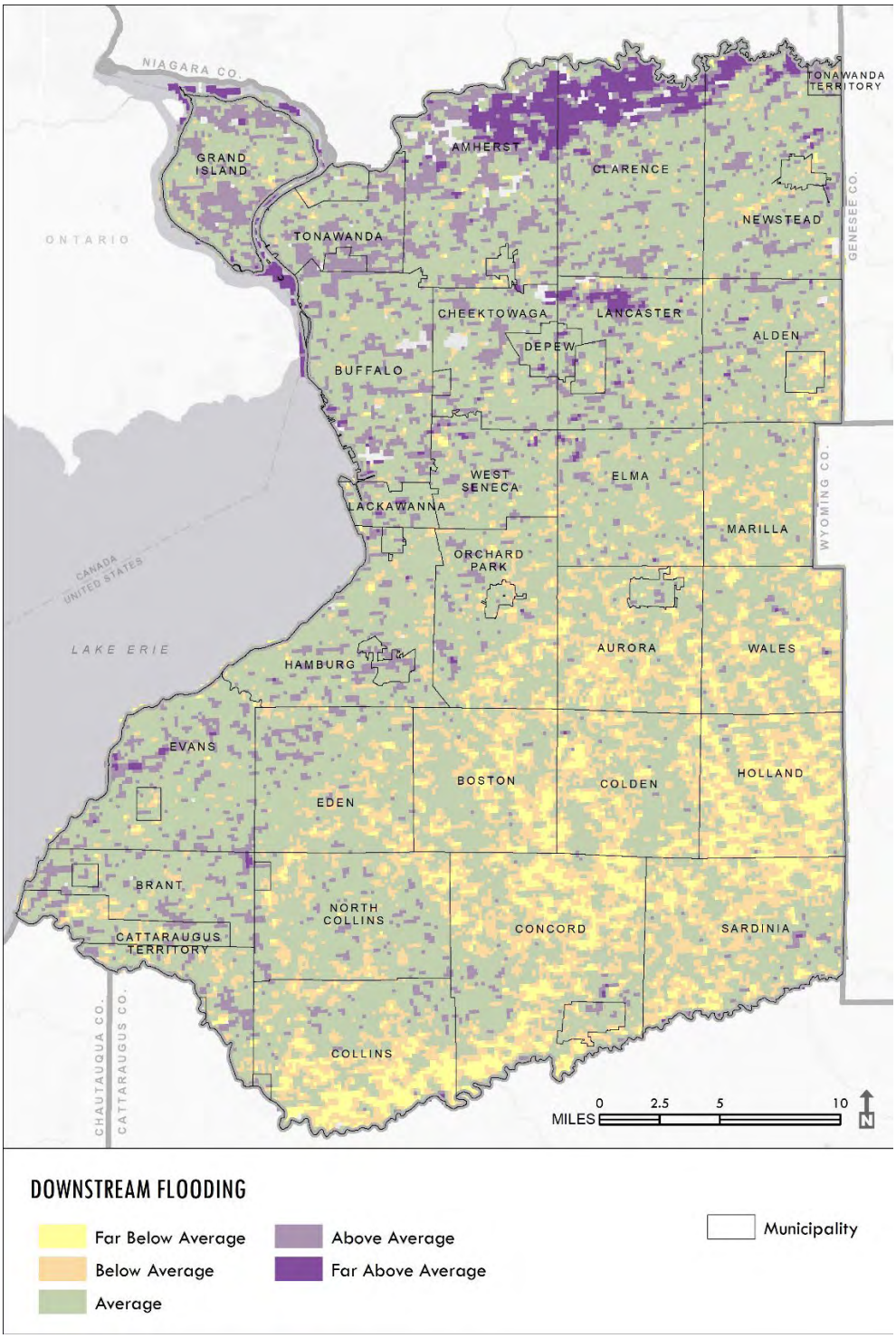



*Figure 7: Sensitivity to downstream flooding from sources of runoff*

## Sensitivity to Flooding Case Studies

Erie County has experienced flooding that has resulted in damage and disruption to communities. In mid-November of 2020 (WGRZ, 2020), a storm battered the Hoover Beach and First Ward of Hamburg and Buffalo, respectively. During this flood event, residents were evacuated from homes at Hoover Beach in Hamburg, and major roadways such as Route 5 were closed, potentially creating issues of access to emergency services for residents in the area. Luckily, major damage was averted and there were no injuries reported. However, this site can be used as a case study for the sensitivity analysis described above, where it can be analyzed and compared to a less-prone area such as Majors Park in East Aurora.

The presence of the Buffalo River and Lake Erie add additional risk in regards to flooding in Hoover beach, as shown by the seiche events witnessed in this example. East Aurora is not only further inland, but the landscape has greater topographical diversity, which reduces the risk of localized flooding and decreased runoff which can reduce risk of issues downstream. This is not to say that there are no risks of either ponding or runoff in East Aurora, only that the relative risk of serious flooding is lower based on the characteristics of the watershed.

*Figure 8: Flooding in the area around Hoover Beach in late 2020, Hamburg NY (WGRZ.com)*

*Table 5: Sensitivity to Flooding as interpreted through the PEOPLES Resiliency Framework's 7 Dimensions*

| | |
|---|---|
| **Populations and Demographics** such as Erie County employees and vulnerable residents may be impacted by on-site flooding and runoff generation in a variety of ways. Erie County employees tasked with managing damage to infrastructure or risk to the public may be at risk of injury when managing extreme conditions, and vulnerable segments of the population may have elevated risk of personal injury and/or damage to their property through on-site flooding or erosion stemming from runoff. | **P** |
| In the lens of the Erie County CVA, the dimension of **Environment and Ecosystems** most directly relates to the parks and forests that Erie County manages and operates. Flooding may damage infrastructure to trails and other park improvements, and erosion may negatively impact the forest land that Erie County manages. These maps above can aid the County in identifying priorities for proactive efforts to prevent such occurrences and/or mitigate the extent of impact for climate-related extreme precipitation events. | **E** |
| Services provided by Erie County are included in the PEOPLES dimension of **Organized Governmental Services**. These services that Erie County provides include maintaining infrastructure, health and human services, as well as emergency services. All of these, and other, aspects of Erie County operations may be impacted in the event of extreme events. These spatially mapped scenarios of flood risk allow for identification of potential problem areas that may limit these services or inhibit the public from accessing these services in times of emergency. | **O** |
| Transportation, sewers, and County-owned buildings are included in the dimension of **Physical Infrastructure**. All of these aspects may be impacted by flooding. Transportation corridors may be limited or destroyed by flood waters, sewers may be overloaded with floodwater and rendered ineffective or damaged, and County-owned buildings can be flooded and impacted in that sense. All of this collectively creates sensitivity to the impact of climate-related extreme precipitation events. | **P** |
| With limited or interrupted access to certain services (health or social services) provided by the County during flooding events, the **Lifestyle & Community Competence** may be negatively impacted. This at least temporarily reduces the quality of life for the residents of Erie County. To prevent this, the sensitivity analysis provided for flooding can identify key areas of high sensitivity to focus preventative or mitigative efforts. | **L** |
| The cost to **Economic Development** from extreme precipitation events and flooding may be substantial. This analysis will allow for identification of mitigation targets that increase percolation of flood waters in some areas while conducting runoff reduction efforts in others. These projects reduce damage, increase quality of life, and maintain access to governmental services. | **E** |
| Collectively, the **Social-Cultural Capital** of a region aids in not only maintaining economic development, but enhancing it in the future through attracting additional populations to the region. The risk of floods and other extreme precipitation-related hazards must be addressed through prevention or mitigation measures. | **S** |

## Chapter 4: Sensitivity Analysis with Respect to Biological Threats

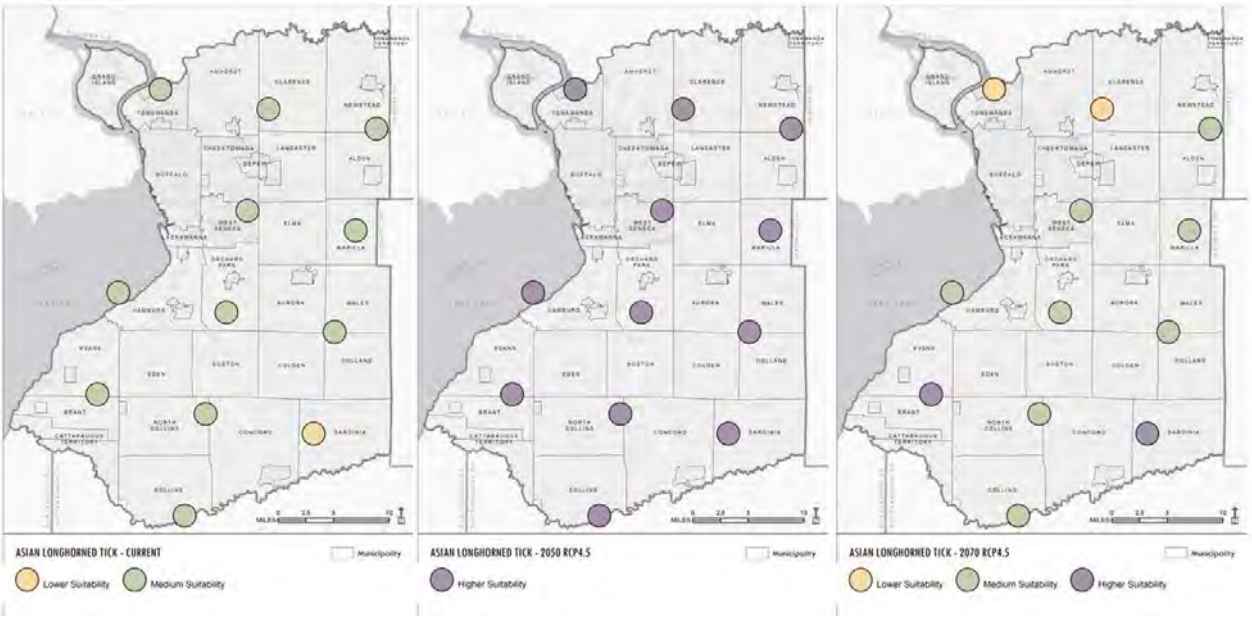
A changing climate will not only result in altered patterns in temperature and precipitation. As the environment changes, so does the habitat that is available for life in the region. These changes in habitat suitability can lead to changes in the geographic range of many species. Vector-borne diseases (VBD), invasive species and other biological threats may become more prevalent or have a greater impact should the region become more suitable for their life history needs (Brownstein et al., 2005). For example, diseases spread by mosquitoes and ticks may become more prevalent where they do occur and/or established in areas where they do not already occur (Khatchikian et al., 2013; Rochlin et al., 2013; Alto & Juliano, 2001). Additionally, invasive species may follow similar patterns (Hellman et al, 2008; Rahel and Olden, 2008; Mainka and Howard, 2010). Other biological threats, such as outbreaks of toxic cyanobacteria blooms ("Harmful Algal Blooms" or HABs) in Lake Erie, are also exacerbated by climate change and are a regional concern (Griffith and Gobler, 2020; Gobler, 2019). These issues have been under consideration for Erie County in the past, as shown in the Climate Action and Sustainability Plan (Erie County, 2019a). However, they have not been analyzed in conjunction with the ability of the County to respond to biological threats that become exacerbated by climate change. Thus, biological threats are analyzed here to provide a baseline assessment of the sensitivity of the County to these types of impacts.

In order to assess the risk that biological threats pose in the lens of a changing climate, a GIS-based tool created by the United States Fish and Wildlife Service (USFWS) was utilized. Their peer-reviewed Risk Assessment Mapping Program ( RAMP - https://www.fws.gov/fisheries/ANS/pdf_files/RAMP-SOP.pdf) is used in a mapping software program, and incorporates the known environmental variables that are present in a given species' native geographic range as applied to a new geographic area or given a certain level of warming, in a map-based visualization (Sanders et al., 2018). The USFWS RAMP program's outputs include a point grid across the selected geographic region (in this case, it was the Great Lakes Basin and/or New York State) that represents relative habitat suitability on a scale of 1-10. In the maps made of suitability for target species in Erie County, these relative rankings are further stratified in a low, medium and high rank. These rankings are relative to Erie County solely, and generally ranged from 5-9 in the original USFWS RAMP output.

*Figure 9: Two species analyzed in this process. The native black-legged tick (Ixodes scapularis) on the right and the invasive Asian long-horned tick (Haemaphysalis longicornis) on the left*

**HABITAT SUITABILITY FOR TWO SPECIES OF DISEASE-CARRYING TICK**

## Asian Longhorned Tick Habitat Suitability




## Deer Tick Habitat Suitability

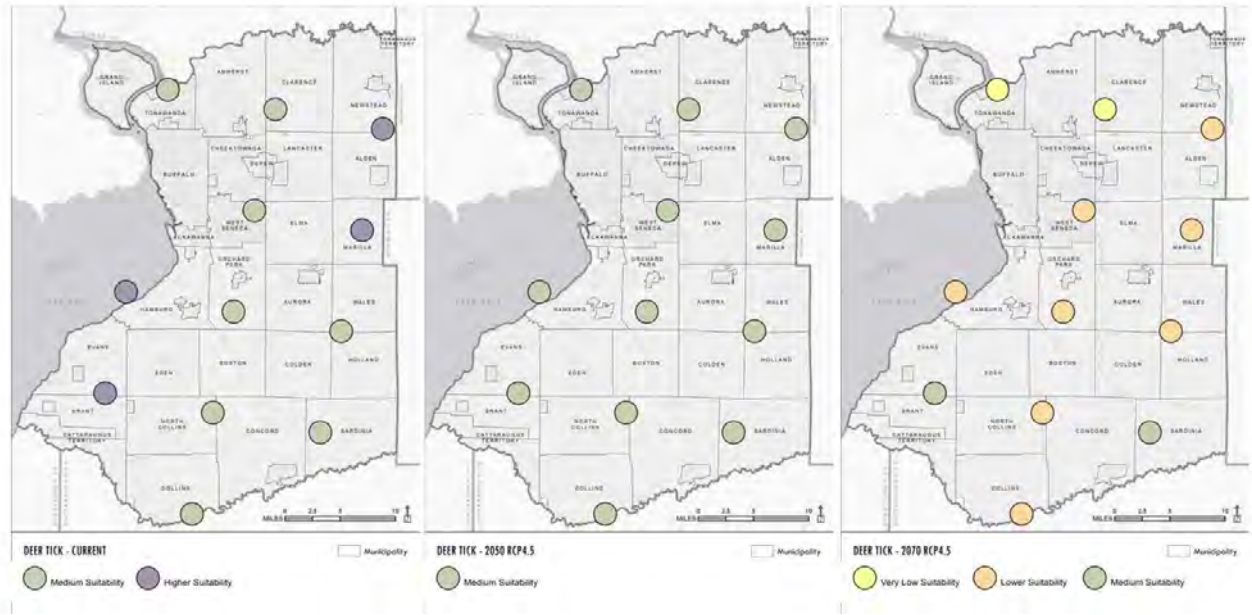



*Figure 10: Habitat suitability as modeled by USFWS Risk Assessment Mapping Tool (4.5 RCP scenario), showing suggested suitability in current conditions, 2050, and 2070. *Note differing color display in these maps where colors denote relative habitat suitability,*

## Sensitivity to Biological Threats Case Studies

Five key case studies were conducted. Out of the 13 species that were analyzed using the USFWS RAMP program, 4 were selected to review in this report. These are the Asian Tiger Mosquito (*Aedes albopictus)*, Asian Longhorned Tick (*Haemaphysalis longicornis)*, Deer or Black-legged Tick (*Ixodes scapularis)*, Spotted Lanternfly (*Lycorma delicatula)* and the Asian Swamp Eel (*Monopterus albus)*. These species were selected as representative examples of an invasive species that is involved in VBD that is currently present in Erie County (*Aedes albopictus)* (Rochlin et al., 2013), an invasive species that is involved in VBD that is not currently present in Erie County (*Haemaphysalis longicornis*) (Wormser et al., 2019), a native species that is involved in VBD (*Ixodes scapularis*) (Khatchikian et al., 2012), and invasive species that are not present in Erie County but are considered "Early Detection" species of concern for WNY PRISM (*Lycorma delicatula*, *Monopterus albus*). Show on the above are two maps – one showing the habitat suitability of the Asian Longhorned Tick and one showing the same for the Deer Tick (Figure 10).

There was a general trend in the change of habitat suitability for native versus invasive species analyzed in this process. Native species, such as the Deer Tick, saw a decline in habitat suitability over time. Invasive species, such as the Asian Longhorned Tick, saw an increase in habitat suitability from the current to 2050 time interval, and a decline in habitat suitability in the 2050-2070 time interval. This is interesting, and suggests that the current issues that Erie County may face in terms of VBDs may morph and change in a dynamic process over time. The current issues with disease and/or invasive species must be addressed, however the County should look to the future when considering mitigation and prevention measures, as there may be new species/diseases that move in and out of the area as the changing climate dictates the suitability of the environment for a given species.

It should be noted that the habitat suitability metrics are not intended to be an in-depth study on precisely where and when an issue may arise in terms of disease or invasive species. Instead, the analyses should be considered a starting point for a discussion on how to approach monitoring existing issues, as well as ramping up surveillance for issues that are just now on the horizon. Additionally, looking farther to the future may aid in readiness to adapt to a newly-introduced species that may create problems not yet considered. An adaptive management approach should be developed, where the County monitors these problems continuously to address the known issues while working to provide information on issues not yet well illuminated. Again, this analysis does not include seasonality and variation across the landscape that may elevate or reduce the sensitivity of a given region to the impacts of biological threats.

*Table 6: Sensitivity to Biological Threats as interpreted through the PEOPLES Resiliency Framework's 7 Dimensions*

| | |
|---|---|
| Sensitivity from these threats as related to the dimension of **Population & Demographics** include human systems such as Erie County employees and vulnerable populations. This includes employees that are conducting regular field work that puts them in contact with vector borne diseases as well as control efforts that may include insecticides or other chemical control that may present health hazards. In addition to Erie County employees working in areas of high tick density, vulnerable populations such as elderly and the immune compromised may face elevated risk of serious illness and long-term disability from tick-borne illnesses as well. | **P** |
| The **Environmental & Ecosystem** dimension of the PEOPLES Resiliency Framework includes natural systems, which are highly vulnerable to the impacts of invasive species. Erie County parks and recreation spaces, as well as County-owned forestland, face habitat degradation which synergistically inhibits the proliferation of native life while reinforcing the ability of invasive species to flourish. Whether the goal of the County is managing their lands for healthy ecosystems or valuable timber, invasive species are an issue. | **E** |
| **Organized Governmental Services** such as the Erie County Department of Health become overburdened when illnesses spread. Increases in the incidence of VBD translate to increased resources that must be devoted to managing the issue. These resources are frequently deducted from the County budget in other ways, depriving other valuable programs of funds un the event of an emergency. Proactive measures may reduce the severity and extent of these issues, and monitoring and surveillance programs for new VBD or problematic invasive species may pay for themselves in terms of avoided cost and expensive public health responses. | **O** |
| Vector-borne diseases don't frequently have a direct impact on **Physical Infrastructure**, however certain designs may promote a VBD and/or establishment of an invasive species. For example, infrastructure designs that pond water in containers may promote larval growth of Asian Tiger Mosquitoes and landscaping. Additionally, Erie County buildings and County-owned properties that contains certain invasive plants may promote the incidence of VBD, as seen with Japanese Barberry and Lyme Disease (Jones, 2011). | **P** |
| Quality of **Lifestyle and Community Competence** suffers when VBD become more common and natural areas become infested with noxious invasive species that negatively impact human and ecosystem health. As noted above, these issues strain budgets of Erie County services, necessitating trade offs with other valuable programs. | **L** |
| The impacts of VBD don't only directly affect human health and strain municipal budgets, they also carry costs to the public that become ill, all of which impacts **Economic Development**. Additionally, one of the three main impacts that define what an invasive species is refers to causing economic harm. Managing these species is critical to a healthy economy. | **E** |
| In order to provide **Social-Cultural Capital**, a region must retain and attract new residents. This is difficult to do if VBD create serious public health issues. Invasive species degrade the health and aesthetic components of a region – further degrading the attraction of new residents. | **S** |

# Chapter 5: Sensitivity with Respect to Wind

The most common association with a changing climate is the rising of temperatures, but as the environment changes, so do it's spatial and temporal wind patterns. Although wind and climate change are inextricably linked, there is little discussion or analysis on the prospective changes that will occur. Through a literature review and interviews with climate experts, this study addresses three main aspects of climate change and wind: wind speed, wind direction and maximum wind events recorded in Erie County, New York. This report also delves into climate change's impact on seasonality, and more specifically, tree health in years to come as the climate warms.

## Higher Wind Speeds

Higher wind speeds will become more prevalent with a warmer climate. Judith Levan, a Warning Coordination Meteorologist at the NOAA National Weather Service in Buffalo, New York explained these effects in a series of interviews. Starting with our position in the atmosphere, humankind lives at the bottom of the atmosphere, where the weight of the air above us is called air pressure. Air pressure varies from day to day at the Earth's surface as we live at the bottom of the atmosphere. Areas where the air is warmed often have lower pressure because the warm air rises. These areas are called low pressure systems (Levan, 2021). A low-pressure system has lower pressure at its center than the areas surrounding it. Wind blows towards areas of low pressure, and where they meet, the air rises in the atmosphere. As the air rises, water vapor inside condenses, creating clouds and precipitation. Levan said that wind speed depends on the strength of the low-pressure system. The stronger the low-pressure system is, the higher the wind speeds will be ("The Highs and Lows of Air Pressure", 2021). With increasing temperatures, the low-pressure system will be stronger, thus making wind speeds stronger as well (Levan, 2021). It is also important to add that, that warmer air can hold more water than cooler air, there is an increase of capacity to hold more water. That water is part of the energy transfer from evaporating water as latent heat into the atmosphere. This means when increased condensation in the atmosphere occurs there is more energy being released adding to a higher temperature gradient and higher wind speeds. Therefore, higher wind speeds will become more prevalent with a warmer climate.

Scott Eichelberger, James McCAA, Bart Nijssen, and Andrew Wood furthered this research and created the report "Climate Change Effects on Wind Speed" where they concluded that wind speed values will likely increase over much of North America during the winter months - December, January, and February, and decrease during the summer months - June, July, and August, but overall strengthen in speed as the climate warms (Eichelberger et al., 2008). In another report conducted to examine the projected changes to mean and extreme surface wind speeds for North America based on regional climate model simulations, it was deemed that changes in surface wind extremes have direct implications for buildings, infrastructure, agriculture, power lines, the desert, and forestry. An interview was conducted with Troy Schinzel, the Commissioner of Parks, Recreation & Forestry in Erie County to understand these regional changes. So far, Parks has seen a multitude of high wind events that were not present in previous years.

## Tree Health

These wind events have had a large impact on our trees and forests and the way that we manage them. In our area, we have a plethora of trees infested by the invasive beetle species the emerald ash border (*Agrilus planipennis* )(Schinzel, 2021). The emerald ash borer (EAB)larvae feed on the inner bark of ash trees, disrupting the tree's ability to transport water and nutrients (Matsoukis). Now weakened, the trees in our area are more susceptible to damage and wind storms that come through are knocking them down. With wind speed and wind seiche events becoming more frequent, more trees will be knocked down and more damages will arise (Schinzel, 2021).

In addition to higher wind speeds resulting from climate change, wind direction will also change with a warmer climate. Erie County, because of its latitude, usually has prevailing winds from the southwest. Storms move from east to west, and since we are close to Lake Erie, the Lake tends to turn winds to a more southwesterly direction.  However, we could potentially experience more northeasterly winds as the climate changes. This potential change will come in with stronger low-pressure systems that are characterized with winds circulating in a counterclockwise direction, resulting in winds generally from the northeast. Because the winds are stronger, we will get odd direction storms more frequently (Levan, 2021). The Intergovernmental Panel on Climate Change also notes this by saying "there is evidence for long-term changes in large-scale atmospheric circulation, such as a poleward shift and strengthening of westerly winds" (Eichelberger et al., 2008).

## The Regional Weather Patterns

In Western New York and the Great Lakes Region, our windiest season is winter because it has the strongest regional storms (dominated by low-pressure systems) and our least windy season is summer because it has the least regional storms (descending air in more frequent high-pressure systems). The passage of these winter storms is controlled by the latitude and waviness of the jetstream and the low-pressure and high-pressure cells. As the climate changes, the latitude of the jetstream is expected to move slightly north, but not an immense amount that would radically alter the number of storms we get. There is an expected slight increase in winter storms since we miss some storms that currently pass to the south of us. In the summer, it is also reasonable to expect a modest increase in the strength of a lake breeze, which is a small-scale wind circulation caused by the land being warmer than the water. This is due to the land warming faster than the lake in the future (Evans, 2021).

As the climate changes we will also see out of season storms and these will result in more damage. A snow storm in April or October will be more detrimental to trees, people's houses, and buildings because they are unexpected. In regards to trees, once leaves on trees are budding out in spring or still remaining on the trees in the fall, the weight of the snow can increase the likelihood of power outages in addition to bringing trees down. Additionally, the weight of the snow will also make trees more susceptible to being knocked down by wind. As for people's houses and buildings, they are unprepared for the harsh winter environment so early on in October. People most likely will not have their patio furniture or be prepared with

snow tires, etc for the winter in October as it is out of season. But, with climate change, out of season storms will occur more frequently and more damage will arise as a result of unexpected weather (Levan, 2021).

### Wind Pattern Change Case Studies

An examination of Western New York's climate data from 1965 to 2016 clearly displays that the area is impacted by climate change. A form of severe weather that may be on the rise in Western New York is strong thunderstorm winds, which indicate a significant increase as time goes on. Thunderstorm winds are defined as winds arising from convection, occurring within 30 minutes of observed or detected lightning, with speeds of at least 58 mph, or winds of any speed producing a fatality, injury, or damage (Vermette, 2017).

### Shifting Wind Direction

The National Oceanic and Atmospheric Administration provides data on wind speed and direction going back to 1942. Through use of this data "wind roses", or diagrams showing direction and speed of wind, can be created for specific years or general time intervals (NOAA, 2021). In this analysis, wind roses were created in 20-year increments for the entire dataset that NOAA provides. These diagrams are shown below in Figure 11. Four wind rose diagrams are compared side by side in this diagram. As noted in the interviews with Judith Levan, wind direction does appear to be shifting over time. In the first wind rose, data from 1942 – 1962 is displayed (A). In this time, the prevailing wind is coming from the southwest, but there are also other stronger directional wind from the south and west as well. In the second wind rose, data from 1962 – 1982 (B) is shown. Here one can see a stronger grouping of wind direction from the southwest. By the 1982 – 2002 time period (C), the prevailing wind is clearly from the southwest, but there is also a strengthening directionality from the northeast as well. This trend continues in the most current data, from 2002 – 2021 (D).

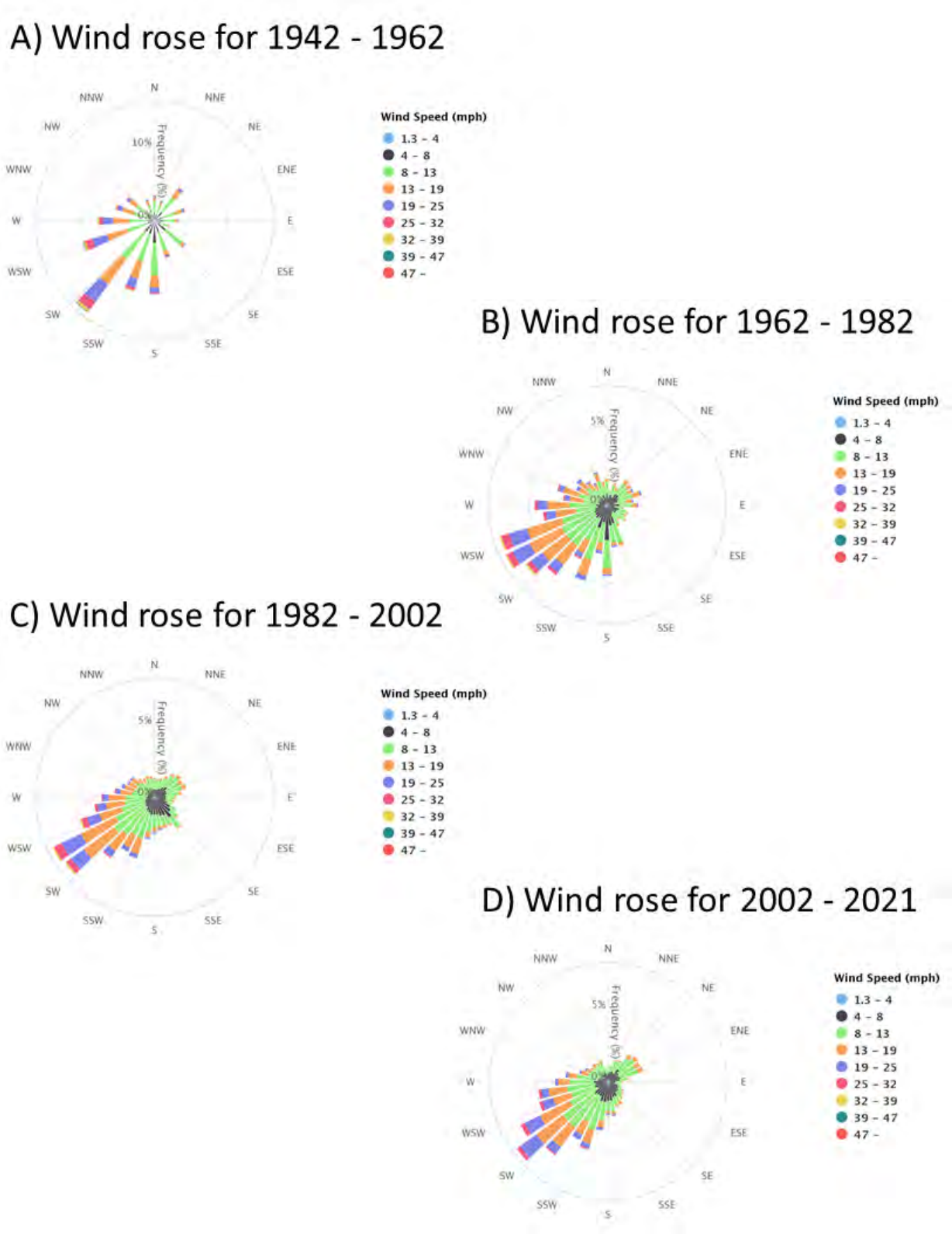



*Figure 11: Wind rose diagram for the Western New York area. The diagrams indicate increasing wind speeds over time and directional shifts.*

## Sensitivity to Wind Case Studies

November 15, 2020 (WBEN, 2021)

- Wind gusts were hurricane force and nearing 70 mph along the Buffalo waterfront and at the airport bringing many large trees down, and a seiche event causing lake shore flooding
- National Grid and NYSEG pressed into action and tens of thousands without power
- City of Buffalo forestry crews responded to approximately 55 tree calls. Half involves whole trees that were down.

September 7, 1998 (NOAA, 2021)

- Derecho, a widespread, long-lived, straight-line wind storm that is associated with a fast moving group of severe thunderstorms
- Some of the worst storm damage occurred in a band across western and central New York, caused by up to 89 mph wind gust (recorded at the Rochester Airport)
- 89 mph wind gust at the Rochester Airport and 77 mph at the Syracuse airport were recorded
- Damage was estimated at about 130 million dollars and hundreds of thousands of homes and business lost power, with some remaining without power for a week

March 8, 2017 (New York Upstate, 2021)

- Winds of up to 81 mph flipped over tractor-trailers, tore down trees and wires, blocked roads and knocked out power to tens of thousands of people
- Down trees, sparking wires and CSX train derailed
- High winds create big waves along the break wall on Lake

January 9, 2020 (11Alive, 2021)

- Wind gusts exceeding 60 mph
- The combination of rain and strong winds significantly increased the risk for uprooted trees, downed power lines and widespread power outages.
- A wind gust of 69 mph was recorded at the National Weather Service office by the airport

*Table 7: Sensitivity to Changes in Wind Pattern as interpreted through the PEOPLES Resiliency Framework's 7 Dimensions*

| | |
|---|---|
| Sensitivity from wind as related to the dimension of **Population & Demographics** include human systems such as Erie County employees and vulnerable populations. This includes people being impacted by wind damages to homes, infrastructure and transportation in reaching their offices providing essential services. | **P** |
| The **Environmental & Ecosystem** dimension of the PEOPLES Resiliency Framework includes natural systems, which are highly vulnerable to changes of wind patterns. These are mainly trees prone to damage due to age and foliage as well as coastal areas in danger of flooding due to seiche events. | **E** |
| **Organized Governmental Services** are critical in providing advanced warning of wind-related emergencies, as well as responding to these emergencies and providing resources to recover from these disasters. | **O** |
| **Physical Infrastructure** may be impacted by damages resulting from windstorms and erosion from wind-related seiche events. These damages in turn may translate to loss of accessibility and mobility to emergency services that can exacerbate the risk of damage and injury/death in the event of a disaster. | **P** |
| **Lifestyle and Community Competence** may be negatively impacted from an increase in the frequency and severity of wind-related damage. Over time, certain regions that may be in higher risk zones could see these impacts amplify, reducing the community's ability to recover from disasters. | **L** |
| **Economic Development** may be constrained due to the increased costs of recovering from damages caused by wind. For example, an increase in seiche events can result in an increase in the loss of lakeshore property and damage to lakeshore homes. As these homes are frequently greater sources of revenue in terms of property taxes, loss of the homes can have a greater effect on economic development in general. | **E** |
| **Social-Cultural Capital** is difficult to maintain and harder to enhance when there are elevated instances of wind that damage homes. The risk of such damages may discourage movement into an area, reducing the ability to generate this important social capital – with spillover impacts on the other dimensions noted above. | **S** |

# Chapter 6: Sensitivity with Respect to Mobility and Accessibility

This chapter focuses on the ability of residents living in Erie County to access critical resources. A key concern in the literature is the potential lack of access to care for underserved populations (Dolan, 2016). Levels of mobility (how far a person can travel in a given amount of time) and levels of accessibility (the number of transportation services a person can reach in that given amount of time) vary across space and socioeconomic demographics (Lee et al., 2018). To illustrate, research has shown that in some cases emergency departments that specifically are meant to improve access to healthcare for underserved populations will actually locate in socioeconomically advantaged areas (Carlson et al., 2019). The same research asserts that, "For low-income populations in urban areas who often rely solely on public transportation, location of healthcare services in close proximity to public transportation is an important factor in access" (Carlson et al., 2019). No one would question the importance of public transportation for urban residents in low-income communities. However, Erie County displays the full urban-rural spectrum. Therefore, any study on county-wide access to emergency departments must consider underserved and vulnerable populations in rural, urban, and suburban areas.

The question we explore is, *Do those who are most sensitive to climate-related hazards have the ability to reach the services and resources they need most?* To answer this question, we explore how *mobile* sensitive residents are, meaning what forms of transportation do they have available to them, and how *accessible* are critical services and resources, including **hospital Emergency Departments (EDs)** and **library Cooling Shelters (CSs)**. While EDs are considered critical services providers in all types of hazards, CSs are particularly important for providing services during extreme heat events. The scientific literature has revealed numerous approaches for highlighting these concerns, especially as Geographic Information Systems technology has become more commonplace (Cutter et al., 2000). The same analysis was used for EDs and CSs respectively. In the first figure below, County census tracts are displayed with area roads shown in grey, public transit lines shown in green, and EDs are shown in red, and CSs shown in blue.

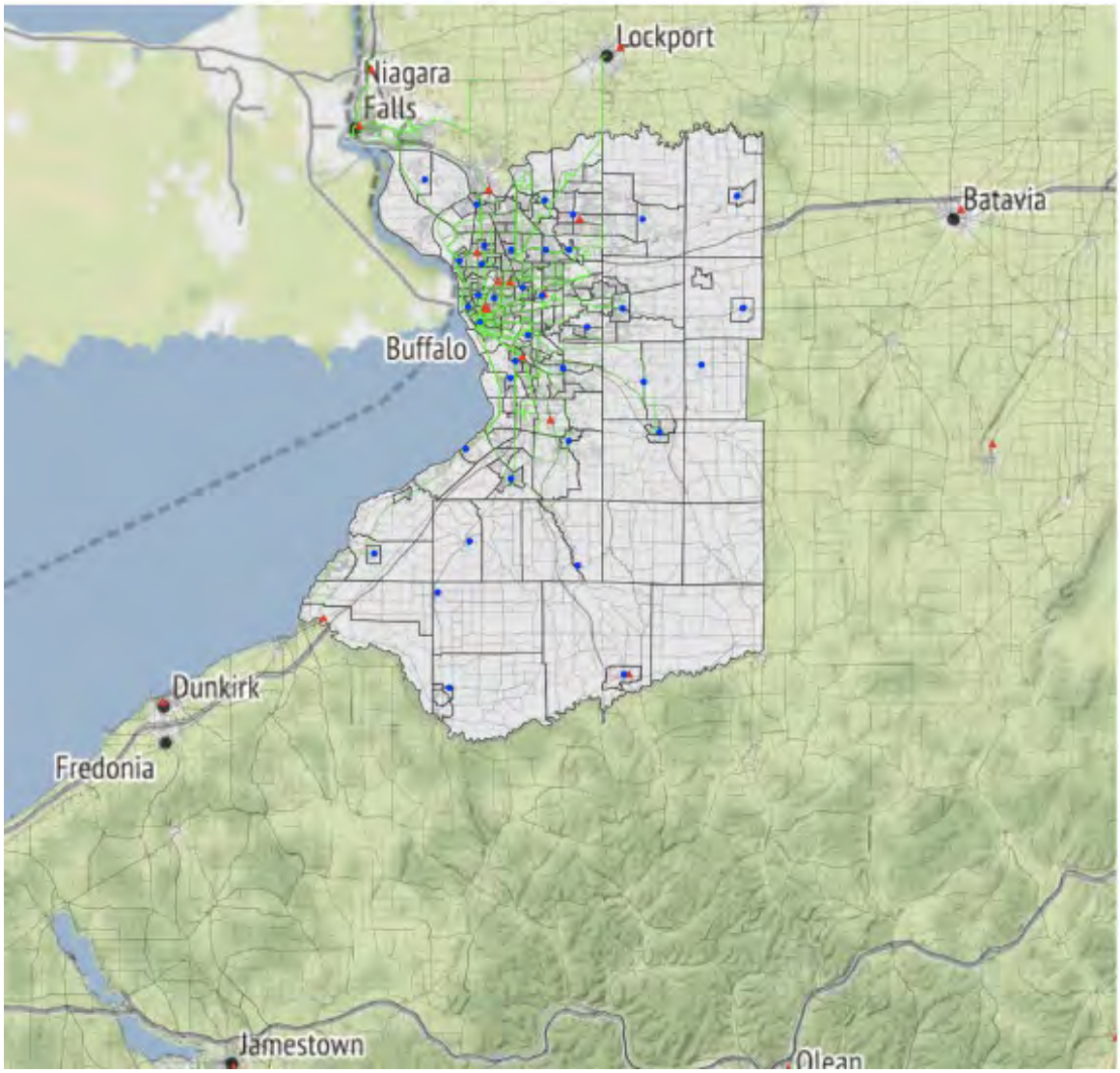



Figure 12: Erie and Surrounding Counties with Roads (grey), NFTA-Metro System (green), EDs (red), and CSs (blue)

## Methodology

The methodology for this component of the Assessment was chosen to highlight the comparative accessibility of Western New York area hospitals with hospital Emergency Departments (EDs) and library Cooling Shelters (CSs) relative to levels of social vulnerability and capacities for community resilience across Erie County. Figure 12 shows the location of 24 EDs and 37 CSs relative to Erie County. Social vulnerability has been generally defined as the potential for loss of life, quality-of-life, and property, and is an essential component in environmental hazard and climate disaster mitigation strategies at the local, national and international levels (Cutter, 1996).

The related concept of resilience is the ability of communities to respond to disaster (Sherrieb et al., 2010). Mobility is incorporated into these ideas by considering the different forms of transportation a person might use to access area hospital EDs, including driving, public transit, and walking. To account for vulnerability and resilience across Erie County, the components of two Census-based approaches will be used, including the Census Bureau Community Resilience Estimates, or CRE, (US Census Bureau, 2020) and Cutter's Social Vulnerability Index (Cutter, Mitchell and Scott 2000). Also collected are estimates from Google Maps of travel times by these three modes of transportation from the center point of each census tract in Erie County to EDs in Western New York. Using this data, we investigated how accessible critical services are (i.e., hospital EDs and cooling centers) in Erie County for residents according to different levels of vulnerability (Community Resilience Estimates, Cutter's Index), and for different modes of transportation (driving, public transit, walking).

The result are maps of the County showing the minimum driving travel times from the geographic center of each County census track to the closest ED or CS. These show how accessible the nearest ED or CS is relative to a census tract's level of social vulnerability.

While the algorithm to derive driving times (A) resulted in results to start a constructive conversation, the algorithm to derive transit and walking times (B and C, respectively) resulted in experimental maps that needed further research and additional investigation and are not shown in this report. As with the other climate hazards assessed in this report, considerations of time of day, seasonality, hours of operation of cooling centers were unable to be incorporated into the report. These are important considerations however since the sensitivity of mobility and access to emergency services discussed here may be heightened in instances of mobility-constricting events, such as lake-effect snow storms and heavy rains or heavy traffic times. These factors are interesting considerations for future work but the representations discussed here are based on the average conditions and do not consider extreme events.

It should also be noted that the critical facilities analyzed in this chapter (i.e. emergency departments and cooling centers) are case study examples employed to illustrate the utility of the analysis. There are undoubtedly other critical facilities where mobility is a factor in regards to climate-related emergencies. Urgent care centers may be more common and more heavy utilized than emergency rooms, and grocery stores and gas stations are also critical in times of extreme events. As mentioned in the chapter on temperature, a power failure or other event (i.e. flooding or downed trees) may make travel much more difficult or altogether impossible. These scenarios above should be considered in future work to better inform these scenarios.

## ACCESSIBILITY OF EMERGENCY DEPARTMENTS IN ERIE COUNTY BASED ON DRIVING TIME

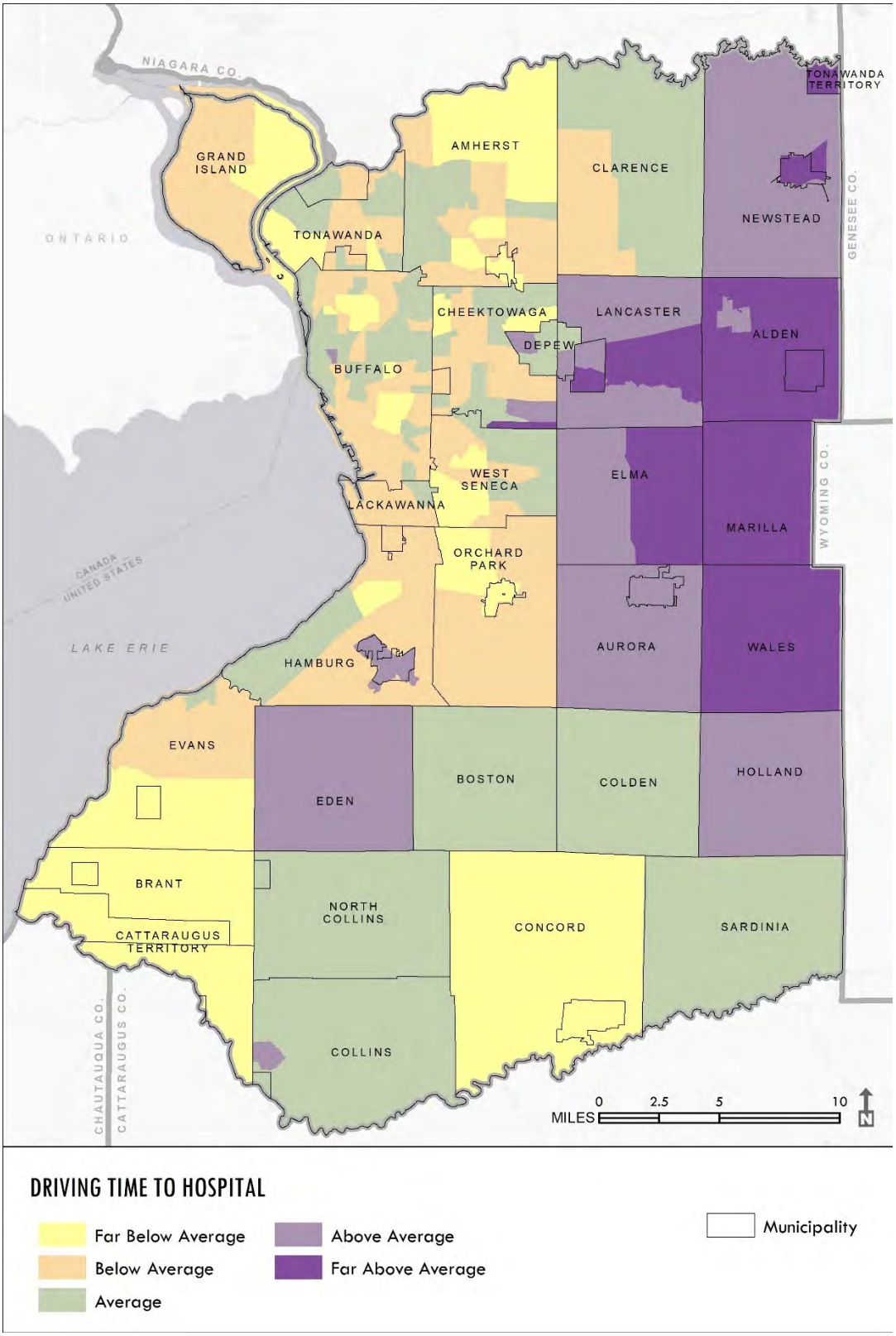



*Figure 13: Accessibility of Emergency Departments via driving.*

## ACCESSIBILITY OF COOLING CENTERS IN ERIE COUNTY BASED ON DRIVING TIME

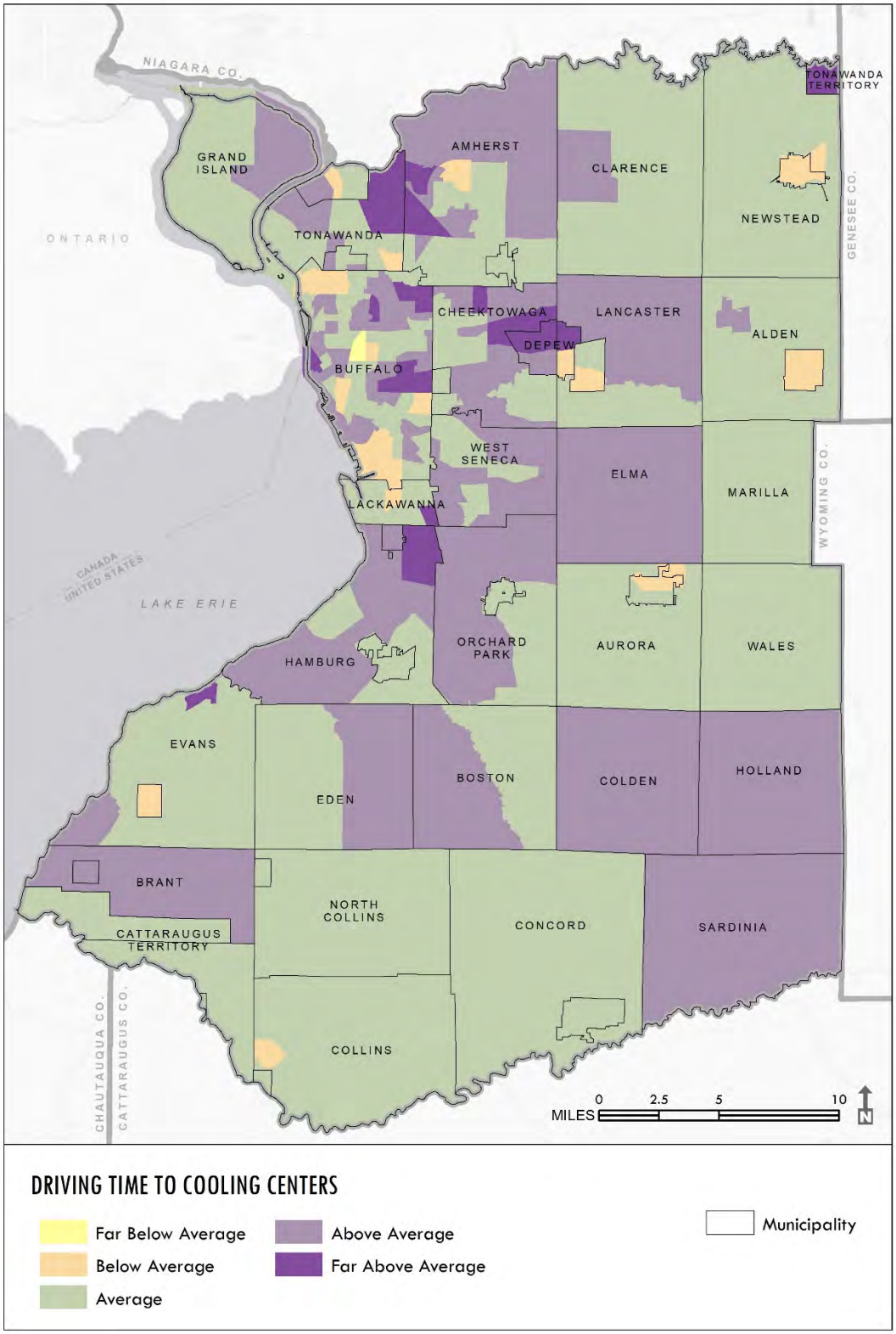



*Figure 14: Accessibility of Cooling Centers via driving.*

## Results[1]

The results for this component of the Assessment are shown in the Census Tract maps in Figures 13 and 14. The color values shown in Figure 13(A) entitled "Accessibility of Emergency Departments in Erie County Based on Driving Time" indicates the driving time necessary to reach an ED, in minutes (Google Maps), relative to what is expected for a census's tracts level of social vulnerability (Cutter's Index, CRE). This means that far above average values (purple) indicate driving travel times that are high for an observed level of vulnerability. On the other hand, values far below (yellow) indicate travel times that are low for an observed level of vulnerability. Expected drive times for a given level of vulnerability are average values (green). Figure 13(a) shows that the values closest to average are mostly found near the City of Buffalo, but also in some suburbs and more rural areas. The eastern rural tracts display a deep cluster of comparatively high travel times and we see some of the lowest comparative travel times in the southern and western parts of the county. These values make sense because if one were to have only considered travel time, the lowest values would be in Buffalo where hospitals are more densely located. Then middle values would be in the suburbs and the highest values would be in the rural areas. However, since vulnerability has been considered, short travel times may be balanced by high vulnerability resulting in average values in the city, far above average values in the eastern part of the county, and far below average values in Lake Erie Beach. For the most vulnerable tracts in Figure 13(a), the average travel time is approximately 24 minutes.

Figure 14(A) displays noticeably different results when vulnerability is considered in terms of accessibility of CSs instead of EDs. Although underlying social vulnerability remains the same, the distribution of CSs around the County is not the same as the distribution of EDs, hence the different results. Here, although the prevalence of above average transit times might seem abundant, the call for concern may not be too high. For tracts with far above average expected travel times, the average time is approximately 7 minutes. This would be feasible for an individual to avoid danger via driving or being driven from their home to a CS in the case of an extreme heat event.

[1] Preliminary results pending further review

*Table 8: Sensitivity to Mobility as interpreted through the PEOPLES Resiliency Framework's 7 Dimensions*

| | |
|---|---|
| **Populations and Demographics** living further from critical services and resources are more vulnerable than those that live closer. Larger households will also be more sensitive as accessibility to more resources will be required. | **P** |
| Aspects of the **Environment and Ecosystem** will play a role in vulnerability with respect to mobility and accessibility to emergency services. For example, during a heat event, active commuting options (walking, biking) may be limited and therefore accessibility is reduced. Extreme precipitation and flooding as well as wind events may result in impassable roadways, preventing County residents from accessing critical services all together or increasing travel times to those services. | **E** |
| Erie County's **Organized Governmental Services** will be interested in knowing where the most vulnerable county residents live in relation to which services they need most. Our results show travel times to EDs and CSs relative to social vulnerability. In the event of an extreme hazard, citizens in the least accessible tracts are more likely to experience high travel times and increased risks. | **O** |
| By identifying accessibility as a function of travel times along public roads and considering levels of vulnerability across the county, candidate tracts for future **Physical Infrastructure** improvement and investment are identified. In other words, areas with the lowest accessibility may make strong candidate sites for road or ED construction. | **P** |
| **Lifestyle and Community Competence** may prove difficult to negotiate since many individuals prefer the urban/suburban/rural context they live in and would prefer not to move, even for reasons of mobility or accessibility. With this in mind, it becomes more important for residents and planners to identify precisely how risks and vulnerabilities are spread across the county in order to preserve quality of life in the face of hazards. | **L** |
| **Economic Development** is an inherent component with respect to mobility and accessibility to emergency services. First, many individuals in the urban population, especially those living in low-income circumstances, do not own a vehicle. The maps displayed in the results show large differences in travel times between driving and public transit travel times. The situation worsens even more moving from public transit to walking. On the other hand, this may identify opportunities for the private sector to step in. Areas that are currently underserved may justify a private investment to provide services. Moreover, efficient transportation systems (or the lack thereof) may promote economic development (or hinder it) itself. | **E** |
| **Social-Cultural Capital is** sensitive to mobility and accessibility in that transportation systems affect individuals' ability to gather. For example, community centers can only serve community members who can reach them. Opportunities for these groups and facilities will exist in the areas that can be shown to be most underserved relative to target populations. | **S** |

## Case Studies

Since accessibility to services in this context is greatly increased (in terms of travel times) on a resident's access to a private vehicle, the key case studies for this component focus on census tracts with high and low access to vehicles. Two extreme cases are presented. For each case, it is possible to interpret whether the mobility observed in the tract, as measured by the US Census Bureau variable for number of workers with no vehicle available, reinforces or balances what has already been observed in the same tract regarding accessibility to hospital EDs (shown previously).

The census tract with the greatest number of workers without access to a vehicle, that is, the tract with the least mobility, is Census Tract 47. This urban tract is located in the Lasalle and University Heights neighborhoods of Buffalo and is directly south of and adjacent to the University at Buffalo South Campus. The results from the drive time is average, compared to the travel times across the County. This indicates that relative to this tract's degrees of vulnerability and resilience, its accessibility to hospital EDs is relatively high. In other words, despite a low degree of vehicle ownership, access is still available in other forms (transit and walking). This means vulnerability here is at least partially mitigated in terms of ED access since travel times are relatively short.

On the other hand, there are multiple census tracts where all workers have access to a vehicle, including Census Tract 149.04. This rural tract is the located in the rural east of Erie County. This tract is identified as having travel times above or far above average relative to its levels of vulnerability and resilience. The accessibility of this area is seemingly poor because the nearest hospitals are quite far. In contrast to the University Hights area, the alternative NFTA transit lines do not cross this this tract. However, since these residents are highly mobile (i.e., have access to vehicles) the overall accessibility is not as concerning.

*Figure 15: Photograph of Main Street in Buffalo, running through the census tract with the lowest access to vehicles on the LEFT and a rural road and land in a census tract with one of the greatest access to vehicles on the RIGHT (Source: google.com).*

# Chapter 7: Conclusion

This report analyzed the sensitivity of Erie County to multiple climate-related hazards (extreme heat, flooding, biological threats, wind and how they interact with mobility and accessibility). For each of these topics, the analysis showed a range of areas in the County with both below and above average sensitivities. The analysis of extreme heat found regions in Erie County that would experience above average sensitivity to extreme heat events, where impacts may be in relation to a lack of access to cooling units or stations, older housing units that are poorly designed, and built environments that are by nature much warmer than natural areas. The local and downstream components of the analysis of sensitivity to flooding showed neighborhood locales that may be more prone to flooded roadways and basements during heavy rain events; as well as the locations where runoff was generated – impacting downstream communities. The analysis of biological threats suggests that there will be new dynamics in habitat suitability that enhance habitat for some species and degrade habitat for others – largely benefiting invasive species that cause environmental, economic, and public health issues. Evaluating mobility and accessibility in Erie County highlighted how convoluted accessibility can be for both urban and rural residents, often counterintuitively. The urban-rural divide in regards to climate vulnerability is documented in the literature (Cutter et al, 2016; Wells, 2012) and has been a source of discussion during this analysis. Specifically, there was greater sensitivity to heat and flooding in urban areas, while rural areas showed more sensitivity to mobility and access to emergency services. Ultimately, each result presents a starting point for future discussions related to evaluating adaptive capacity (Phase III of this CVA project), as well as future research and reduction/mitigation measures.

Despite the utility of these results, there are important limitations to consider. For all facets of the analysis, there were limitations in data, capacity, and funding. This is not to say that a robust analysis wasn't conducted, only that there are many other directions of analysis and research topics that could also be considered for each of the hazards under review. Another issue is the issue of scale. Where data was available, it was frequently available at the federal, state or county scale. These differences made analyses at fine spatial scales difficult, both for specific hazards and for comparisons between analyses. Thermal sensitivity and mobility/accessibility were analyzed at the census-tract scale, flooding was analyzed at the pixel-level scale, and biological threats were analyzed at the state scale. To accommodate the issue of differentiating scale in our data sources, the results were aggregated to display scales between –1 to 1, and the averages of these scales displayed for analysis. Therefore the results shows in the previous chapters display sensitivities ***relative*** to other locations within the County.

As noted above, there were a considerable number of additional avenues of research into how sensitivity to climate-related impacts may impact Erie County. Further analysis on how these hazards will impact the health of Erie County employees and residents will refine the recommendations stemming from this research. How will extremely hot days impact those that

work outdoors for Erie County in the summer months? How will flooding impact Erie County facilities and the workers that may be present in those buildings? Will tick-borne illnesses be of greater concern to these workers in coming decades? How does the stormwater system that Erie County manages become stressed during heavy rains, and will this create blockages or failures that can lead to flooding?

There are several facets of sensitivity that were outside of the scope of this project but are particularly important avenues for future research, and in some cases were emphasized by project stakeholders. While not directly discussed in this report, agriculture is a vital industry that may be negatively impacted by climate-related impacts. Extreme heat may stress crops and reduce yields (Environmental Law and Policy Center, 2019). Heavy rains may flood croplands and stifle productivity (Easterling et al, 2017). Invasive pests may decimate crops and destroy harvests (Mainka and Howard, 2010; Hellmann et al, 2008). Wind may blow away prime farmland and reduce the quality of soils in affected areas (Weil and Nyle, 2017).

Climate migration is another important consideration. The Erie County region has recently been described as a potential "climate oasis", as the proximity to the Great Lakes region provides a cooling effect in addition to ample fresh water (Aldia Environmental, 2020; NBC News, 2020). However, these resources have been strained for decades from pollution and human development, and may not be reliable as a resource in the ace of climate change and an influx of additional human populations that further stress these ecosystems (Environmental Law & Policy Center, 2019). Assessing Erie County's sensitivity and ability to respond to this issue is critical in preparing for the impacts that may result.

How stormwater systems in Erie County interact with flooding is an aspect of the issue that was not fully assessed in this analysis. These systems may provide drainage in both natural and developed settings, and this drainage may alleviate excess runoff or local ponding in heavy rain events. Conversely, these systems may become clogged and create issues with localized flooding and elevated runoff. Thus, it is important to include where these systems are and how they may be related to flood-prone landscapes in the analysis of sensitivity (Okazawa et al, 2011). This information will be incorporated into future reports.

In summary, this sensitivity report has highlighted a number of important issues facing the County specifically related to the climate impacts of heat, flooding, wind and biological threats. The report also highlights areas for which further analysis and assessment are warranted to have a richer understanding of specific, high-resolution impacts of various climate change threats and scenarios. The County views the results of this report as a foundation from which to build a common understanding of the local impacts of climate change as well as strategies to mitigate them. The next phase of the Climate Vulnerability Assessment is to assess the adaptive capacity of the County to plan for and mitigate the consequences of the hazards discussed here, and will be the focus of our next report.

## Literature Cited


11Alive. 2021. High winds roar through Western New York. https://www.11alive.com/article/weather/flood-watch-issued-for-most-of-wny-this-weekend/71-3860b81f-cf94-462e-ba24-487075524b81. Accessed 5/1/2021.

Aldia Environment. "Why Buffalo is the best U.S. city for climate refugees". Accessed July 17, 2020. https://aldianews.com/articles/cultura/environment/why-buffalo-best-us-city-climate-refugees/57108

Alto, Barry & Juliano, Steven. 2001. Precipitation and Temperature Effects on Populations of Aedes albopictus (Diptera: Culicidae): Implications for Range Expansion. Journal of medical entomology. 38. 646-56. 10.1603/0022-2585-38.5.646.

Aminipouri, M., Knudby, A., & Ho, H. C. (2016). Using multiple disparate data sources to map heat vulnerability: Vancouver case study. The Canadian Geographer/Le Géographe canadien, 60(3), 356-368.

Andrew MK, Mitnitski AB, Rockwood K (2008) Social Vulnerability, Frailty and Mortality in Elderly People. PLoS ONE 3(5): e2232. https://doi.org/10.1371/journal.pone.0002232

Arguad, L., Ferry, T., & Le, Q. (2007). Short- and long-term outcomes of heatstroke following the 2003 heat wave in Lyon, France. Arch Intern Med, 167(20), 2177-2183. doi:10.1001/archinte.167.20.ioi70147

Aroca, Estefanía & Bodoque, J. & García, Juan. (2020). How to construct and validate an Integrated Socio-Economic Vulnerability Index: Implementation at regional scale in urban areas prone to flash flooding. Science of The Total Environment. 746. 1-16. 10.1016/j.scitotenv.2020.140905.

Bolin B. (2007) Race, Class, Ethnicity, and Disaster Vulnerability. In: Handbook of Disaster Research. Handbooks of Sociology and Social Research. Springer, New York, NY

Bouchama, A. (2007). Prognostic factors in heat wave–related deaths: A meta-analysis. Archives of Internal Medicine, 167(20), 2170–2176. doi:10.1001/archinte.167.20.ira70009

Bowler, D. E., Buyung-Ali, L., Knight, T. M., & Pullin, A. S. (2010). Urban Greening to cool towns and cities: A systematic review of the empirical evidence. Landscape and Urban Planning, 97(3), 147-155. doi:10.1016/j.landurbplan.2010.05.006

Brownstein, J. S., Holford, T. R., & Fish, D. 2005. Effect of Climate Change on Lyme Disease Risk in North America. EcoHealth, 2(1), 38–46. doi:10.1007/s10393-004-0139-x

Buffalo Niagara Riverkeeper. 2014. Healthy Niagara – Niagara River Watershed Management Plan.

Centers for Disease Control and Prevention (CDC) - Agency for Toxic Substances and Disease Registry. 2020. CDC Social Vulnerability Index. Accessed 1/5/2021. https://www.atsdr.cdc.gov/placeandhealth/svi/index.html

Chapin, F. S., Matson, P. A., & Mooney, H. A. 2002. Principles of terrestrial ecosystem ecology. New York: Springer.

Chatzidimitriou, Angeliki & Yannas, Simos. (2015). Microclimate development in open urban spaces: The influence of form and materials. Energy and Buildings. 108. 156-174. 10.1016/j.enbuild.2015.08.048.

Cimellaro, G. & Renschler, Chris & Reinhorn, Andrei & Arendt, Lucy. (2016). PEOPLES: A Framework for Evaluating Resilience. Journal of Structural Engineering. 142. 04016063. 10.1061/(ASCE)ST.1943-541X.0001514.

Cleveland, Ohio. (2018). Climate Hazard and Social Vulnerability Assessment.

Colburn, Lisa & Jepson, Michael & Weng, Changhua & Seara, Tarsila & Weiss, Jeremy & Hare, Jon. (2016). Indicators of climate change and social vulnerability in fishing dependent communities along the Eastern and Gulf Coasts of the United States. Marine Policy. 74. 10.1016/j.marpol.2016.04.030.

Cutter, S. L., Ash, K. D., & Emrich, C. T. (2016). Urban–rural differences in disaster resilience. Annals of the American Association of Geographers, 106(6), 1236-1252.

Cutter, Susan & Boruff, Bryan & Shirley, W.. (2003). Social Vulnerability to Environmental Hazards. Social Science Quarterly. 84. 242-261. 10.1111/1540-6237.8402002.

Cutter, S. L., Mitchell, J. T., & Scott, M. S. (2000). Revealing the vulnerability of people and places: A case study of Georgetown County, South Carolina. *Annals of the Association of American Geographers, 90*(4), 713-737.

Das, Apurba & Rokaya, Prabin & Lindenschmidt, Karl-Erich. 2017. Assessing the impacts of climate change on ice jams along the Athabasca River at Fort McMurray, Alberta, Canada.

Desai, Ankur & Austin, Jay & Bennington, Val & Mckinley, Galen. 2009. Stronger winds over a large lake in response to weakening air-to-lake temperature gradient. Nature Geoscience. 2. 10.1038/ngeo693.

Dreher, DB & Harley, RA. (1998). A fuel-based inventory for heavy-duty diesel truck emissions. Journal of the Air & Waste Management Association. 48. 352-358.

Easterling, D.R., K.E. Kunkel, J.R. Arnold, T. Knutson, A.N. LeGrande, L.R. Leung, R.S. Vose, D.E. Waliser, and M.F. Wehner, 2017: Precipitation change in the United States. In: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 207-230, doi: 10.7930/J0H993CC.

Eichelberger, S., McCaa, J., Nijssen, B., & Wood, A. (2008). *Climate Change Effects On Wind*

*Speed* . ResearchGate.

https://www.researchgate.net/publication/281611243_Climate_change_effects_on_

wind_speed.

Eichelberger, S. & Mccaa, James & Nijssen, Bart & Wood, A.. 2008. Climate change effects on wind speed. NAm Wind. 7. 68-72.

Environmental Law & Policy Center. 2019. An Assessment of the Impacts of Climate Change on the Great Lakes.

Erie County. 2019a. Erie County Climate Action and Sustainability Plan, Internal Operations. Erie County - Department of Environment and Planning Report No. 1 Contract No. 57240

Erie County. 2019b. Regional Niagara River Lake Erie Watershed Management Plan Phase 2. Erie County – Department of Environment and Planning. http://www2.erie.gov/environment/sites/www2.erie.gov.environment/files/uploads/pdfs/ECS_WMP%20FINAL.pdf

Evans, S. (2021). Personal interview [Personal interview].

Federal Emergency Management Agency (FEMA). 2020. Accessed 12/13/2020. Special Flood Hazard Areas. https://www.fema.gov/special-flood-hazard-area

Fothergill, Alice. (2004). Poverty and Disasters in the United States: A Review of Recent Sociological Findings. Natural Hazards. 32. 89-110. 10.1023/B:NHAZ.0000026792.76181.d9.

Frankson, K. Kunkel, S. Champion, B. Stewart, W. Sweet, and A. T. DeGaetano, 2017. New York State Climate Summary. NOAA Technical Report NESDIS 149-NY, 4 pp.

Gobler, Christopher. 2019. Climate Change and Harmful Algal Blooms: Insights and perspective. Harmful Algae. 91. 101731. 10.1016/j.hal.2019.101731.

Griffith, Andrew & Gobler, Christopher. 2020. Harmful algal blooms: A climate change co-stressor in marine and freshwater ecosystems. Harmful Algae. 91. 10.1016/j.hal.2019.03.008.

Jones, Beth. (2011). Barberry, Bambi and bugs: The link between Japanese barberry and Lyme disease. Scientific American. https://blogs.scientificamerican.com/guest-blog/barberry-bambi-and-bugs-the-link-between-japanese-barberry-and-lyme-disease/

Hamstead, Z., Coseo, P., AlKhaled, S., Boamah, E. F., Hondula, D. M., Middel, A., & Rajkovich, N. (2020). Thermally resilient communities: creating a socio-technical collaborative response to extreme temperatures. Buildings and Cities, 1(1), 218–232. DOI: http://doi.org/10.5334/bc.15

Hellmann, Jessica & Byers, James & Bierwagen, Britta & Dukes, Jeffrey. 2008. Five Potential Consequences of Climate Change for Invasive Species. Conservation biology: the journal of the Society for Conservation Biology. 22. 534-43. 10.1111/j.1523-1739.2008.00951.x.

Hiemstra, P. (2013). Package "automap": Automatic interpolation package, R package version 1.0-14. In.

Khajehei, Sepideh & Ahmadalipour, Ali & Shao, Wanyun & Hamid, Moradkhani. (2020). A Place-based Assessment of Flash Flood Hazard and Vulnerability in the Contiguous United States. Scientific Reports. 10. 10.1038/s41598-019-57349-z.

Khatchikian, Camilo & Prusinski, Melissa & Stone, Melissa & Backenson, Bryon & Wang, Ing-Nang & Levy, Michael & Brisson, Dustin. 2012. Geographical and environmental factors driving the increase in the Lyme disease vector Ixodes scapularis. Ecosphere (Washington, D.C). 3. 10.1890/ES12-00134.1.

Kherde, Rajesh & Priyadarshi, Dr. (2014). A GIS Based Variable Source Area Model for Large-scale Basin Hydrology. Research Journal of Applied Sciences, Engineering and Technology. 7. 3797-3802. 10.19026/rjaset.7.736.

Kumar, Parveen & Geneletti, Davide & Nagendra, Harini. (2016). Spatial assessment of climate change vulnerability at city scale: A study in Bangalore, India. Land Use Policy. 58. 514-532. 10.1016/j.landusepol.2016.08.018.

Levan, J. (2021). Personal interview [Personal interview]

Lowe, Dianne & Ebi, Kristie & Forsberg, Bertil. (2013). Factors Increasing Vulnerability to Health Effects before, during and after Floods. International journal of environmental research and public health. 10. 7015-7067. 10.3390/ijerph10127015.

Luber, G., & McGeehin, M. (2008). Climate change and extreme heat events. American Journal of Preventive Medicine, 35(5), 429-435. doi:10.1016/j.amepre.2008.08.021

Lumley, T., & Lumley, M. T. (2013). Package 'leaps'. *Regression Subset Selection. Thomas Lumley Based on Fortran Code by Alan Miller. Available online: http://CRAN. R-project. org/package= leaps (accessed on 18 March 2018)*.

Mainka, Susan & Howard, Geoffrey. 2010. Climate change and invasive species: Double jeopardy. Integrative zoology. 5. 102-11. 10.1111/j.1749-4877.2010.00193.x.

Margles, Shawn & Agostini, Vera & Roth, Lynnette & Gilmer, Ben & Schill, Steve & Knowles, John & Blyther, Ruth. (2016). Assessing vulnerability: an integrated approach for mapping adaptive capacity, sensitivity, and exposure. Climatic Change. 136. 10.1007/s10584-016-1642-0.

Marshall, Nadine & Marshall, N & Marshall, Paul & Tamelander, Jerker & Obura, David & Malleret-King, Delphine & Cinner, Joshua. (2010). A Framework for Social Adaptation to Climate Change: Sustaining Tropical Coastal Communitites [sic] and Industries.

Matsoukis, C. (n.d.). *Emerald Ash Borer Information Network*. Emerald Ash Borer. http://www.emeraldashborer.info/.

Melo, R., Rodriguez, T., & Zarruk, D. (2017). gmapsdistance: distance and travel time between two points from Google Maps. In: R package version.

Morrow, B. H. (1999). Identifying and mapping community vulnerability. Disasters, 23(1), 1-18. doi:10.1111/1467-7717.00102

Moss, Richard & Brenkert, Antoinette & Malone, Elizabeth. (2001). Vulnerability to Climate Change. A Quantitative Approach.

Mucke, P (2012) World Risk Report 2012: environmental degradation increases disaster risk worldwide alliance development works, Berlin

Munyai, R. B., Musyoki, A., & Nethengwe, N. S. (2019). An assessment of flood vulnerability and adaptation: A case study of Hamutsha-Muungamunwe village, Makhado municipality. *Jamba (Potchefstroom, South Africa)*, *11*(2), 692. https://doi.org/10.4102/jamba.v11i2.692

National Oceanic and Atmospheric Administration (NOAA). 2021. September 7, 1998 Derechos. https://www.spc.noaa.gov/misc/AbtDerechos/casepages/sep71998page.htm. Accessed 5/1/2021

National Oceanic and Atmospheric Administration (NOAA), National Centers for Environmental Information. 2020. Storm Events Database. Accessed July 19, 2020. https://www.ncdc.noaa.gov/stormevents/listevents.jsp?eventType=%28C%29+Tornado&beginDate_mm=04&beginDate_dd=01&beginDate_yyyy=1950&endDate_mm=04&endDate_dd=30&endDate_yyyy=2020&county=ERIE%3A29&hailfilter=0.00&tornfilter=0&windfilter=000&sort=DT&submitbutton=Search&statefips=36%2CNEW+YORK; https://www.ncdc.noaa.gov/stormevents/listevents.jsp?eventType=%28Z%29+Seiche&beginDate_mm=04&beginDate_dd=01&beginDate_yyyy=1950&endDate_mm=04&endDate_dd=30&endDate_yyyy=2020&county=ERIE%3A29&hailfilter=0.00&tornfilter=0&windfilter=000&sort=DT&submitbutton=Search&statefips=36%2CNEW+YORK

Nayak, S. G., Shrestha, S., Kinney, P. L., Ross, Z., Sheridan, S. C., Pantea, C. I., ... & Hwang, S. A. (2018). Development of a heat vulnerability index for New York State. Public Health, 161, 127-137.

NBC News. “Move to Buffalo? With Earth warming, northern cities could become oases.” Accessed July 17, 2020. https://www.nbcnews.com/science/environment/buffalo-oasis-scientists-say-warmer-earth-could-make-colder-cities-n1113711

New York State Attorney General Eric T. Schneiderman, Environmental Protection Bureau. 2014. Current and Future Trends in Extreme Rainfall Across New York State.

New York Upstate. 2021. Incredible hurricane-force winds hit Western New York. https://www.newyorkupstate.com/weather/2017/03/hurricane-like_winds_hit_western_ny_finger_lakes_photos.html. Accessed 5/1/2021.

Ngo, E. B. (2001). When disasters and age collide: Reviewing vulnerability of the elderly. Natural Hazards Review, 2(2), 80-89. doi:10.1061/(asce)1527-6988(2001)2:2(80)

Okazawa, Yuko & Yeh, Pat & Kanae, Shinjiro & Oki, Taikan. (2011). Development of a global flood risk index based on natural and socio-economic factors. Hydrological Sciences Journal – Journal des Sciences Hydrologiques. 56. 789-804. 10.1080/02626667.2011.583249.

Pebesma, E. J. (2018). Simple features for R: Standardized support for spatial vector data. *R J., 10*(1), 439.

Pohlman, Catherine & Turton, Steve & Goosem, Miriam. (2009). Temporal variation in microclimatic edge effects near powerless, highways and streams in Australian tropical rainforest.. Agricultural and Forest Meteorology. 149. 84–95.

Rahel, Frank & Olden, Julian. 2008. Assessing the Effects of Climate Change on Aquatic Invasive Species. Conservation biology : the journal of the Society for Conservation Biology. 22. 521-33. 10.1111/j.1523-1739.2008.00950.x.

Reid, C., Mann, J., Alfasso, R., English, P., King, G., Margolis, H., … Balmes, J. (2011). Evaluation of a heat vulnerability index on abnormally hot days: An application of environmental public health tracking data. ISEE Conference Abstracts, 2011(120), 715-720. doi:10.1289/isee.2011.01022

Renschler, Chris. (2015). The PEOPLES Resilience Framework – An Integrated Quantitative Measure and Modeling of Sustainable Development and Disaster Risk Reduction.

Renschler, Chris & Reinhorn, Andrei & Arendt, Lucy & Cimellaro, G.. (2011). THE P.E.O.P.L.E.S. RESILIENCE FRAMEWORK: A CONCEPTUAL APPROACH TO QUANTIFY COMMUNITY RESILIENCE. 10.13140/RG.2.1.3355.1767.

Renschler, Chris & Frazier, Amy & Arendt, Lucy & Cimellaro, G. & Reinhorn, Andrei & Bruneau, M.. (2010). Developing the peoples resilience framework for defining and measuring disaster resilience at the community scale. Proceedings of the 9th US National and 10th Canadian Conference on Earthquake Engineering. 25-29.

Ridgeway, G., Edwards, D., Kriegler, B., Schroedl, S., & Southworth, H. (2015). gbm: Generalized Boosted Regression Models, 2010. *URL http://CRAN. R-project. org/package= gbm. R package version, 2*.

Ripley, B. (2016). Tree: classification and regression trees, R package version 1.0-37. *Avaliable at https://CRAN. R-project. org/package= tree. Accessed August, 3*, 2017.

Rochester, NY. (2018). Climate Vulnerability Assessment Report. City of Rochester Office of Energy & Sustainability.

Rochlin I, Ninivaggi DV, Hutchinson ML, Farajollahi A. 2013. Climate Change and Range Expansion of the Asian Tiger Mosquito (Aedes albopictus) in Northeastern USA: Implications for Public Health Practitioners. PLoS ONE 8(4): e60874. https://doi.org/10.1371/journal.pone.0060874

Sanders, S., C. Castiglione, and M. Hoff. 2018. Risk Assessment Mapping Program: RAMP, Version 3.1. U.S. Fish and Wildlife Service.

Schinzel, T. (2021). Personal interview [Personal interview].

Shen, Suwan & Feng, Xi & Peng, Zhong-Ren. (2016). A framework to analyze vulnerability of critical infrastructure to climate change: the case of a coastal community in Florida. Natural Hazards. 84. 10.1007/s11069-016-2442-6.

Shepard, Christine & Agostini, Vera & Gilmer, Ben & Allen, Tashya & Stone, Jeff & Brooks, William & Beck, Michael. (2012). Assessing future risk: Quantifying the effects of sea level rise on storm surge risk for the southern shores of Long Island, New York. Natural Hazards. 60. 10.1007/s11069-011-0046-8.

Smit, Barry & Wandel, Johanna. (2006). Adaptation, Adaptive Capacity and Vulnerability. Global Environmental Change. 16. 282-292. 10.1016/j.gloenvcha.2006.03.008.

Sun, Ranhao & Chen, Li-Ding. (2012). How can urban bodies be designed for climate adaptation?. Landscape and Urban Planning. 105. 27–33. 10.1016/j.landurbplan.2011.11.018.

The Highs and Lows of Air Pressure. (2021). Retrieved April 19, 2021, from

https://scied.ucar.edu/learning-zone/how-weather-works/highs-and-lows-air-pressure#:~:text=. A low pressure system has,forming clouds and often precipitation.&text=Winds blow away from high pressure

URS. 2015. Erie County, New York Multijurisdictional Hazard Mitigation Plan Update

Vermette, S. 2017. Weathering Change in WNY: Climatic Trend Analysis (1965-2016). Report prepared for Designing to Live Sustainably (d2ls), Buffalo, NY. 14pp.

Vermette, S.J. and Bittner, C. 2010. Seasonal Temperature and Precipitation Forecasts Using a Climate Probability Approach: Buffalo, New York. Middle States Geographer, 43: 44-49

Walker, K. (2016). tigris: An R Package to Access and Work with Geographic Data from the US Census Bureau. *R J., 8*(2), 231.

Walker, K., Eberwein, K., & Herman, M. (2018). Tidycensus: Load us census boundary and attribute data as' tidyverse'and'sf'-ready data frames. *R package version 0.9, 6*.

Weil, Raymond & Brady, Nyle. (2017). The Nature and Properties of Soils. 15th edition.

Wells, M. (2012). Resilience in older adults living in rural, suburban, and urban areas. Online Journal of Rural Nursing and Health Care, 10(2), 45-54.

WBEN. 2021. Project cnealup: Thousands lose power as fierce wind rolls through WNY. https://www.audacy.com/wben/news/weather/thousands-lose-power-as-fierce-wind-rolls-through-wny. Accessed 5/1/2021

WGRZ. 2020. Flooding causes voluntary evacuations in Hamburg during Sunday storm. https://www.wgrz.com/article/weather/storms/parts-of-buffalo-experiencing-flooding-during-sunday-storm/71-b7a35a0d-3fd4-4290-bc1c-8f233adc3b8a. Accessed 12/9/2020.

Wilson, John & Gallant, John. (2000). Digital Terrain Analysis in Terrain Analysis: Principles and Applications.

Wormser, Gary & McKenna, Donna & Piedmonte, Nicholas & Vinci, Vanessa & Egizi, Andrea & Backenson, Bryon & Falco, Richard. (2019). First Recognized Human Bite in the United States by the Asian Longhorned Tick, Haemaphysalis longicornis. Clinical infectious diseases : an official publication of the Infectious Diseases Society of America. 70. 10.1093/cid/ciz449.

# Adaptive Capacity Assessment

Part III of Climate Vulnerability Assessment for Erie County

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# Contents

# Introduction

The Erie County Climate Vulnerability Assessment (CVA) was conducted from 2019 to 2022 with funding from New York State's Climate Smart Communities Program by the Erie County Department of Environment & Planning in collaboration with a research team at the University at Buffalo. This assessment was initiated to identify and analyze the climate change-related hazards that are of particular concern to Erie County and the County's jurisdictional responsibilities. The County manages an impressive portfolio of physical infrastructure (roads, bridges, water treatment facilities, buildings, vehicles, etc.); human systems (emergency management, social and health services, support for vulnerable populations, etc.); and natural systems (parks, beaches, forests, etc.). These and other systems/services may be impacted by the hazards that a changing climate may bring, and it is critical that an assessment is conducted so that the County may proactively gauge the current programmatic efforts in place to address these hazards, as well as identify gaps in effort. The CVA has three phases: 1) identifying climate hazards, 2) analyzing sensitivity to key hazards, and 3) assessing adaptive capacity of the County to address hazards. Here we summarize each phase for context before focusing on the results of the Adaptive Capacity Assessment, which is the primary focus of this report.

The first phase of the CVA was to better understand the key climate hazards facing the region, according to the priorities and obligations of Erie County. This was completed by reviewing relevant literature on the topic as well as Erie County's and other governmental reports on climate change and mitigation efforts. An additional tool, the PEOPLES Resilience Framework, was also employed to provide a holistic lens in identifying the potential impacts of each hazard across different County systems (Renschler et al, 2010). There were four key climate hazards identified in the *Climate Hazards Summary Report* including temperature, precipitation, biological threats, wind, as well as mobility/accessibility related to the above threats. These identified threats are the focus of the remaining aspects of the CVA.

The second part of the CVA was to conduct a sensitivity analysis of the County to understand the degree to which the County is affected by its exposure to these identified climate risks. The *Sensitivity Analysis Report* was primarily based on the use of geographic information systems (GIS) to spatially analyze data related to socioeconomics of Erie County, the environmental landscape, and the existing built infrastructure in the context of the climate hazards outlined above. The analysis identified regions of the County that may be differentially sensitive to extreme heat; localized on-site flooding as well as off-site transport of runoff from precipitation events; biological threats such as vector-borne diseases, harmful algal blooms, and invasive species; impacts from wind related to thunderstorms, nor'easters, and the interaction between wind and invasive forest pests; and how all of these threats relate to a County residents' ability to access critical services in times of emergency. The report provides an initial spatial assessment to inform future County resilience and emergency planning efforts. This report makes some references to the sensitivity analysis, which provided a starting point for discussions with County departments as well as guidance for potential mitigation measures to come for the last phase of the project.

In this third and final phase of the CVA, the adaptive capacity of Erie County is evaluated in the context of the climate-related hazards identified in the first phase, and the results of the sensitivity analysis completed in the second phase. **Adaptive capacity refers to the ability of the County to adapt or adjust to climate hazards and risks.** This is an important component of the CVA process, providing a qualitative assessment of where the County is in terms of being prepared for increasing climate-related risks.

Capacities are interpreted in the context of the four phases of emergency management: *mitigation, preparation, response,* and *recovery* (FEMA, 2021). In this context, *mitigation* can be thought of as the actions that are undertaken to remove the risk that the climate hazards in question pose to Erie County. While it is generally not possible to remove all risk, proactive measures can substantially reduce the potential for loss of life/personal injury or damage to property. These measures can also utilize limited resources more efficiently and save money in the process. *Preparation* refers to developing the capacity of Erie County and allied organizations to address an ongoing emergency as well as the aftermath or damage from that emergency. This can be accomplished via planning; training staff or increasing staff; ascertaining what resources are required, where they will be sourced, and how they will be purchased; and identifying what Erie County infrastructure/buildings will be needed in the process. The *response* phase addresses an ongoing emergency. These efforts work to reduce loss of life/personal injury and damage to property that is taking place in real time and include emergency response, restoration of the infrastructure that is critical to life-saving measures (electricity, transportation etc.), and provision of the services that are necessary to accomplish this, such as policing and the departments relevant to restoration of critical infrastructure. After response has taken place post-emergency, *recovery* is the next step. This phase of emergency management is critical, as it entails reconstruction efforts that are essential to returning to normal life, or ideally enhancing quality of life after an emergency. Everything from economic development, resurfacing roads, and financial support to provide resources to impacted communities is included in this phase. It should also be noted that *mitigation* and *preparation* are considered “pre-event” actions, whereas *response* and *recovery* are post-event actions. Next, we summarize our methods for assessing the Adaptive Capacity of Erie County.

## Methods

To conduct an adaptive capacity assessment, representatives from relevant Erie County departments were interviewed and asked to respond to questions about current practices and planning related to the climate sensitivities identified in the Sensitivity Analysis Report. Each interview was conducted virtually (during the COVID-19 pandemic) and most lasted about an hour. These sessions often included several County representatives at once, as appropriate based on overlapping responsibilities. For example, we met with representatives from the health department at the same time we spoke with social and emergency services, given their overlapping efforts to address health-related issues across the County. Each meeting was also attended by more than one member of the UB research team. Each meeting was recorded and meeting notes were shared and reviewed with County representatives. Table 1 outlines the

specific Erie County departments, units and divisions that were interviewed, as well as the date of the meeting, and finally the County system(s) of focus in each meeting.

Table 1. Summary of Interviews for Assessing Adaptive Capacity

| Department | Office/Division | Date of Meeting | Focal System(s) |
|---|---|---|---|
| Environment and Planning | Geographic Information Systems | Several meetings throughout Project | All Systems |
| Environment and Planning | Watershed Management | Several meetings throughout Project | Natural Systems |
| Environment and Planning | Stormwater Management | Several meetings throughout Project | Physical Infrastructure; Natural Systems |
| City of Buffalo | Buffalo Sewer Authority | April 14, 2021 | Physical Infrastructure |
| Environment and Planning | Sewerage Management | April 21, 2021 | Physical Infrastructure |
| Parks, Recreation and Forestry | | April 28, 2021 | Natural Systems |
| Homeland Security and Emergency Services | | June 30, 2021 | Human Systems; Emergency Services |
| Health | Environmental Health | June 30, 2021 | Human Systems |
| Social Services | | July 6, 2021 | Human Systems; Emergency Services |
| Senior Services | | July 6, 2021 | Human Systems; Emergency Services |
| Public Works | | September 21, 2021 | Physical Infrastructure |

The CVA team also spoke with other governmental/steering entities such the Erie County Climate Change Task Force (C3TF) as well as consultants that are working on similar projects around the region. These efforts were made to ensure our assessment was informed by the internal stakeholders at Erie County, external stakeholders such as the Buffalo Sewer Authority (BSA) and C3TF, and other expert practitioners in the field.

The results of the *adaptive capacity* assessment are first provided in the form of narratives from each interview session, including information related to each key climate hazard: extreme heat, flooding, wind, biological threats as well as mobility and accessibility issues related to each. The

narratives are organized based on the department/system of focus as outlined in Table 1. These systems include Physical Infrastructure (i.e. sewers, highways and roads, buildings etc.); Human Systems (i.e. Erie County employees and the vulnerable populations that Erie County serves); Natural systems (i.e. parks, beaches, and forestland); and Emergency Services (i.e. firefighters, police, public health emergencies). Each of these systems are evaluated below through the lens of Erie County's jurisdictional responsibilities. This evaluation is summarized in **Table 2**, where each Erie County Department is cross-referenced with the major issues that climate change will bring to their specific department. Alongside that, these issues are outlined in regard to the existing adaptive capacity of that department and categorized according to the four phases on emergency management discussed previously, specifically in reference to the issues that had been discussed in departmental interviews. Concluding remarks on this analysis are included at the end of the report.

# Results: Physical Infrastructure Systems

To assess the adaptive capacity of Erie County's physical infrastructure systems to the impacts of climate change, the Erie County Division of Sewerage Management, Buffalo Sewer Authority, and Erie County Department of Public Works were interviewed. The information present below represents the collection and dissemination of the content of these interviews.

## Physical Infrastructure and Changing Temperature

### Sewers

The Erie County Division of Sewerage Management (DSM) is impacted by fluctuations in temperature, such as those wrought by the impacts of climate change. Mechanical weathering, a physical process that includes freeze/thaw action, may be exacerbated by a potential increase in the number of winter warmup events that speed up the rate of mechanical weathering and thus an increase in the decomposition rate of the built environment that DSM depends on for treating wastewater. While not currently a major issue, future heat waves and drought-related conditions may cause sewer systems to be too dry, which DSM notes can result in settling of bacterial loads and septic conditions that may present a public health concern. The Buffalo Sewer Authority also related a similar concern regarding hot conditions and a low-flow conditions in sewers that fail to remove wastes.

### Buildings

The Erie County Department of Public Works (DPW) is also impacted by fluctuations in temperature – particularly when it comes to the design, operation, and improvements on County-owned buildings. These buildings must have building shell systems, mechanical systems, and climate controls to ensure safe and comfortable working conditions to the County employees and visitors within. Energy performance contracts are in place at this time to improve performance and resilience for existing structures. This not only provides for better use of resources and reduced costs, but also ensures that heating and cooling will continue during extreme temperature events. These type of weatherization, mechanical, and control retrofits are anticipated to have relatively quick financial payback to the County as well as reduce the amount of greenhouse gas emitted by energy consumption in County buildings, helping address climate mitigation goals.  Backup power generation is also an important consideration

for buildings, as the utility grid is vulnerable to disruption during heat events. Most backup generation systems in county buildings are not sized to power space cooling systems.

### Highways/Roads

Operations related to highways and roads at DPW are less impacted by temperature extremes, and in some cases, there are existing mitigation strategies in place to account for extreme heat. For example, paving County roadways is already a heat-intensive process. The raw asphalt itself can be several hundred degrees during application to the roadway. Because this is already an extreme condition to put County employees in, maintenance projects are scheduled to avoid both the hottest parts of the year and the hottest times of the day whenever possible. Employees are also encouraged to take frequent breaks and drink plenty of water while working in extreme conditions. Erie County roads are designed using similar design and maintenance standards used in southern states of the U.S., where climates are warmer. Therefore, the materials and methods used are engineered to be able to withstand both increases in average temperatures expected in the region as well as more frequent heat waves. Climate change may increase the need for road repair because anticipated increased number of freeze and thaw cycles is damaging to roadways, and as hotter temperatures reduce the integrity and lifespan of asphalt over time.

## Physical Infrastructure and Changing Precipitation

### Sewers

Excess precipitation has the potential to flood low lying areas, and many DSM facilities are located in these areas. Designed to aid in venting sewer systems, manhole covers are also susceptible to over-topping. This allows stormwater to enter sanitary sewers, a potential hazard if that water overloads the system, or brings in sediments that can clog or back up the system. Interviews with BSA also noted the influx of storm-related sediments as a potential clogging agent for sewer systems. The decline in the City of Buffalo's population over recent decades has allowed for real-time control projects that are able to store stormwater in unused sewer lines. In this regard, in some areas of the Buffalo, BSA appears well-equipped to handle heavy rain events. Other areas of the city currently experience sewer backups during rain events, and this may be exacerbated by climate change. An influx of population to the region, including because of climate migration from more highly impacted areas, could compound the stress on sewer systems from increased rain events.

Another potential issue is flood events at or near a wastewater treatment facility that reduces the functionality of that facility or cause difficulties or the inability of staff to reach that site. Responses to these types of situations are likely reactive in nature and may require more strategic or proactive considerations if extreme precipitation events become more frequent and/or severe.

### Buildings

Other than ensuring that building's parking areas and sidewalks etc. were cleared of excess snow and ice, changing precipitation had a minor impact on the buildings that DPW manages, according to departmental interviews.

### Highways/Roads

Specific to County bridges, the final design of a bridge is overseen by New York State and FEMA. All Erie County bridges are built according to these standards. Bridges are higher than the FEMA designated "100-year flood" at a minimum, whatever that threshold may be for a particular stream or waterbody. Given the potential increases in heavy precipitation events, the 100-year flood standard should be evaluated. Culverts may be more impacted by floodwater than are bridges. This is dependent on the size of the culvert. However, roads that are in FEMA Special Flood Hazard Areas (SFHA) are engineered differently with the potential for flooding in mind. According to DPW, their greatest concern in terms of precipitation is not necessarily the potential for increased flooding, but greater volumes of snow. Removal of snow from roadways is essential for the operation of the County and the people the County serves, and this is a major priority. Increased cold weather precipitation may also cause increased road salt use, and salt impacts on infrastructure and surrounding ecosystems may be increased.

## Physical Infrastructure and Changing Biological Threats

### Sewers

While DSM doesn't often consider issues such as vector-borne diseases as overly relevant to their operations, there may be other causes for concern when considering climate change-related biological threats and the built sewerage system. One example can be found in the potential for the breakdown of the biological interactions that aid in effective treatment of wastewater. As DSM noted in the interview process, generally warmer temperatures can enhance biological action to treat wastewater but there is a threshold where reaction catalysts like temperature begin to impede such interactions. Extreme heat events of the future may make treatment of water problematic. Another example is the potential for septic conditions in sewers during low-rain/high-heat scenarios. Combined sewer overflows (CSOs) can discharge wastewater during heavy rains, ejecting these septic effluents into the environment. On a positive note, DSM notes that wastewater treatment plant discharge limitations have been utilized in the past to address negative impacts of nutrient overload in aquatic systems that lead to blooms of cyanobacteria in Lake Erie.

### Buildings

Interviews with DPW did not point to any concerns regarding biological threats in buildings. However, it is true that allergens and other air quality issues may be exacerbated from climate-related impacts. Energy performance retrofits as well as newly engineered buildings may aid in mitigating this potential issue through new/improved heating and cooling systems with more modern filtering capacity. Recent improvements to air filtration in some buildings may also reduce air quality impacts.

### Highways/Roads

Invasive species are the major concern to DPW in terms of biological threats. As DPW controls and manages the right-of-ways (ROWs) in Erie County, they must address infestations of invasive species. One example is giant hogweed (*Heracleum mantegazzianum*). This species grows to an immense size, and through skin contact can cause severe photo-dermatitis (i.e., rash) and ulcerating blisters. Future invaders may have an adaptive edge as the climate changes to suit their ecological needs as compared to the native species currently adapted to the existing conditions, and ROWs are natural corridors of invasion putting DPW staff at the front edge of these pathways. Increases prevalence of ticks and tick-borne diseases are also increasingly a threat to DPW staff.

## Physical Infrastructure and Wind

### Sewers

The biggest concern that DSM had in relation to climate-related wind impacts regarded the reliability of the electrical grid. The entirety of DSM's network of treatment facilities are reliant on the grid for operation. All of the systems have backup generators and spare parts in storage, so are well-equipped for short-term losses of power, but may be vulnerable to longer duration outages. An additional concern regarding wind involved the proximity of certain systems to the shore of Lake Erie. Some facilities are at risk of impacts from seiche events that are driven by winds driving Lake Erie waters east towards Erie County. The Buffalo Sewer Authority also noted seiche events as a cause for concern for their systems, as well as the potential for sewer backups into basements.

### Buildings

Based on the experience of County staff, it was explained that taller buildings, such as those found in downtown Buffalo and other urban areas, are more exposed to wind than other areas where DPW manages. The movement of intense wind around these buildings may create a wind tunnel effect and enhancing the wind speed and potential for damage. In general, man-made structures, especially high-rise buildings create obstacles for wind movement and can result in complex wind effects including high wind speeds and turbulence (cite wind article). There is also an interaction between these wind tunnels and temperature. The wind chill during extreme cold events may be more severe in a situation like this, making warming centers potentially more important in areas with more extreme winds. Wind can also disrupt electric power to buildings, making backup power generation systems more important.

### Highways/Roads

Department of Public Works employees did not consider wind to be of major concern to their operations. Downed trees due to wind may be an issue to address, but they are generally singular in nature, are mitigated by rights of way cleared of trees on many roadways, and do not pose a risk of overwhelming DPW employees.

## Physical Infrastructure and Emergency Services

### Sewers

While neither entity that was interviewed regarding climate change and sewer systems (i.e. DSM and BSA) specifically mentioned any concerns regarding sewer systems and access to emergency services, there are some potential issues worth noting. In a flood emergency, many homes may experience sewer backups into their basements. Concurrent with that, access to emergency services may be limited due to impassable roadways. Emergency responders may be unable to reach those in need, and those in need may be unable to leave their flooded homes due to the same conditions. Staff access to critical facilities may also be impaired during flooding events, as discussed in the precipitation section above.

### Buildings

Many of the warming and cooling centers in Erie County are operated out of County-owned libraries. As noted above, ensuring these buildings are kept in operation, and providing a climate-controlled environment during times of extreme temperatures and utility disruption, is a priority. This includes during snowfall events, and ensuring that these buildings are accessible during times of lake-effect snow. Backup power generation systems for heating and cooling centers need to be sized to power climate control systems during utility disruptions.

### Highways/Roads

County-owned roads will be used to travel to reach emergency services. As with County-owned buildings, ensuring that these roads are open and navigable is the highest priority to DPW. The measures noted above, design, engineering, operation, retrofitting and maintenance etc., are all designed to ensure that this is the case.

## Results: Human Systems

To assess the adaptive capacity of Erie County's human systems to the impacts of climate change, the Erie County Department of Homeland Security and Emergency Services, Health, Social Services, and Senior Services were interviewed. Other Erie County Departments, such as Parks, Recreation and Forestry, also had relevant feedback to include in this section. The information present below represents the collection and dissemination of the content of these interviews.

### Human Systems and Changing Temperature

#### Employees

The majority of Erie County employees tend to work in a climate-controlled office setting, so as long as buildings systems can maintain adequate climate control, extremes in hot and cold temperatures don't have a major impact on this segment of Erie County's purview over human systems under typical conditions. However, there are certain departments and positions that are primarily working outdoors (i.e. Public Works and Parks, Recreation and Forestry) as well as those that are traveling from site to site as part of their position (i.e. Sanitarians with the Health Department). During Interviews with Erie County personnel, it was noted that staff are required to wear appropriate field gear (for weather conditions as well as to prevent insect bites) and take frequent breaks to either cool down or warm up in inclement weather. As extreme temperatures become more common, the County may need to update protective gear and protocols.

### Vulnerable Populations

Vulnerable populations are particularly sensitive to the impacts of temperature extremes. Erie County utilizes its public libraries to offer cooling centers in the summer and warming centers during the winter. These shelters are effective at aiding those that can reach them, however there may be issues with accessibility (see section below). Additionally, Erie County staff noted that reliability of the power grid was a major issue during extreme heat events. From discussion with Library and County staff, at least

some libraries lack backup power generation adequate to power climate control systems during utility disruption. During a power outage, these centers would likely not be functional as emergency shelters for the most vulnerable.

Erie County's Social Services and Senior Services Departments are frequently contacted during extreme cold events, but have not yet had many calls during extreme heat events, which may become more frequent in the future. These departments operate programmatic efforts to address issues with heating and cooling equity in vulnerable populations through the Home Energy Assistance Program (HEAP). Home assistance cooling programs are available to eligible applicants that can aid in purchasing and installing air conditioning units, and emergency assistance is available to aid in covering electrical utility costs for heating. These programs are effective in assisting some vulnerable individuals, yet there are improvements that could be made. Funding was highlighted as a major issue. There are not enough funds budgeted to meet demand, and thus there will be vulnerable individuals that may be negatively impacted. Retail availability of air conditioning units is also an issue, particularly during an era of COVID-19 supply shortages. Many buildings are either not set up for certain cooling units, or the owners of rental properties outright prohibit install of such units by weatherization programs, something that Erie County has encountered as an obstacle to aiding those that need cooling units in their homes.

Social Services and Senior Services Departments stressed a need for a more proactive approach to provision of home cooling resources, beyond what is currently available through HEAP. Although additional assistance can be found in programs at the state level through the New York State Energy Research and Development Authority (NYSERDA). NYSERDA provides programs and funding to conduct home energy audits, assist in financing, and provide direct assistance in home weatherization, but existing program capacity is not adequate to meet local needs. The County has embarked on the NYSERDA-funded Erie County Low Income Program for Sustainable Energy (ECLIPSE), and this program will evaluate the range of energy services available to low- and moderate-income residents, and develop programmatic interventions working with NYSERDA, HEAP and other programs. An important consideration for ECLIPSE will be how these programs can make the built environment more protective for vulnerable residents as impacts from climate change increase.

## Human Systems and Changing Precipitation

### Employees

As noted above, Erie County employees are predominately indoor and office-based. However, the same departments outlined above have staff that may experience impacts from climate-related changes in precipitation. This includes both extremes in rainfall as well as snow and other forms of precipitation. Extreme precipitation was not noted as a particular concern for Erie County staff during interviews. However, all employees of the County should be taking care to stay safe and act accordingly during lake-effect snowfall or extreme rainfall events. This includes those working outside in these conditions as well as those driving in inclement weather. Recent experiences during COVID-19 that enabled many County staff to work remotely may provide additional adaptive capacity for some County employees to work remotely during extreme snow or rainfall events.

### Vulnerable Populations

Erie County's Department of Homeland Security and Emergency Services coordinates with fire departments and other first responders to aid vulnerable populations during times of flooding, but does not have a program in place to track and monitor flood-prone areas that are outside of federally-listed flood zones. Rural areas in the County are potentially at risk of floods and subsequent contamination of drinking water wells from hazardous materials, flooded basements, agricultural leaching into drinking water supplies, and contamination from septic systems. Historical floods, such as the flooding of Gowanda that destroyed Gowanda's wastewater treatment plant in Cattaraugus County, may be viewed as an example of the types of extreme impacts we may see more frequently in certain communities in Erie County. For example, the municipality of Collins has two drinking water supply wells in close proximity to Clear Creek, which may present an issue should that creek flood. In other communities, there are measures in place to mitigate these risks. These measures include construction of facilities so that the footprint or sand filter portion of the system is situated above flood stage, as seen in facilities along Tonawanda Creek. Additionally, check valves at facilities prevent inflow during flooding and septic systems are prohibited from being sited in flood areas.

Seniors are of particular concern to the County regarding vulnerability to floods, and seniors make up a major component of the calls that Senior Services received regarding flooding. Seniors are most likely to own their own homes, making them financially responsible for flood and water damages associated with extreme precipitation events. Unfortunately, many homeowners drop their mortgage-mandated flood insurance upon paying off their loans, making them additionally vulnerable to flood-related impacts. The County does not currently have specific programs in place to address this particular vulnerability and ensure that seniors have adequate flood insurance coverage, but Senior Services addresses the aftermath of seniors who experience a flood and then a subsequent economic hardship. Programmatic efforts that specifically target this vulnerability to either ensure residents have insurance or provide funding for flood relief would enhance the County's adaptive capacity

## Human Systems and Changing Biological Threats

### Employees

Biological threats analyzed in the CVA process included vector-borne diseases, invasive species, and harmful algal blooms. Of those threats, vector-borne disease and invasive species currently pose risks to Erie County employees, mainly to the staff of the departments outlined above (Public Works and Parks, Recreation and Forestry as well as those that are traveling from site to site as part of their position (i.e. Sanitarians with the Health Department). Despite the Department of Health's comments on rising numbers of Lyme Disease cases in Erie County in general, Parks, Recreation and Forestry had not noted an increases in reported instances of tick bites and/or Lyme Disease among employees or visitors to County parks. This may be partly due to the preventative measures that this Department takes to avoid tick bites (i.e. long pants and sleeves, use of insect repellant etc.

Invasive species pose less of a threat to human health, but it should be noted that there are invasive tick species associated with vector borne disease, and there are invasive plant species that can result in severe injury (i.e. giant hogweed (*Heracleum mantegazzianum*)). Currently, it does not appear that climate change is linked to an increase in the spread of giant hogweed, but it is an example of a biological threat that Erie County employees may face in the day-to-day operation of their roles. There

may be new invasive species entering the region in the future, so it behooves Erie County to survey for such potential invasions and provide information and training to their employees so any potential for health impacts can be avoided. The County may also want to display educational signage in parks regarding these threats.

### Vulnerable Populations

The greatest biological threat to vulnerable populations is vector-borne disease, specifically Lyme Disease. Cases of Lyme Disease have increased consistently over the past decade. While many recover from early antibiotic treatment, the disease can result in long-term impacts to an infected person's joints and cardiac as well as nervous system. Currently, Erie County is considered a "Sentinel County" by the New York State Department of Health. This means that Lyme Disease is now endemic. These case numbers were referred to as "the tip of the iceberg" by Erie County staff, as many cases are treated by medical professionals based on symptoms, not a confirmed test. Only confirmed tests for the disease are tracked by state regulatory authorities. This leaves many cases that are treated left unverified. Increased cases in pediatric instances have also been observed, with many pediatricians noting that these cases are occurring earlier in the season than they had in previous years. Other biological threats, such as bacterial contamination and harmful algal blooms, are handled through closure of affected areas, generally beaches and swimming areas in the parks that Erie County manages. A new Lyme disease vaccine is expected to be available within a few years, pending late stage trials, and once available the County may want to develop public health programing to support awareness and vaccine uptake.

Social and Senior Services Departments noted that their sectors are often relied upon to address the impacts of biological threats such as vector-borne disease. Where other Departments attempt to track outbreaks and address the issue from a public health or emergency services perspective, these departments often take on the longer-lasting impacts. These measures include addressing child care and access to housing. For example, during the COVID-19 crisis, Social Services dealt with a sudden increase in the need for Erie County residents to have access to child care while they were working from home and their children were not in school. Those individuals that experienced long-term loss of employment due to the pandemic were (and are) at risk of losing their housing due to an inability to pay their rent or mortgage. Another example can be found in physical fitness. These Departments also develop programmatic efforts to encourage positive measures to improve personal wellbeing through diet and exercise programs. These are interdepartmental efforts that need to be expanded to provide better services to vulnerable populations that have experienced decades of inequity resulting in chronic health problems that may exacerbate the impact of climate-related biological threats.

## Human Systems and Wind

### Employees

Erie County employees that are addressing the impact and damage from wind events (seiche events and damage related to windstorms, thunderstorms, and tornadoes) may be at risk of injury during the initial response as well as during cleanup and reconstruction. Enhanced adaptive capacity may be found in planning mitigative and response efforts, and careful execution of recovery efforts to ensure that all relevant precautions are taken to keep Erie County employees safe during these events.

### Vulnerable Populations

Extreme wind can obviously damage property and result in injury or death. For those vulnerable segments of the population, this damage can be more severe (such as in lower quality housing units). Additionally, as noted above, seniors are more likely to own their homes – placing them at greater financial vulnerability to repair wind-related damage. A synergistic interaction between biological threats not necessarily associated with climate change, and climate change-related wind storms can be found in the emerald ash borer (*Agrilus planipennis*) and its impacts on ash trees (*Fraxinus* species). Emerald ash borers are an invasive beetle whose larvae kill ash trees. As these trees die, they become more susceptible to wind damage. This susceptibility is enhanced when winds are high, or when they are coming from a direction that a tree has not encountered frequently over the life of the tree (in other words, a tree's roots may be better buttressed on the side of the tree where the prevailing winds are most common). This issue has costs for vulnerable populations in two main ways. Proactive removal of Emerald ash borer-afflicted trees is costly, and repairing damage to one's home is also potentially expensive. To promote the County's adaptive capacity in this frame of reference, strategic planning and preparation for wind damage related to climate change is crucial.

## Human Systems and Emergency Services

### Employees

Access to emergency services for Erie County employees was not highlighted as a concern in any of the interviews with departmental staff.

### Vulnerable Populations

With the exception of earthquakes and other hard-to-predict events, Homeland Security and Emergency Services generally has several days to prepare for a given emergency event such as a heat wave or extreme precipitation forecast. Additionally, they and Senior Services have contact lists they utilize to work to notify vulnerable residents of the County that an impending emergency may be taking place. However, County staff discussed that these lists may not be complete and/or may need to be updated more frequently. Social Services and Senior Services noted mobility and accessibility to emergency services as dire issues. Investment in roads, bicycle infrastructure, sidewalks and street trees (to create protective routes to walk to cooling centers and green spaces) were specifically noted. Many sidewalks are failing and in need of repair or replacement. This issue can make it difficult for mobility-limited residents to traverse, impeding their access to emergency services or cooling/warming shelters. This is particularly true during extreme snowfall events – when the issue is compounded as the falling snow obscures cracked and heaved sidewalks. Access to transportation is also an issue for seniors, as well as those residing in rural communities. A lack of uniformity between towns and other municipalities in how senior services are funded and coordinated makes emergency response difficult. All of this is yet further compounded when considering these problems through the lens of racial disparities that continue to plague many communities in Erie County. Mobility and access is deeply entwined with racial justice, and therefore climate justice overall.

# Results: Natural Systems

To assess the adaptive capacity of Erie County's natural systems to the impacts of climate change, the Erie County Department of Parks, Recreation and Forestry (Parks) as well as Environment and Planning were interviewed. Other Erie County Departments and staff, such as the Department of Health, Sewerage Management (DSM), and Geographic Information Systems (GIS) also had relevant data and feedback to include in this section. One of the important takeaways from the interviews with Erie County staff was a statement from Parks that they have had to design and plan for events and hazards they never had to consider in the past. The information present below represents the collection and dissemination of the content of these interviews.

## Natural Systems and Changing Temperature

### Parks and Beaches

Extreme heat events are not a large concern to Parks in regards to parks and beaches that the County manages. The Department is conscious of the risks that heat waves pose to Erie County employees and those recreating in these areas. However, they felt that this issue was addressed through careful examination of on-site conditions and proactive measures to ensure that the health of employees was protected. This includes encouraging those out in these conditions to take frequent breaks and drink plenty of water, and to continually assess one's personal health while working.

### Forests

Generally, the trees living in the region are adapted to withstanding periods of extreme heat. The changing climate may elevate these periods to levels that are hard for the trees in Erie County forests to withstand, creating issues in forest health. To account for this, Parks has developed and implemented a tree planting policy. This policy requires greater care and detail when planting trees on Erie County lands. In addition, the policy advocates for planting of drought-tolerant and hardy species, so that in the future the County's forests may be more resilient to the impacts of a changing climate.

## Natural Systems and Changing Precipitation

### Parks and Beaches

The changes in precipitation that are related to a changing climate may impact the natural systems that Erie County manages in a number of ways. Extreme precipitation can lead to flooding, erosion and sedimentation; in the winter months the interaction of changing temperature, precipitation and wind can exacerbate the level at which ice jams develop; and the combination of wind and precipitation can additionally exacerbate seiche events. In interviews with Parks, staff noted that while many of Erie County parks are inland and largely free of flooding, certain areas (i.e. Ellicott Creek Park and Bowen Park along Cayuga Creek) do experience floods, that could become worse in the future.

Erosion and sedimentation are an issue in several County parks. For example, the Bailey Peninsula, Higgins Park and Seneca Bluff all experience shoreline impacts related to debris that can scour the shore while leaving debris on the park area that needs to be removed. Ellicott Creek Park's island has been experiencing shoreline erosion, something that needs regular maintenance and repair. While not an Erie County property, Parks relayed ongoing issues in the Town of Evans where the marina at Sturgeon Point

has lost functionality due to sedimentation in the marina basin that prevents many boats from being able to access this site.

### Forests

Erie County's forests face similar issues to their parks and beaches when changes in precipitation are concerned. Extreme rain events that lead to erosion on steep slopes can result in downed trees. To protect these forested lands, it is important to not only consider species diversity when planting, but also to carefully manage these forests and consider the landscape characteristics when planning a timber harvest or other management action that will remove a tree.

## Natural Systems and Changing Biological Threats

### Parks and Beaches

There are three key threats outlined in this analysis when climate change and biological hazards are considered in relation to Erie County parks and beaches. These include vector-borne diseases, invasive species, and harmful algal blooms. During the interviews with Parks, they conveyed that while vector-borne diseases like Lyme Disease are a concern, there are preventative measures in place (for example, long pants are required for those working in outdoor settings) and to-date they are not aware of any Erie County employee that has had a tick bite from the black-legged tick that is the vector for Lyme Disease.

In regards to harmful algal blooms, Parks does not consider this to be a major concern. Beach closures are more associated with bacterial growth associated with heavy storms and runoff. This is not an issue that Parks is focused on.

### Forests

Invasive species are a larger concern for Erie County's forests. This applies to both forests in parks and forests that the County manages. The Emerald ash borer, a species of beetle from Asia, has invaded much of Western New York, causing senescence of many ash trees, with more damage to come in future years. The hemlock woolly adelgid (HWA), a small aphid-like insect from Asia, has been slowly spreading in New York State. Where previously the extreme cold during winter months here apparently kept this invasive insect population in check, increases in temperate during this period may allow an explosion in their populations. While Parks admits that much more needs to be done to manage invasive species in the County-owned lands, there has been progress in planning for future changes in the biological frontiers of Erie County. One such example is the development, mentioned above, of a tree planting policy that considers climate change, including an emphasis on planting native trees, where possible, that are hardy and resistant to wind, heat and drought.

## Natural Systems and Wind

### Parks and Beaches

Wind impacts Erie County parks and beaches primarily through seiche events. Seiche events take place when winds drive Lake Erie waters from west to east, creating high lake levels and increasing wave-action. These wind-related events cause greater erosion along the shores of Lake Erie than normal,

resulting in damage to property and even loss of property as wave action removes beach material. Recent seiche events have resulted in multiple instances where the lake was over 10 feet above normal. The increase in seiches has forced Parks to design and plan for erosion and other destructive seiche-related events that damage the County's lakeshore parks. This includes costs for regular maintenance, as practices that in the past were sufficient to maintain the regular loss of beach associated with typical wave action are no longer adequate.

### Forests

The interaction of wind, biological threats, precipitation and temperature collectively create what appears to be the greatest concern of Parks in managing Erie County-owned lands. Forest health impacts from invasive species like EAB reduces the tolerance of ash trees (for example) to drought and wind throw. During the sensitivity analysis portion of this CVA process, it was found that there are changes taking place in the strength and intensity of prevailing winds, as well as an increase in the frequency of nor'easter storms. Trees tend to buttress their roots more heavily on the side of the tree that receives the most intense winds, and changes in wind direction can result in windthrow and toppled trees. When a tree is further stressed or dying from an invasive (or even native) pest, this increases the likelihood that a tree will be blown over in such an event. During periods where the ground is frozen and thaws during winter months, and a wind storm develops, this issue is further exacerbated.

Based on this issue, Parks now needs to focus more heavily on removal of trees near structures and sensitive zones. These removals need to happen sooner and more frequently than in prior years. Suburban sprawl is another factor to consider. As homes are built closer and closer to park boundaries, the tolerance for unhealthy, weakened, or snag trees is reduced due to the risk of a tree falling on someone's home in these developments. This is particularly a concern near Como Lake Park, Chestnut Ridge Park, and Emory Park.

The Parks representatives conveyed that the issues above have become so problematic, that they have had to include much greater expenses in their work plans and budgets. Also, for the first time, Parks has had to issue a capital budget request to bid out tree removal projects, indicating the financial burden this places on the Department. In the past, Parks would contract for a single tree-level removal but is now contracting with forestry companies to conduct stand-level projects.

## Natural Systems and Emergency Services

Although the topic of emergency services in relation to Erie County employees and County-managed lands did not come up in the interview  it is critical that this be considered when staff are responding to events at these sites that may put employees at risk. Those working in these areas in instances of high heat, extreme rain events, or responding to the impacts of climate-related hazards should have an emergency travel plan at hand to allow them to easily identify the nearest emergency room, cooling center, urgent care center or other care center in the event of an emergency. Also, during forecasted events, it may be necessary to pre-position County staff in preparation to more effectively respond to threats and hazards (and reduce likelihood that staff may not be able to reach and service areas during certain events like floods and snowstorms).

Those recreating or otherwise using the natural systems that Erie County manages should also be able to easily access emergency services in the event of a climate-related emergency or other extreme event that necessitates emergency services. As with County employees, emergency plans should be in place that aid these populations in finding a care center as appropriate.

## Results: Emergency Services Systems, Accessibility and Mobility

The sensitivity analysis conducted as part of the CVA process identified differential access to emergency services in Erie County. Emergency services are necessary when other systems fail. The analysis focused on access to emergency rooms and cooling centers. In this analysis, access to emergency rooms in event of an emergency is largely infeasible when one is attempting to access these sites via public transit or walking, as many vulnerable populations would be relying on as a mode of transportation. A similar analysis relating to cooling centers was also conducted. This analysis also found a disparity in access to cooling centers, however this disparity related to travel via public transit more than travel via walking. From these results, it is clear that while Erie County has capacity in this regard, the capacity is limited in terms of public transit, which is exacerbated in more rural parts of the County.

The Department of Homeland Security and Emergency Services has a well-developed capacity to respond to emergencies. Opportunities exist for more proactive steps that may reduce the scope of an emergency response after an extreme event. Additional care centers (i.e. shelters from extreme heat, cold, or precipitation) located in shopping centers, for example, could help to increase accessibility, and ride sharing or other transportation would increase mobility to these care centers. Provision of back-up generators adequate to handle cooling systems to existing care centers, such as those found in the Erie County Public Library system, would also increase adaptive capacity in this way. Exploring renewable energy-based micro-grid energy systems that can provide service independently from the power grid during emergencies and reduce greenhouse gas emissions from energy consumption during non-emergencies, may be a good option for the County to explore.

## Summary of Results

Our key results from the above narratives are summarized in Table 2 below, where each type of threat is cross referenced with the qualitative adaptive capacity of each system. Blank spaces in the “Adaptive Capacity” column indicate where there may be opportunities to improve the capacity of Erie County to respond to climate-related impacts.

Table 2: Matrix of Departments, Climate-related Issues, and Adaptive Capacity. Capacities are listed in 4 major categories: Pre-event adaptive capacity: *mitigation* and *preparation,* and Post-event adaptive capacity: *response* and *recovery*. It should be noted that this is not a complete list, and is based on the direct departmental interviews that the CVA team had with Erie County staff and representatives. Please note that cells left blank under ‘Adaptive Capacity’ represent areas of opportunity for the County to potentially build more adaptive capacity in the future.

| **Temperature** | | |
|---|---|---|
| **Department** | **Issues** | **Adaptive Capacity** |

| | | |
|---|---|---|
| DEP Geographic Information Systems | Spatial and temporal patterns of temperature-related hazards and the vulnerable communities that are sensitive to extreme heat | *Preparation*: Assist in data provision, mapping |
| Sewerage Management | High temperatures cause increased mechanical weathering, and can result in dry sewers | |
| | Biological treatment may experience limited efficacy during extreme temperatures | |
| Parks, Recreation and Forestry | Employee health and safety in extreme conditions when traveling or working outdoors | *Mitigation*: Precautionary policies to ensure risk is minimized |
| Homeland Security & Emergency Services | Climate change is expected to increase variability in weather patterns, potentially resulting in greater duration, intensity, and frequency of extreme heat events | *Response:* Coordination with Erie County Library system to provide cooling centers and other forms of shelter during extreme events |
| Health | Extreme heat | *Preparation*: Public health bulletins warning the public of extreme events |
| | Extreme heat can result in increased atmospheric ozone, degrading air quality. This can be a health concern for some vulnerable communities | *Preparation*: Public health bulletins warning the public of extreme events |
| Social Services | Vulnerable communities lack access to cooling units for their homes, which may exacerbate health conditions during heat waves | *Mitigation:* HEAP provides air conditioners through programs that fund purchase and installation of cooling units. |
| Senior Services | Elderly residents of the county are particularly sensitive to heat-related impacts, while at the same time lack mobility. | *Preparation*: Senior alert programs via phone call and text message to increase awareness of potential issues related to extreme heat. |
| Public Works | Control of climate in County-owned buildings is necessary for health and wellbeing of employees, yet can be expensive and resource-intensive | *Preparation:* Energy performance contracts in place to improve efficiency and weatherization |
| | Paving roadways is hot in normal times, risk of heat-related issues with employees may increase | *Mitigation*: Projects are scheduled during the coolest part of the day and employees are encouraged to drink plenty of water and take frequent breaks. |
| | County-owned roadways are at risk of heat-related damage to roadways during extreme heat events | *Mitigation*: Roadways are engineered according to designs suitable for southern climates, |

| | | |
|---|---|---|
| | | making them resilient in the event of a heat wave. |
| **Precipitation** | | |
| **Department** | **Issues** | **Adaptive Capacity** |
| DEP Geographic Information Systems | Spatial and temporal patterns of temperature-related hazards and the vulnerable communities that are sensitive to this issue | *Preparation:* Assist in data provision, mapping |
| Sewerage Management | More frequent or intense precipitation events increases the likelihood of flooded sewers | *Response:* The City of Buffalo has capacity to store stormwater in un-used sewer pipes, reducing the potential for flood sewers. |
| | Influx of sediment/debris during heavy rains or floods may result in clogged systems | *Mitigation:* Installation of green infrastructure that reduces the amount of sediment influx |
| Parks, Recreation and Forestry | Flooding of County-owned land from excess rain or seiche events. This includes public parks and forests, as well as beaches | *Mitigation:* Engineered responses that are more resilient to flood damage |
| Homeland Security & Emergency Services | Flooding of homes and basements during heavy precipitation events | *Response:* Coordinate response with local fire departments |
| | Lack of tracking areas where localized and large-scale flooding frequently takes place | |
| Health | Drinking water quality may become impacted as pollutant-laden floodwater enters homes and/or well heads where drinking water is sourced | *Mitigation:* Engineering to protect some water supplies |
| Social Services | Flooding disproportionately impacts vulnerable communities, which may require support financially to recover | *Recovery:* Post-flood impact recovery |
| | | |
| Senior Services | | |
| | Seniors frequently cancel flood insurance when their home mortgages are paid off and they are no longer required to hold insurance | *Recovery:* Post-flood impact recovery |
| | Snowstorms may create barriers when accessing critical or emergency services. | |
| Public Works | Ensuring buildings and roadways are accessible during heavy snowfall events is a major priority | *Response:* Snow removal plans are detailed and well developed. |
| | Potential for flooding of bridges and roadways during heavy precipitation events or other flooding event | *Preparation:* Bridges are all designed to be higher than the FEMA-designated “100-year |

| | | |
|---|---|---|
| | | flood, and roadways in floodplains are all engineered to account for flooding when sited in floodplain areas. |
| **Biological Threats** | | |
| **Department** | **Issues** | **Adaptive Capacity** |
| DEP Geographic Information Systems | Spatial and temporal patterns of biological hazards and the vulnerable communities that are sensitive to this issue | *Preparation:* Assist in data provision, mapping |
| Sewerage Management | Droughts that may form due to extreme heat events can leave isolated pools in sewer systems. These pools can develop bacterial growths resulting in septic conditions in sewers. | |
| Parks, Recreation and Forestry | County employees that work outdoors may be exposed to vector-borne diseases from ticks and other vectors. | *Mitigation:* Precautionary policies to ensure risk is minimized for employees and visitors |
| | Invasive species proliferation in County-owned parks and forests diminishes the resilience of these landscapes to the impacts of climate change | |
| Homeland Security & Emergency Services | Transport and storage of hazardous materials may be impacted by a climate-related disaster, resulting in spills or other environmental release. | *Mitigation:* Planning efforts and regular updates to these plans (i.e. Multi-Jurisdictional Hazard Mitigation Plans) |
| Health | Increase in the prevalence and distribution of certain vector-borne diseases that is associated with changing habitat suitability | *Preparation:* Public health mandates and public service messaging |
| | Lack of tracking prevalence and distribution of vector-borne diseases that may be exacerbated by the impacts of climate change | |
| Social Services | Vector-borne diseases can lead to indirect issues such as evictions, loss of work, increased child care costs and other financial hardships for vulnerable communities. | *Recovery:* Assistance to vulnerable populations (i.e. SNAP benefits, child day care programs etc.) |
| Senior Services | Seniors are particularly vulnerable to biological threats. | *Mitigation:* Senior wellness programs to encourage seniors to get fit and stay healthy to proactively enhance wellbeing. |

| | | |
|---|---|---|
| Public Works | Climate change may result in instances of degraded air quality through increases in ozone and elevated levels of allergens. | *Mitigation*: Building retrofits of County-owned structures may improve the heating and cooling and associated air filtration systems |
| | Invasive species that can result in human-health impacts may be found on County-managed right-of-ways | |
| **Wind** | | |
| **Department** | **Issues** | **Adaptive Capacity** |
| DEP Geographic Information Systems | Spatial temporal patterns of wind-related hazards and the vulnerable communities that are sensitive to this issue | *Preparation:* Assist in data provision, mapping |
| Sewerage Management | Reliability of the electrical grid is a concern in the event of extreme winds that topple trees and sever connectivity | *Mitigation:* Back-up generators |
| | High winds off of Lake Erie can lead to seiche events that subsequently push water into effluent discharge systems, causing sewer backups | |
| Parks, Recreation and Forestry | Forest health is declining as invasive species weaken and kill trees. This issue combined with a windstorm, can cause hazard trees to topple. | *Mitigation:* Proactive removal of hazard trees |
| | Changes in prevailing winds can result in more frequent and intense nor'easter storms. This also places wind in directions that are opposite to a tree's natural strengths – increasing the odds of blow overs. | *Response:* Removal of fallen trees in Parks-owned areas and facilities. |
| Homeland Security & Emergency Services | Large-scale storms can create multiple areas of power outages, downed lines, trees and other unsafe conditions. | *Response:* Coordinate to restore safe conditions and critical services |
| Health | | |
| Social Services | Hazard trees are expensive to remove and present a danger to public safety. Wind-related tree fall presents a financial burden to the socioeconomically disadvantaged | |
| Senior Services | Seniors are more likely to own their home and live off of a fixed retirement income. As such, they may not be required to hold homeowner's | |

| | | |
|---|---|---|
| | insurance and would not be able to afford removal of hazard trees or recovery from a fallen tree on their home. | |
| Public Works | Trees on County-owned roads or properties may be knocked over by powerful winds | DPW has staff in place to address downed trees in these areas. |
| **Emergency Services, Accessibility and Mobility** | | |
| **Department** | **Issues** | **Adaptive Capacity** |
| DEP Geographic Information Systems | Geospatial data to analyze emergency services networks for mapping and analysis. | *Preparation:* Assist in data provision, mapping |
| Sewerage Management | Clogged and backed up sewer systems may coincide with flood emergencies. Addressing clogs and backups during and after a flood event may become problematic. | |
| Parks, Recreation and Forestry | Provision of emergency services to those working and recreating in County-owned parks and forests. | *Response:* respond to emergency service calls during an emergency event. |
| Homeland Security & Emergency Services | Proactive planning to reduce the severity and extent of an emergency. | *Preparation:* Hazard mitigation planning |
| | Emergency response that is highly coordinated and efficient so as to be as effective as possible. | *Response:* Coordination across the County of all relevant first responders during an emergency. |
| Health | Provision of clear and current directives and announcement so that the public is aware of the situation and the opportunities for help. | *Preparation:* Public service messaging |
| Social Services | Accessibility to services during and after emergency/extreme events (many can find transport to services, but lack access in their community) | |
| Senior Services | Mobility to services during and after emergency/extreme events (many have access to services, but as seniors lack mobility) | |
| Public Works | County-owned structures are used for various essential services to the people that the County serves, and associated roadways are critical to accessing these services | |

# Conclusion

This Adaptive Capacity Assessment found many existing capacities and much hard work being done by County departments and others to assure that our community is a safe place, and much of this will serve us well as we enter this period of increasing climate change. We also found some areas were the County will need to have a special focus or will need to increase capacities as the climate changes. This work should be considered an preliminary assessment, and we expect that the County's preparation for climate change will be ongoing topic for the foreseeable future, requiring future revisions to this assessment as climate hazards come into sharper focus. We are grateful and indebted to the many staff and community partners who met with us, responded to our surveys, and made information available for this report.

The Department-by-Department structure and funding mechanisms for Erie County creates a challenging position for the County to adapt to the changing climate. This position is made more complex when considering the diverse groups and populations that Erie County serves. Clearer roles on *types* of emergency services that County and partners respond to is an opportunity to potentially address these problems prior to an actual emergency. For example, not all departments have funding specifically to plan for or react to the impacts of climate change, and the staff in these departments may not have any specified role to work on climate-related issues. This is the case for the Department of Homeland Security and Emergency Services. This Department does an excellent job in planning for the response to an emergency event yet has nothing specified in the most recent budget that is related to considering, planning for, or responding to climate change-related emergencies. This issue is borne out in other departments. Another issue is funding. Funding is a serious constraint to some departments, which limits the ways in which the department is able to serve the communities they are responsible for. An example of this is found in the Departments of Social Services and Senior Services. During the interview process both Departments stressed that they lack critical funding to adequately carry out the HEAP program that provides and installs air conditioning units to thermally vulnerable community members that cannot afford one, and to assist with electric costs for cooling that may be unaffordable. The Department of Senior Services also noted that many seniors lack flood and/or homeowner insurance, putting them at risk of financial liability in the event of a flood or other type of damage to their home. In this example, the Department of Senior Services was addressing the post-event impact of flooding through the *recovery* phase, they were unable to *mitigate* or *prepare* to assist vulnerable seniors because they have no jurisdiction over floodplains or flood insurance.

Another opportunity to enhance the effectiveness of preventative or mitigative measures can be found in the structure of work plans and job descriptions for those working for Erie County. Currently, climate-related actions are not directly written in many job descriptions for Erie County employees. Rectifying this would provide an incentive to be more proactive at the administrative level, which would generate more involvement in the process. In addition to directly incorporating climate vulnerability and adaptation into the job descriptions of Erie County employees, another opportunity can be found in generating a list of representatives from the County to act as "Climate Liaisons", similar to the "Green Team", to work on adaptation measures. This group could coordinate annual reports on the state of the climate, condense recommendations from other reports and increase coordination across groups working in this space. This may create conditions conducive to engage key stakeholders, such as encouraging and supporting local municipalities to apply for funds to conduct localized climate

vulnerability assessments. This would aid in collection of local data as well as validation of the County's own CVA.

## References


Eris County Department of Health. 2021. Accessed 9/13/2021. Ticks and Lyme Disease. https://www2.erie.gov/health/sites/www2.erie.gov.health/files/uploads/pdfs/BookletTicksandLymeDisease.pdf

Federal Emergency Management Agency (FEMA). 2021. Accessed 9/9/2021. Emergency Management Institute. https://training.fema.gov/

New York State Energy Research and Development Authority. 2021. Accessed 9/13/21. Home Energy Efficiency Programs. https://www.nyserda.ny.gov/all-programs/programs/home-energy-efficiency-upgrades

Renschler, Chris & Frazier, Amy & Arendt, Lucy & Cimellaro, G. & Reinhorn, Andrei & Bruneau, M.. (2010). Developing the peoples resilience framework for defining and measuring disaster resilience at the community scale. Proceedings of the 9th US National and 10th Canadian Conference on Earthquake Engineering. 25-29.

# Appendix: Sensitivity Analysis Report

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# Contents

# Sensitivity Analysis Methods

This document is an appendix to the 2021 Sensitivity Analysis Report, Part II of the Climate Vulnerability Assessment (CVA) for Erie County. The methods employed in the sensitivity analysis will assess the climate hazards outlined in the CVA's Threat Assessment Report from August, 2020 (https://www2.erie.gov/environment/sites/www2.erie.gov.environment/files/uploads/CVA_Climate_Hazards_Summary_Draft.pdf). These hazards are: extreme heat, flooding, wind, and biological threats. As an additional perspective, sensitivity will also be analyzed with respect to mobility and accessibility to critical services in the County. The methods employed include a review of relevant literature, Erie County-specific information (directly from Erie County departments as well as other nongovernmental, local, state and federal entities) as appropriate and available, and data that is analyzed using Geographic Information Systems. This appendix is intended to supplement the full report with more detailed methodologies, and an enhanced set of figures not included in the full report.

## Sensitivity with Respect to Extreme Heat:

*Our sensitivity analysis with respect to extreme heat considered two distinct aspects. First, we considered factors related to the landscape or environment that are known to have either a warming or cooling effect for the surrounding area. Second, we considered demographic and socio-economic information to determine which aspects of the population living in Erie County may be most vulnerable to heat. Please note that methodology to assess sensitivity to heat in Erie County described here was adapted from previous work by Zoe Hamstead, Susan Clark and colleagues at the University at Buffalo, completed in 2017, funded by the UB RENEW Institute.*

### Landscape Sensitivity

Sensitivity related to landscape is divided into two categories: 1) heat sinks and 2) heat sources, with six sub-factors shared between them. Heat sinks (or key aspects of the environment that tend to have a cooling affect) include tree canopy cover, proximity to large water sources and the prevalence of pervious (non-paved) surfaces. The heat sources (or aspects of the environment that tend to have a warming affect) included are industrial parcels and truck terminals. Each sub-factor, as well as which factor they belong to and their data source are summarized in (Table 1).

Factors were chosen based on their relevance to having a warming or cooling affect on their surrounding microclimates. Specifically, each of the sub-factors considered as heat sources are associated with fossil fuel emissions, both warming the surrounding area in the short term and ultimately warming our planet in the long term through anthropogenic climate change. The heat sinks are a bit more distinctive. Tree canopy can provide shade in the short term and they absorb $CO_2$, a major greenhouse gas contributing to Climate Change, in the long term. Large bodies of water both keep areas near them more temperate in the short term, and can absorb and store $CO_2$ in the long term. Finally, pervious surfaces (such as grass or other vegetation) reflect more sunlight than impervious surfaces (like asphalt), resulting in less heat available for the surfaces to radiate at night, keeping temperatures in surrounding areas relatively cooler in

the short term, compared to areas that are predominately asphalt or concrete (such as parking lots and highways).

Sensitivity related to landscape data was processed by averaging together each sub-factor for heat sources and heat sinks separately, creating an overall map of heat sources and a map of heat sinks (see these maps in the at the end of this document). These values were not standardized, to prevent unnecessary weight to any particular value. The equation **"Sensitivity to the landscape = Heat Sources - Heat Sinks**" was used to find overall sensitivity to heat related to the landscape. Values with a positive value (shown in pinks and purples on the maps) contained more heat sources, and values with a negative value (shown in yellow on the maps) contained more heat sinks. This makes negative values more desirable, as they would be experienced as relatively cooler locations during an extreme heat situation. The maps for overall heat sinks and overall heat sources in Erie County can be seen in Figures 1 and 2, respectfully.

### Socio-Economic Sensitivity

Sensitivity to heat related to socio-economic variables was also considered in our analysis. The major categories of sensitivity include:  economic sensitivity, physiological sensitivity, social isolation, mobility-based sensitivity, marginalization, and residential and housing sensitivity, each with a variety of subfactors. These can be seen in Figure X, along with data sources for each. Data availability played a large role in determining what data categories were included, however the overall factors contributing to heat sensitivity are well documented in peer reviewed literature (,e.g. Aminipouri, Knudby and Ho 2016; Nayak et al. 2018)

Except for residential and housing category, a simple average was calculated for each of the sub-factors within a category at the block group scale. Within the residential and housing category specifically, the sub-factor of population density was standardized by median year built. This was to incorporate the median year built because unlike all other data in this part of the analysis, this category was not given as a percentage. Like the other categories, the sub-factors in the residential and housing category was then averaged together. After an average was found for each, the maximum and minimum averages were identified for each category to standardize the data from 0 to 1 for easier comparison. The equation used for the socio-economic sensitivity is: "**Sensitivity = (x/min)/(max-min)"**. After finding all of the standardized factors for all of the socio-economic categories, each were again averaged together to create the complete socio-economic attributes of sensitivity map, shown in Figure 1.

### Overall Sensitivity to Heat:

The overall sensitivity to heat was found by summing the previous landscape and socioeconomic sensitivities together. By doing this, the final sensitivity to heat map for Erie County includes areas highlighted in yellow that contain lower sensitivities (typically more heat sinks and fewer sensitive populations), while areas in purple have higher sensitivities (typically more heat sources and more sensitive populations).

## Sensitivity: Threat of Flooding

### Methodologies

To assess sensitivity with respect to flooding, runoff generation was analyzed from both an on-site and an off-site perspective as outlined above. Exposure and sensitivity were combined as shown above in ArcMap GIS to provide a relative measure of risk or vulnerability. Exposure to on-site flooding was assessed using hydrologic soil group data extracted from the Natural Resource Conservation Service's (NRCS) GIS soil metadata. Exposure to downstream flooding was assessed by creating a wetness index derived from elevation data. Sensitivity was applied via analysis of the Federal Emergency Management Agency's Special Flood Hazard Areas (SFHA). Specific methods are described in detail below.

### Sensitivity to Landscape Attributes

#### *On-site Assessment*

As noted above, the on-site assessment of flooding was conducted using NRCS soil data. Their dataset comes with an extensive geodatabase with a variety of soil properties and functions, one of which is data on hydrologic soil groups. Hydrologic Soil Groups (HSG) are soil classifications that denote the minimum infiltration rate for a soil type after a sustained period of saturation. They are ranked as A, B, C, or D soils. In addition to that, this project further defined U soils as those mapped un urban environs with little to no permeable surfaces. Group A soils are soils with little runoff potential and high rates of infiltration in saturated conditions. Group B soils are soils with moderate runoff potential and moderate rates of infiltration in saturated conditions. Group C soils are soils with low rates of infiltration and water transmission. Group D soils are souls with high runoff potential and very low infiltration rates. Additionally, drainage is also a factor for certain soil types that fall in to Groups A-C. These are denoted as A/D, B/D, C/D. Essentially, these subcategories reflect soils that are close to the water table and lack drainage. Thus, if they were drained they may be in a soil Group with lower runoff generation/greater infiltration. In this analysis, HSG units were mapped in two different ways – one showing the soil units' current condition, and one showing the soil units ranked as if they had been "improved", and thus altering their runoff generation and infiltration potential. The HSG data is in vector format. This dataset was rasterized in ArcMap GIS and reclassified to numerically rank the distinct Groups. Groups with greater infiltration had a lower score than groups with poorer infiltration, as shown below in Table 1. The visualization of the HSG data is presented below in Figure 10 for current conditions and Figure 11 for improved conditions.

### *Off-site Assessment*

Off-site assessment was done through generation of a wetness index. Wetness indices have been demonstrated to be useful in the literature to assess runoff generation. These indices provide an assessment on how topography impacts where runoff generation originates and how big that area is (Wilson & Gallant, 2000). This index was created in ArcMap GIS. Elevation data was obtained in the form of a Digital Elevation Model from the United States Geological Survey's (USGS) National Elevation Dataset (NED). This DEM was then used to calculate a map of slope for Erie County using ArcMap's Slope tool in the Surface subheading of the Spatial Analyst toolbox. This map of slope was then processed using the Flow Direction too in the Hydrology subheading of the Spatial Analyst Toolbox, followed by Flow Accumulation. Once flow accumulation was calculated, the flow accumulation and slope data was processed in ArcMap's Raster Calculator to create the wetness index using the following formula: "**Ln(flow accumulation/slope)**". A visualization of the wetness index is provided below in Figure 13. This index was reclassified using the Quantile Interval classification in ArcGIS (Kherde & Priyadarshi, 2014) to provide a similar number of numerical ranks as the HSG data above.

## Sensitivity to Socioeconomic Attributes

To assess sensitivity to flooding, the framework of incorporating an off-site and an on-site component into the analysis was also used. However, where exposure analysis utilized two different types of data, the sensitivity portion of the analysis used data from the Federal Emergency Management Agency (FEMA). The Federal Emergency Management Agency provides a wealth of data on floodplains and flood risk (FEMA, 2020). For this analysis, FEMA data was processed to identify only their "Special Flood Hazard Areas" (SFHA). After transformation into a consistent projection, FEMA SFHA was extracted from the layer using ArcMap's Select by Attributes tool to create a shapefile that consisted solely of FEMA-designated SFHA, or 100-yr/1% flood risk (in Erie County this includes Zones A, AE, AH and AO. The resulting SFHA layer was then clipped to the boundary of Erie County (Figure 14). This vector shapefile was then rasterized and reclassified numerically. As each of these SFHAs are based on the same relative flood risk (i.e. "100-yr flood"), they all received the same rank. The SFHA data was then combined with the hydrologic soil groups data and the wetness index generated in the exposure analysis to assess overall risk of flooding, as seen in Figures 7 and 8.

Spatial data on HSGs and FEMA SFHAs were reclassified in ArcGIS to rank them numerically. As outlined in Table 2, HSG soil units were assigned a rank ranging from –0.5 (for soils that were most permeable) to 0.75 (for soils of greatest runoff potential). The areas of 100-year flood risk delineated by FEMA were all assigned a rank of 0.25, and areas that were not within a SFHA boundary were given a value of -0.25. This aided in an overlay with the TWI and HSG data. When combined as outlined in the workflow above (Figure 6), the HSG and SFHA data provide a spatially mapped index of on-site flood risk. The Topographic Wetness Index, ranked similarly to HSGs, was also combined with SFHA data. This combination provided a spatially mapped index

of downstream flood risk (Figure 9). All data was mapped with reference to Erie County census blocks. This allows for a consistent framework of analysis with other climate hazards analyzed in this report.

## Sensitivity: Biological Threats

### Methodologies

In order to assess the risk that biological threats pose in the lens of a changing climate, it is helpful to use GIS to model how habitat suitability may change over time and across warming scenarios. The United States Fish and Wildlife Service (USFWS) has developed a GIS-based tool to do just this. Their peer-reviewed Risk Assessment Mapping Program (RAMP) is used in ArcMap, and incorporates the known environmental variables that are present in a given species' native geographic range as applied to a new geographic area or given a certain level of warming, in a map-based visualization (Sanders et al., 2018).

### Sensitivity to Landscape Attributes:

To assess exposure to these biological threats across the landscape of Erie County, RAMP models were generated for 13 species of disease-causing organism and/or invasive species shown below in Table 3. These species were selected in consultation with Erie County Department of Environment and Planning (ECDEP) as well as the Western New York Partnership for Invasive Species Management (WNY PRISM). The RAMP tool allows for different regional analyses, and these species were analyzed at the Great Lakes Basin (GLB) scale as well as the New York State (NYS) scale. The models were created for current conditions, a 2050 projection, and a 2070 projection for each geographic scale. Additionally, they were also created for one of three climate scenarios using a representative concentration pathway (RCP). For each time interval RCP2.6, RCP4.5, and RCP8.5 were included, representing the least amount of extreme change at RCP2.6 to the most extreme change at RCP8.5.

## Sensitivity with Respect to Wind

### Methodologies

The methodologies for analyzing sensitivity with respect to wind included a literature review, and open-ended interviews with local experts that were familiar with this issue. Due to a lack of data for a spatial assessment, the goal instead was to more qualitatively examine wind as a hazard. Experts on the topic that were interviewed as part of this analysis included Judith Levan, Meteorologist In Charge at the NOAA National Weather Service in Buffalo, New York; Stuart Evans, PhD, Assistant Professor in the Department of Geography at the University at Buffalo; and additionally Troy Schinzel, the Commissioner of Parks, Recreation & Forestry in Erie County was interviewed to provide local context on how this climate hazard impacts Erie County operations.

## Sensitivity with Respect to Mobility & Accessibility

### Methodologies

The methodology for this component of the Assessment was chosen to identify comparative accessibility of hospital emergency departments (EDs) and Cooling Shelters (CSs) for different levels of vulnerability across Erie County. Mobility is incorporated by considering the different forms of transportation a person might use to access the EDs or CSs, including driving, public transit, and walking. To account for vulnerability across Erie County, the components of two Census-based approaches will be used, including the Census Bureau Community Resilience Estimates (Census Bureau, 2020) (CRE) and Cutter's Social Vulnerability Index (Cutter, Mitchell and Scott 2000). Also collected are Google Maps estimates of travel times by the three modes of transportation, including driving, public transit, and walking, from the center point of each census tract in Erie County to EDs in Western New York. With all of this data retrieved, the central question may now be approached, that is, for different levels of vulnerability (Community Resilience Estimates, Cutter's Index), and for different levels of mobility (driving, public transit, walking), how accessible are critical services (EDs) for Erie County residents?

To complete this component, the methodology is divided into two procedures, one using Geographic Information Systems (GIS) techniques and the other using Machine Learning (ML) techniques. The GIS procedure can be described in the following 6 steps: (1) Find the centroid of every Erie County Census Tract; (2) Find the nearest point on the nearest road of every centroid; (3) Retrieve travel times by travel mode from the Google Maps; (3a) Data imputation (transit travel mode); (4) Select the minimum travel time by travel mode for each tract; (5) Estimate a smooth surface across Erie County of estimated travel times by travel mode; (6) Aggregate mean values of travel times by travel mode for each tract. The conclusion of step 6 provides a single empirical input that can be used by the ML models in the second procedure.

In the second procedure, 9 ML models for each of the 3 travel modes are estimated. The models estimated include OLS, Ridge, and Lasso Regression, GAM, Regression Tree, Pruned Regression Tree, Bagging, Random Forest, and Boosting. For each model estimated, a measure of precision, known as RMSE, or root mean square error, was calculated and the results were tabulated. These values were used to compare models and select the most precise model for each travel mode. The results of the most precise models can then be used to spatially map accessibility to EDs and CSs for differing levels of vulnerability and different transportation modes.

Most importantly, these methods can be easily altered in terms of target, or critical service or resource of which residents and planners wish to investigate in terms of accessibility, and in terms of source, or the definition of vulnerability which may be of greatest concern. This is to say that for alternative hazard emergency and hazard scenarios, residents and planners can use these methods to assess accessibility to other types of critical services such as pharmacies or vaccination sites. The main alternatives to consider include On-site Sheltering in Place, Off-site Sheltering in Place, and Evacuation.

# Results and Discussion

## Sensitivity with Respect to Extreme Heat

The results of our sensitivity analysis can be seen below in Figure 1. Based on our analysis, areas more vulnerable to heat in the region are shown in yellow, with lower-risk areas shown in purple. As can be seen, the most vulnerable areas are in the city of Buffalo. This pairs well with what we know about microclimates, specifically concerning the urban heat island effect, a natural phenomenon found where urban areas are consistently warmer than surrounding suburban and rural areas. Cities are also more likely to house minorities, poorer populations, and people without their own vehicle- all socio-economically sensitive populations- which also pairs well with the trend of high sensitivity in the city of Buffalo. Rural areas seem to house populations less sensitive both landscape and socio-economics wise. Separate maps showing the results of only the sensitivity to the landscape and only socio-economic sensitivity separately can also be seen in Figures 2 and 3, respectively.

Unfortunately, this information doesn't show the whole picture. Because both rural and urban areas are compared together in this study, we could be experiencing urban-rural bias. By looking at areas of a high baseline of sensitivity and areas of a low baseline of sensitivity, we negate any nuance in these areas. This can result in urban areas looking uniformly more sensitive and rural areas looking uniformly less sensitive, resulting in rural areas that may need assistance or resources in the event of extreme heat not receiving said assistance.

The seven PEOPLES dimensions can be used to better understand how the results of this sensitivity analysis effect the county and the people living there.

While this study is a good start to understanding the sensitivity to extreme heat in Erie County, many improvements can be made. As stated before, urban-rural bias is at work in this study; by comparing both the urban and rural areas in the same study, any variation in those areas is not significant enough to make an impact, therefore showing the rural areas as plainly "less sensitive" than the urban areas. Other next steps include adding other data layers to see the impact they have on sensitivity, if any at all. Some suggestions include weatherization data, data on personal health, and crime data for socio-economic factors, and wind data for landscape sensitivity. With more relevant data, results can be even more accurate.

## Sensitivity with Respect to Flooding

The results of the on-site flood assessment are included below in Figure 7 representing current conditions, and Figure 8 representing conditions if soils were altered with flood risk in mind. Areas of greater risk of local flooding (ponding, pooling etc.) are shown in yellow, with areas of lower risk shown in purple. Urban areas, with a preponderance of pavement and other impermeable surfaces, can be seen in the greater Buffalo region. Large areas of flood zones as designated by FEMA can be seen in the north end of the County This analysis aids in identifying

the areas that are sensitive to the impacts of runoff that pools in areas of low elevation or with soils/surfaces of low permeability as well as areas where improvements could be made in order to reduce sensitivity.

The results of the downstream flood assessment are included below in Figure 9. Areas of greater runoff potential are shown in yellow, while areas of lower runoff potential are shown in purple. Areas of high runoff generation may see exacerbated instances of erosion in instances of extreme precipitation and may contribute that runoff to areas downstream where flooding may occur.

## Sensitivity with Respect to Biological Threats

The sensitivity analysis with respect to biological threats resulted in a number of notable outputs. As noted in the methods, this analysis reviewed several species that create biological threats – those that are involved in vector-borne illnesses (VBD) as well as those that are classified as invasive species and may be of concern to Erie County. In two examples, the focal species are both invasive and involved in VBD. The products of the analyses of these species using the USFWS RAMP program are outlined below, followed by an analysis of how they relate to the PEOPLES Resiliency Framework. The output from the USFWS RAMP program is shown as a grid of points in the map – purple points illustrate lower relative suitability, green points illustrate medium relative suitability and yellow points denote higher relative suitability. It is important to note that these outputs are not intended for interpretation at the fine-scale, and as such are used as a reference point to begin further investigations that may be warranted based on these determinations.

The analysis of how climate change may affect the habitat suitability for the Asian Longhorned Tick is shown in Figure 15 below. In this map, suitability of the current climate, the climate of 2050 in the RCP4.5 scenario, and the climate of 2070 in the RCP4.5 scenario are shown. In this collective scenario, it appears that the suitability of climate for the Asian Longhorned Tick will follow a similar pattern as the other nonnative species analyzed in this manner, such as the Asian Tiger Mosquito, which will be enhanced in the time period between now and 2050, and decline in the time between 2050 and 2070. Conversely, the native Deer Tick, a vector for Lyme Disease, shows a different pattern. In Figure 16, one can see the habitat suitability of this species of tick consistently decline over time from the current analysis, to the 2050 and 2070 analyses.

As noted above, the outputs of the analyses for these two species of tick follow a similar pattern for the Asian Tiger Mosquito. Based on this assessment, it appears that the suitability of climate for the Asian tiger mosquito will be enhanced in the time period between now and 2050, and decline in the time between 2050 and 2070. The analysis of how climate change may affect the habitat suitability for the Spotted Lanternfly provided similar results. The pattern of change in habitat suitability closely follows that of the Asian Tiger Mosquito and Asian

Longhorned Tick, with an increase in habitat suitability by 2050 followed by declining suitability in 2070. The analysis of how climate change may affect the habitat suitability for the Asian Swamp Eel closely follows that of the Asian Tiger Mosquito, Asian Longhorned Tick, and Spotted Lanternfly; with an increase in habitat suitability by 2050 followed by declining suitability in 2070.

Interestingly, the patterns in habitat suitability shown above seemed to fall along native versus invasive designations. The nonnative species (Asian Tiger Mosquito, Asian Longhorned Tick, Spotted Lanternfly, Asian Swamp Eel) showed enhanced habitat suitability over the short term while the native species (Deer Tick) showed a consistent decline. Again, these determinations are in terms of relative suitability, and should be considered as useful for insight into sensitivity to biological threats rather than an in-depth analysis on a given species. What is apparent is that, in the short term and for these species, Erie County may want to take proactive measures to mitigate the impacts that species in these case studies may bring as climate change promotes environmental conditions favorable to them.

## Sensitivity with Respect to Wind

The most common association with a changing climate is the rising of temperatures, but as the environment changes, so do it's wind patterns. Although wind and climate change are inextricably linked, there is little discussion or analysis on the prospective changes that will occur. Through a literature review and interviews with climate experts, this study addresses three main aspects of climate change and wind: wind speed, wind direction and maximum wind events recorded in Erie County, New York. This report also delves into climate change's impact on seasonality, and more specifically, tree health in years to come as the climate warms.

Higher wind speeds will become more prevalent with a warmer climate. Judith Levan, Meteorologist In Charge at the NOAA National Weather Service in Buffalo, New York explained this change in an interview. She first described our position in the atmosphere. Humankind lives at the bottom of the atmosphere, where the weight of the air above us is called air pressure. Air pressure varies from day to day at the Earth's surface as we live at the bottom of the atmosphere. Differential heating causes circulations in the atmosphere which result in high and low-pressure systems (Levan, 2021). A low-pressure system has lower pressure at its center than the areas surrounding it. Wind blows towards areas of low pressure, and where they meet, the air rises in the atmosphere. As the air rises, water vapor inside condenses, creating clouds and precipitation. Levan said that wind speed depends on the strength of the low-pressure system. The stronger the low-pressure system is, the higher the wind speeds will be ("The Highs and Lows of Air Pressure", 2021). With increasing temperatures, the low-pressure system will be stronger, thus making wind speeds stronger as well (Levan, 2021). Scott Eichelberger, James McCAA, Bart Nijssen, and Andrew Wood furthered this research and created the report "Climate Change Effects on Wind Speed" where they concluded that wind speed values will likely increase over much of North America during the winter months - December, January, and February, and decrease during the summer months - June, July, and

August, but overall strengthen in speed as the climate warms (Eichelberger et al., 2008). In another report conducted to examine the projected changes to mean and extreme surface wind speeds for North America based on regional climate model simulations, it was deemed that changes in surface wind extremes have direct implications for buildings, infrastructure, agriculture, power lines, the desert, and forestry. An interview was conducted with Troy Schinzel, the Commissioner of Parks, Recreation & Forestry in Erie County to understand these regional changes. So far, Parks has seen a multitude of high wind events that were not present in previous years. These wind events have had a large impact on our trees and forests and the way that we manage them. In our area, we have a plethora of trees infested by the invasive species the emerald ash border (Schinzel, 2021). The emerald ash borer larvae feed on the inner bark of ash trees, disrupting the tree's ability to transport water and nutrients (Matsoukis). Now weakened, the trees in our area are more susceptible to damage and wind storms that come through are knocking them down. With wind speed and wind seiche events becoming more frequent, more trees will be knocked down and more damages will arise (Schinzel, 2021).

In addition to higher wind speeds resulting from climate change, wind direction will also change with a warmer climate. Erie County, because of its latitude and proximity to Lake Erie, usually has prevailing winds from the southwest. Storms move from east to west, and since we are close to Lake Erie, the Lake tends to turn winds to a more southwesterly direction. However, we could potentially experience more northeasterly winds as the climate changes. This potential change will come in with stronger low pressure systems that are characterized with winds circulating in a counterclockwise direction, resulting in winds generally from the northeast. Because of these changes in wind patterns, we will get odd direction storms more frequently, and stronger nor'easters will result in stronger winds from an atypical direction (Levan, 2021). Historical data on wind provides further evidence for changes in patterns of wind, as shown in the wind rose diagrams in FIGURE 18 (NOAA, 2021). The Intergovernmental Panel on Climate Change also notes this by saying "there is evidence for long-term changes in large-scale atmospheric circulation, such as a poleward shift and strengthening of westerly winds" (Eichelberger et al., 2008).

In the Buffalo region, the windiest season is winter because it has the strongest storms and our least windy season is summer because it has the least. The passage of these winter storms is controlled by the latitude and waviness of the jetstream. As the climate changes, the latitude of the jetstream is expected to move slightly north, but not an immense amount that would radically alter the number of storms we get. There will be a slight increase in winter storms since we miss some storms that currently pass to the south of us. In the summer, it is also reasonable to expect a modest increase in the strength of a lake breeze, which is a small-scale wind circulation caused by the land being warmer than the water. This is due to the land warming faster than the lake in the future (Evans, 2021).

As the climate changes we will also see out of season storms and these will result in more damage. A snow storm in April or October will be more detrimental to trees, people's houses, and buildings because they are unexpected. In regards to trees, once leaves on trees are budding out, the weight of the snow can increase the likelihood of power outages in addition to bringing trees down. Additionally, the weight of the snow will also make trees more susceptible to being knocked down by wind. As for people's houses and buildings, they are unprepared for the harsh winter environment so early on in October. People most likely will not have their patio furniture or be prepared with snow tires, etc. for the winter in October as it is out of season. But, with climate change, out of season storms will occur more frequently and more damage will arise as a result of unexpected weather (Levan, 2021).

An examination of Western New York's climate data from 1965 to 2016 clearly displays that the area is impacted by climate change. A form of severe weather that may be on the rise in Western New York is strong thunderstorm winds, which indicate a significant increase as time goes on. Thunderstorm winds are defined as winds arising from convection, occurring within 30 minutes of observed or detected lightning, with speeds of at least 58 mph, or winds of any speed producing a fatality, injury, or damage (Vermette, 2017).

Sensitivity to Wind Case Studies

November 15, 2020

https://www.audacy.com/wben/news/weather/thousands-lose-power-as-fierce-wind-rolls-through-wny

- Gusts were hurricane force and nearing 70 mph along the Buffalo waterfront and at the airport
- National Grid and NYSEG pressed into action
- Tens of thousands without power
- Flooding seiche event
- Many large trees down
- City of Buffalo forestry crews responded to approximately 55 tree calls. Half involves whole trees that were down.

September 7, 1998

https://www.spc.noaa.gov/misc/AbtDerechos/casepages/sep71998page.htm

- Derecho (a band of storms – wind and/or thunder – that move quickly and typically result in damaging impacts (Levan, 2021).
- Some of the worst storm damage occurred in a band across western and central New York
- 89 mph wind gust at the Rochester Airport and 77 mph at the Syracuse airport were recorded
- Damage was estimated at about 130 million dollars
- Hundreds of thousands of homes and business lost power, with some remaining without power for a week

March 8, 2017

https://www.newyorkupstate.com/weather/2017/03/hurricane-like_winds_hit_western_ny_finger_lakes_photos.html

- Winds of up to 81 mph flipped over tractor-trailers, tore down trees and wires, blocked roads and knocked out power to tens of thousands of people
- CSX train derailed
- Down trees, sparking wires
- Property damage
- High winds create big waves along the break wall on Lake

January 9, 2020

https://www.11alive.com/article/weather/flood-watch-issued-for-most-of-wny-this-weekend/71-3860b81f-cf94-462e-ba24-487075524b81

- Wind gusts exceeding 60 mph
- The combination of rain and strong winds significantly increased the risk for uprooted trees, downed power lines and widespread power outages.
- A wind gust of 69 mph was recorded at the National Weather Service office by the airport

## Sensitivity with Respect to Emergency Services Access

### On-site Sheltering in Place

In the On-site Sheltering in Place scenario, a hazard has occurred wherein residents will need to remain in their homes for an extended period of time (i.e. heavy lake-effect snow). In this scenario, the services or recourses of interest will include basic necessities including, food, pharmaceuticals, fuel, alternative sources of energy, and more. In these cases, it may be wise to include in the source information, data on the number of residents per household, the age of residents, the health-related risks of residents, the types of energy used by household (especially considering those most sensitive to climatological hazards), and vehicle ownership rates. Targets of interest may then include locations of grocery stores, pharmacies, gas stations, and tool supply retailers (i.e. Home Depot, Lowe's, etc.). In this scenario, residents and planners will be interested in knowing whether the most vulnerable individuals in the county will have access to the services and resources they need before and during a hazard.

### Off-site Sheltering in Place

This scenario involves individuals leaving their residence to seek shelter in a safer location. This is especially relevant to extreme temperatures, for example, those without access to proper heating and cooling facilities will need to seek shelter elsewhere during extremely high or extremely low temperature spells. Like the previous scenario, source information of interest may include land-usage, age-related and health-related data as well as income-related data. For example, elderly members of the urban low-income population are especially susceptible to heat waves. Target information may include Erie County's many heating and cooling shelters. The goal in this example would be to identify, for levels of temperature sensitivity, how accessible off-site shelters are to those individuals who need them most.

### Evacuation

In the Evacuation scenario, large portions of the population no longer can stay in their residences. In this situation, these individuals will need access to large-scale alternative shelter. This may occur in the case of flooding in urban or low-lying areas and will require the conversion of large local facilities into temporary shelter (recall the extreme event of New Orleans residents taking shelter inside of the city NFL stadium during Hurricane Katrina). In this scenario, source information will include soil, land-usage and more local detail on the surface of the earth. Target information will be locations of large facilities that can be converted in these scenarios. In this scenario, residents and planners are most interested in understanding how, for varying levels of geospatial vulnerability, accessible are major evacuation shelters.

# Literature Cited


Aldia Environment. “Why Buffalo is the best U.S. city for climate refugees”. Accessed July 17, 2020. https://aldianews.com/articles/cultura/environment/why-buffalo-best-us-city-climate-refugees/57108

Alto, Barry & Juliano, Steven. 2001. Precipitation and Temperature Effects on Populations of Aedes albopictus (Diptera: Culicidae): Implications for Range Expansion. Journal of medical entomology. 38. 646-56. 10.1603/0022-2585-38.5.646.

Aminipouri, M., Knudby, A., & Ho, H. C. (2016). Using multiple disparate data sources to map heat vulnerability: Vancouver case study. The Canadian Geographer/Le Géographe canadien, 60(3), 356-368.

Andrew MK, Mitnitski AB, Rockwood K (2008) Social Vulnerability, Frailty and Mortality in Elderly People. PLoS ONE 3(5): e2232. https://doi.org/10.1371/journal.pone.0002232

Arguad, L., Ferry, T., & Le, Q. (2007). Short- and long-term outcomes of heatstroke following the 2003 heat wave in Lyon, France. Arch Intern Med, 167(20), 2177-2183. doi:10.1001/archinte.167.20.ioi70147

Aroca, Estefanía & Bodoque, J. & García, Juan. (2020). How to construct and validate an Integrated Socio-Economic Vulnerability Index: Implementation at regional scale in urban areas prone to flash flooding. Science of The Total Environment. 746. 1-16. 10.1016/j.scitotenv.2020.140905.

Bolin B. (2007) Race, Class, Ethnicity, and Disaster Vulnerability. In: Handbook of Disaster Research. Handbooks of Sociology and Social Research. Springer, New York, NY

Bouchama, A. (2007). Prognostic factors in heat wave–related deaths: A meta-analysis. Archives of Internal Medicine, 167(20), 2170–2176. doi:10.1001/archinte.167.20.ira70009

Bowler, D. E., Buyung-Ali, L., Knight, T. M., & Pullin, A. S. (2010). Urban Greening to cool towns and cities: A systematic review of the empirical evidence. Landscape and Urban Planning, 97(3), 147-155. doi:10.1016/j.landurbplan.2010.05.006

Brownstein, J. S., Holford, T. R., & Fish, D. 2005. Effect of Climate Change on Lyme Disease Risk in North America. EcoHealth, 2(1), 38–46. doi:10.1007/s10393-004-0139-x

Buffalo Niagara Riverkeeper. 2014. Healthy Niagara – Niagara River Watershed Management Plan.

Centers for Disease Control and Prevention (CDC) - Agency for Toxic Substances and Disease Registry. 2020. CDC Social Vulnerability Index. Accessed 1/5/2021. https://www.atsdr.cdc.gov/placeandhealth/svi/index.html

Chapin, F. S., Matson, P. A., & Mooney, H. A. 2002. Principles of terrestrial ecosystem ecology. New York: Springer.

Chatzidimitriou, Angeliki & Yannas, Simos. (2015). Microclimate development in open urban spaces: The influence of form and materials. Energy and Buildings. 108. 156-174. 10.1016/j.enbuild.2015.08.048.

Cimellaro, G. & Renschler, Chris & Reinhorn, Andrei & Arendt, Lucy. (2016). PEOPLES: A Framework for Evaluating Resilience. Journal of Structural Engineering. 142. 04016063. 10.1061/(ASCE)ST.1943-541X.0001514.

Cleveland, Ohio. (2018). Climate Hazard and Social Vulnerability Assessment.

Colburn, Lisa & Jepson, Michael & Weng, Changhua & Seara, Tarsila & Weiss, Jeremy & Hare, Jon. (2016). Indicators of climate change and social vulnerability in fishing dependent communities along the Eastern and Gulf Coasts of the United States. Marine Policy. 74. 10.1016/j.marpol.2016.04.030.

Cutter, S. L., Ash, K. D., & Emrich, C. T. (2016). Urban–rural differences in disaster resilience. Annals of the American Association of Geographers, 106(6), 1236-1252.

Cutter, Susan & Boruff, Bryan & Shirley, W.. (2003). Social Vulnerability to Environmental Hazards. Social Science Quarterly. 84. 242-261. 10.1111/1540-6237.8402002.

Cutter, S. L., Mitchell, J. T., & Scott, M. S. (2000). Revealing the vulnerability of people and places: A case study of Georgetown County, South Carolina. *Annals of the Association of American Geographers, 90*(4), 713-737.

Das, Apurba & Rokaya, Prabin & Lindenschmidt, Karl-Erich. 2017. Assessing the impacts of climate change on ice jams along the Athabasca River at Fort McMurray, Alberta, Canada.

Desai, Ankur & Austin, Jay & Bennington, Val & Mckinley, Galen. 2009. Stronger winds over a large lake in response to weakening air-to-lake temperature gradient. Nature Geoscience. 2. 10.1038/ngeo693.

Dreher, DB & Harley, RA. (1998). A fuel-based inventory for heavy-duty diesel truck emissions. Journal of the Air & Waste Management Association. 48. 352-358.

Easterling, D.R., K.E. Kunkel, J.R. Arnold, T. Knutson, A.N. LeGrande, L.R. Leung, R.S. Vose, D.E. Waliser, and M.F. Wehner, 2017: Precipitation change in the United States. In: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 207-230, doi: 10.7930/J0H993CC.

Eichelberger, S., McCaa, J., Nijssen, B., & Wood, A. (2008). *Climate Change Effects On Wind*

*Speed* . ResearchGate.

https://www.researchgate.net/publication/281611243_Climate_change_effects_on_

wind_speed.

Eichelberger, S. & Mccaa, James & Nijssen, Bart & Wood, A.. 2008. Climate change effects on wind speed. NAm Wind. 7. 68-72.

Environmental Law & Policy Center. 2019. An Assessment of the Impacts of Climate Change on the Great Lakes.

Erie County. 2019a. Erie County Climate Action and Sustainability Plan, Internal Operations. Erie County - Department of Environment and Planning Report No. 1 Contract No. 57240

Erie County. 2019b. Regional Niagara River Lake Erie Watershed Management Plan Phase 2. Erie County – Department of Environment and Planning. http://www2.erie.gov/environment/sites/www2.erie.gov.environment/files/uploads/pdfs/ECS_WMP%20FINAL.pdf

Evans, S. (2021). Personal interview [Personal interview].

Federal Emergency Management Agency (FEMA). 2020. Accessed 12/13/2020. Special Flood Hazard Areas. https://www.fema.gov/special-flood-hazard-area

Fothergill, Alice. (2004). Poverty and Disasters in the United States: A Review of Recent Sociological Findings. Natural Hazards. 32. 89-110. 10.1023/B:NHAZ.0000026792.76181.d9.

Frankson, K. Kunkel, S. Champion, B. Stewart, W. Sweet, and A. T. DeGaetano, 2017. New York State Climate Summary. NOAA Technical Report NESDIS 149-NY, 4 pp.

Gobler, Christopher. 2019. Climate Change and Harmful Algal Blooms: Insights and perspective. Harmful Algae. 91. 101731. 10.1016/j.hal.2019.101731.

Griffith, Andrew & Gobler, Christopher. 2020. Harmful algal blooms: A climate change co-stressor in marine and freshwater ecosystems. Harmful Algae. 91. 10.1016/j.hal.2019.03.008.

Jones, Beth. (2011). Barberry, Bambi and bugs: The link between Japanese barberry and Lyme disease. Scientific American. https://blogs.scientificamerican.com/guest-blog/barberry-bambi-and-bugs-the-link-between-japanese-barberry-and-lyme-disease/

Hamstead, Z., Coseo, P., AlKhaled, S., Boamah, E. F., Hondula, D. M., Middel, A., & Rajkovich, N. (2020). Thermally resilient communities: creating a socio-technical collaborative response to extreme temperatures. Buildings and Cities, 1(1), 218–232. DOI: http://doi.org/10.5334/bc.15

Hellmann, Jessica & Byers, James & Bierwagen, Britta & Dukes, Jeffrey. 2008. Five Potential Consequences of Climate Change for Invasive Species. Conservation biology: the journal of the Society for Conservation Biology. 22. 534-43. 10.1111/j.1523-1739.2008.00951.x.

Hiemstra, P. (2013). Package "automap": Automatic interpolation package, R package version 1.0-14. In.

Khajehei, Sepideh & Ahmadalipour, Ali & Shao, Wanyun & Hamid, Moradkhani. (2020). A Place-based Assessment of Flash Flood Hazard and Vulnerability in the Contiguous United States. Scientific Reports. 10. 10.1038/s41598-019-57349-z.

Khatchikian, Camilo & Prusinski, Melissa & Stone, Melissa & Backenson, Bryon & Wang, Ing-Nang & Levy, Michael & Brisson, Dustin. 2012. Geographical and environmental factors driving the increase in the Lyme disease vector Ixodes scapularis. Ecosphere (Washington, D.C). 3. 10.1890/ES12-00134.1.

Kherde, Rajesh & Priyadarshi, Dr. (2014). A GIS Based Variable Source Area Model for Large-scale Basin Hydrology. Research Journal of Applied Sciences, Engineering and Technology. 7. 3797-3802. 10.19026/rjaset.7.736.

Kumar, Parveen & Geneletti, Davide & Nagendra, Harini. (2016). Spatial assessment of climate change vulnerability at city scale: A study in Bangalore, India. Land Use Policy. 58. 514-532. 10.1016/j.landusepol.2016.08.018.

Levan, J. (2021). Personal interview [Personal interview]

Lowe, Dianne & Ebi, Kristie & Forsberg, Bertil. (2013). Factors Increasing Vulnerability to Health Effects before, during and after Floods. International journal of environmental research and public health. 10. 7015-7067. 10.3390/ijerph10127015.

Luber, G., & McGeehin, M. (2008). Climate change and extreme heat events. American Journal of Preventive Medicine, 35(5), 429-435. doi:10.1016/j.amepre.2008.08.021

Lumley, T., & Lumley, M. T. (2013). Package 'leaps'. *Regression Subset Selection. Thomas Lumley Based on Fortran Code by Alan Miller. Available online: http://CRAN. R-project. org/package= leaps (accessed on 18 March 2018)*.

Mainka, Susan & Howard, Geoffrey. 2010. Climate change and invasive species: Double jeopardy. Integrative zoology. 5. 102-11. 10.1111/j.1749-4877.2010.00193.x.

Margles, Shawn & Agostini, Vera & Roth, Lynnette & Gilmer, Ben & Schill, Steve & Knowles, John & Blyther, Ruth. (2016). Assessing vulnerability: an integrated approach for mapping adaptive capacity, sensitivity, and exposure. Climatic Change. 136. 10.1007/s10584-016-1642-0.

Marshall, Nadine & Marshall, N & Marshall, Paul & Tamelander, Jerker & Obura, David & Malleret-King, Delphine & Cinner, Joshua. (2010). A Framework for Social Adaptation to Climate Change: Sustaining Tropical Coastal Communitites [sic] and Industries.

Matsoukis, C. (n.d.). *Emerald Ash Borer Information Network*. Emerald Ash Borer. http://www.emeraldashborer.info/.

Melo, R., Rodriguez, T., & Zarruk, D. (2017). gmapsdistance: distance and travel time between two points from Google Maps. In: R package version.

Morrow, B. H. (1999). Identifying and mapping community vulnerability. Disasters, 23(1), 1-18. doi:10.1111/1467-7717.00102

Moss, Richard & Brenkert, Antoinette & Malone, Elizabeth. (2001). Vulnerability to Climate Change. A Quantitative Approach.

Mucke, P (2012) World Risk Report 2012: environmental degradation increases disaster risk worldwide alliance development works, Berlin

Munyai, R. B., Musyoki, A., & Nethengwe, N. S. (2019). An assessment of flood vulnerability and adaptation: A case study of Hamutsha-Muungamunwe village, Makhado municipality. *Jamba (Potchefstroom, South Africa)*, *11*(2), 692. https://doi.org/10.4102/jamba.v11i2.692

National Oceanic and Atmospheric Administration (NOAA), National Centers for Environmental Information. Storm Events Database. Accessed July 19, 2020. https://www.ncdc.noaa.gov/stormevents/listevents.jsp?eventType=%28C%29+Tornado&beginDate_mm=04&beginDate_dd=01&beginDate_yyyy=1950&endDate_mm=04&endDate_dd=30&endDate_yyyy=2020&county=ERIE%3A29&hailfilter=0.00&tornfilter=0&windfilter=000&sort=DT&submitbutton=Search&statefips=36%2CNEW+YORK; https://www.ncdc.noaa.gov/stormevents/listevents.jsp?eventType=%28Z%29+Seiche&beginDate_mm=04&beginDate_dd=01&beginDate_yyyy=1950&endDate_mm=04&endDate_dd=30&endDate_yyyy=2020&county=ERIE%3A29&hailfilter=0.00&tornfilter=0&windfilter=000&sort=DT&submitbutton=Search&statefips=36%2CNEW+YORK

Nayak, S. G., Shrestha, S., Kinney, P. L., Ross, Z., Sheridan, S. C., Pantea, C. I., ... & Hwang, S. A. (2018). Development of a heat vulnerability index for New York State. Public Health, 161, 127-137.

NBC News. “Move to Buffalo? With Earth warming, northern cities could become oases.” Accessed July 17, 2020. https://www.nbcnews.com/science/environment/buffalo-oasis-scientists-say-warmer-earth-could-make-colder-cities-n1113711

New York State Attorney General Eric T. Schneiderman, Environmental Protection Bureau. 2014. Current and Future Trends in Extreme Rainfall Across New York State.

Ngo, E. B. (2001). When disasters and age collide: Reviewing vulnerability of the elderly. Natural Hazards Review, 2(2), 80-89. doi:10.1061/(asce)1527-6988(2001)2:2(80)

Okazawa, Yuko & Yeh, Pat & Kanae, Shinjiro & Oki, Taikan. (2011). Development of a global flood risk index based on natural and socio-economic factors. Hydrological Sciences Journal – Journal des Sciences Hydrologiques. 56. 789-804. 10.1080/02626667.2011.583249.

Pebesma, E. J. (2018). Simple features for R: Standardized support for spatial vector data. *R J., 10*(1), 439.

Pohlman, Catherine & Turton, Steve & Goosem, Miriam. (2009). Temporal variation in microclimatic edge effects near powerless, highways and streams in Australian tropical rainforest.. Agricultural and Forest Meteorology. 149. 84–95.

Rahel, Frank & Olden, Julian. 2008. Assessing the Effects of Climate Change on Aquatic Invasive Species. Conservation biology : the journal of the Society for Conservation Biology. 22. 521-33. 10.1111/j.1523-1739.2008.00950.x.

Reid, C., Mann, J., Alfasso, R., English, P., King, G., Margolis, H., … Balmes, J. (2011). Evaluation of a heat vulnerability index on abnormally hot days: An application of environmental public health tracking data. ISEE Conference Abstracts, 2011(120), 715-720. doi:10.1289/isee.2011.01022

Renschler, Chris. (2015). The PEOPLES Resilience Framework – An Integrated Quantitative Measure and Modeling of Sustainable Development and Disaster Risk Reduction.

Renschler, Chris & Reinhorn, Andrei & Arendt, Lucy & Cimellaro, G.. (2011). THE P.E.O.P.L.E.S. RESILIENCE FRAMEWORK: A CONCEPTUAL APPROACH TO QUANTIFY COMMUNITY RESILIENCE. 10.13140/RG.2.1.3355.1767.

Renschler, Chris & Frazier, Amy & Arendt, Lucy & Cimellaro, G. & Reinhorn, Andrei & Bruneau, M.. (2010). Developing the peoples resilience framework for defining and measuring disaster resilience at the community scale. Proceedings of the 9th US National and 10th Canadian Conference on Earthquake Engineering. 25-29.

Ridgeway, G., Edwards, D., Kriegler, B., Schroedl, S., & Southworth, H. (2015). gbm: Generalized Boosted Regression Models, 2010. *URL http://CRAN. R-project. org/package= gbm. R package version, 2*.

Ripley, B. (2016). Tree: classification and regression trees, R package version 1.0-37. *Avaliable at https://CRAN. R-project. org/package= tree. Accessed August, 3*, 2017.

Rochester, NY. (2018). Climate Vulnerability Assessment Report. City of Rochester Office of Energy & Sustainability.

Rochlin I, Ninivaggi DV, Hutchinson ML, Farajollahi A. 2013. Climate Change and Range Expansion of the Asian Tiger Mosquito (Aedes albopictus) in Northeastern USA:

Implications for Public Health Practitioners. PLoS ONE 8(4): e60874. https://doi.org/10.1371/journal.pone.0060874

Sanders, S., C. Castiglione, and M. Hoff. 2018. Risk Assessment Mapping Program: RAMP, Version 3.1. U.S. Fish and Wildlife Service.

Schinzel, T. (2021). Personal interview [Personal interview].

Shen, Suwan & Feng, Xi & Peng, Zhong-Ren. (2016). A framework to analyze vulnerability of critical infrastructure to climate change: the case of a coastal community in Florida. Natural Hazards. 84. 10.1007/s11069-016-2442-6.

Shepard, Christine & Agostini, Vera & Gilmer, Ben & Allen, Tashya & Stone, Jeff & Brooks, William & Beck, Michael. (2012). Assessing future risk: Quantifying the effects of sea level rise on storm surge risk for the southern shores of Long Island, New York. Natural Hazards. 60. 10.1007/s11069-011-0046-8.

Smit, Barry & Wandel, Johanna. (2006). Adaptation, Adaptive Capacity and Vulnerability. Global Environmental Change. 16. 282-292. 10.1016/j.gloenvcha.2006.03.008.

Sun, Ranhao & Chen, Li-Ding. (2012). How can urban bodies be designed for climate adaptation?. Landscape and Urban Planning. 105. 27–33. 10.1016/j.landurbplan.2011.11.018.

The Highs and Lows of Air Pressure. (2021). Retrieved April 19, 2021, from https://scied.ucar.edu/learning-zone/how-weather-works/highs-and-lows-air-pressure#:~:text=A low pressure system has,forming clouds and often precipitation.&text=Winds blow away from high pressure

URS. 2015. Erie County, New York Multijurisdictional Hazard Mitigation Plan Update

Vermette, S. 2017. Weathering Change in WNY: Climatic Trend Analysis (1965-2016). Report prepared for Designing to Live Sustainably (d2ls), Buffalo, NY. 14pp.

Vermette, S.J. and Bittner, C. 2010. Seasonal Temperature and Precipitation Forecasts Using a Climate Probability Approach: Buffalo, New York. Middle States Geographer, 43: 44-49

Walker, K. (2016). tigris: An R Package to Access and Work with Geographic Data from the US Census Bureau. *R J., 8*(2), 231.

Walker, K., Eberwein, K., & Herman, M. (2018). Tidycensus: Load us census boundary and attribute data as' tidyverse'and'sf'-ready data frames. *R package version 0.9, 6*.

Weil, Raymond & Brady, Nyle. (2017). The Nature and Properties of Soils. 15th edition.

Wells, M. (2012). Resilience in older adults living in rural, suburban, and urban areas. Online Journal of Rural Nursing and Health Care, 10(2), 45-54.

WGRZ. 2020. Flooding causes voluntary evacuations in Hamburg during Sunday storm. https://www.wgrz.com/article/weather/storms/parts-of-buffalo-experiencing-flooding-during-sunday-storm/71-b7a35a0d-3fd4-4290-bc1c-8f233adc3b8a. Accessed 12/9/2020.

Wilson, John & Gallant, John. (2000). Digital Terrain Analysis in Terrain Analysis: Principles and Applications.

Wormser, Gary & McKenna, Donna & Piedmonte, Nicholas & Vinci, Vanessa & Egizi, Andrea & Backenson, Bryon & Falco, Richard. (2019). First Recognized Human Bite in the United States by the Asian Longhorned Tick, Haemaphysalis longicornis. Clinical infectious diseases : an official publication of the Infectious Diseases Society of America. 70. 10.1093/cid/ciz449.

# Tables and Figures

## Extreme Heat

*Table 1: Factors and subfactors used in analysis of sensitivity to extreme heat.*

| Factors | Sub-Factors |
|---|---|
| Socio-Economic Sensitivity | |
| Economic Sensitivity | % under poverty line |
| | % over 25 without a high school diploma |
| | % unemployed |
| Physiological Sensitivity | % 5 years old and under |
| | % 65 years old and over |
| Social Isolation | % foreign born |
| | % aged 20-65 with disability status |
| Mobility-based Sensitivity | % active commuters |
| Residential + Housing Sensitivity | Median year built |
| | Population density |
| | % Multi-family dwellings |
| | % Affordable housing |

| Extreme Heat Sensitivity Factors | | |
|---|---|---|
| Factors | Sub-Factors | Source |
| | Landscape Sensitivity | |
| Heat Sinks | % Tree Canopy | NLCD, USGS |
| | Proximity to water sources | Null |
| | % of pervious surfaces | NLCD, USGS |
| Heat Sources | % area covered by industrial parcels | Erie County Parcel Data Set, City of Buffalo Office of Environmental Planning |
| | % area covered by truck terminals | Erie County Parcel Data Set, City of Buffalo Office of Environmental Planning |
| | Proxmity to major roads, standardized by AADT | NYS Roadway Inventory System Geodatabase, NYDOT |

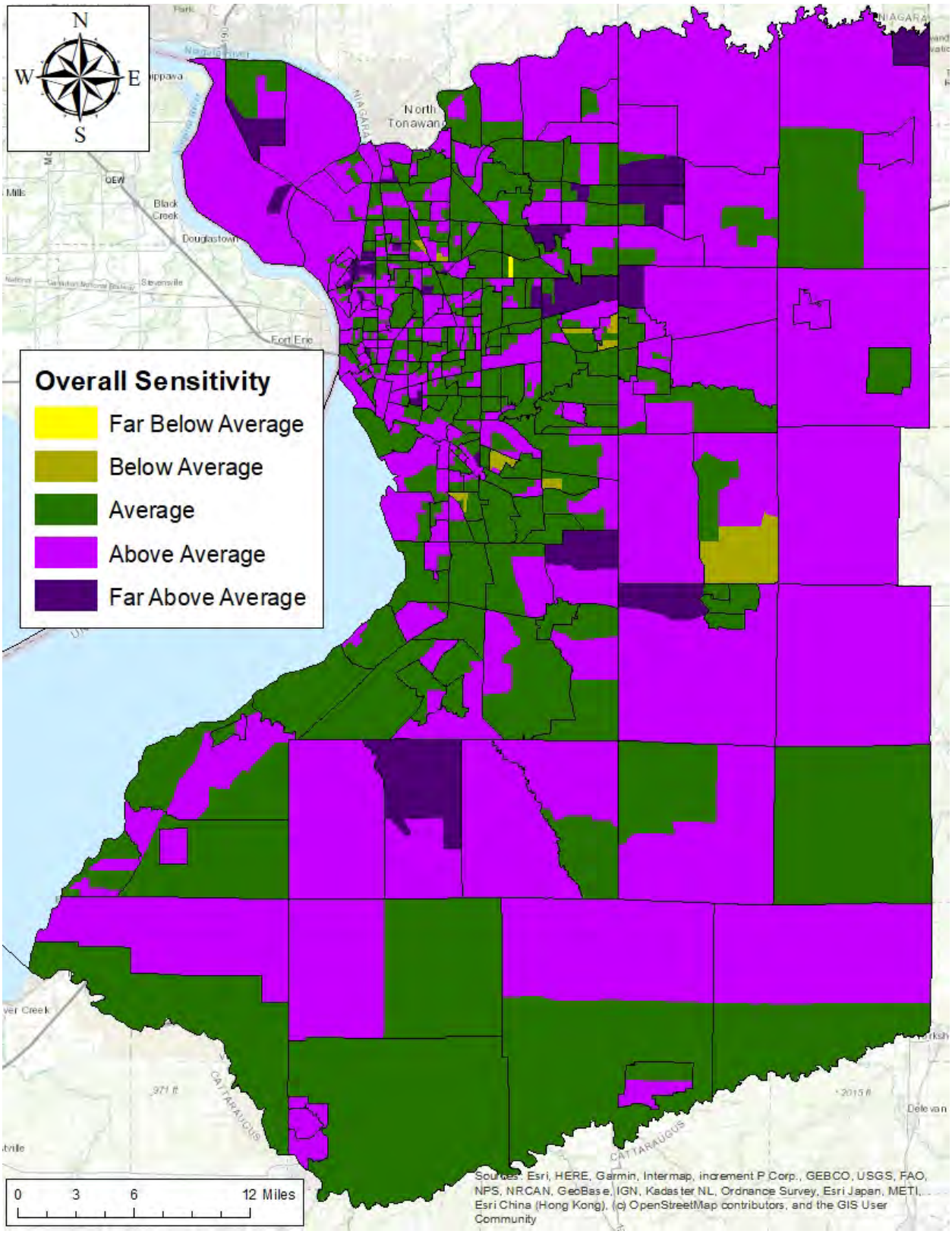



*Figure 1: Overall Sensitivity to extreme heat*

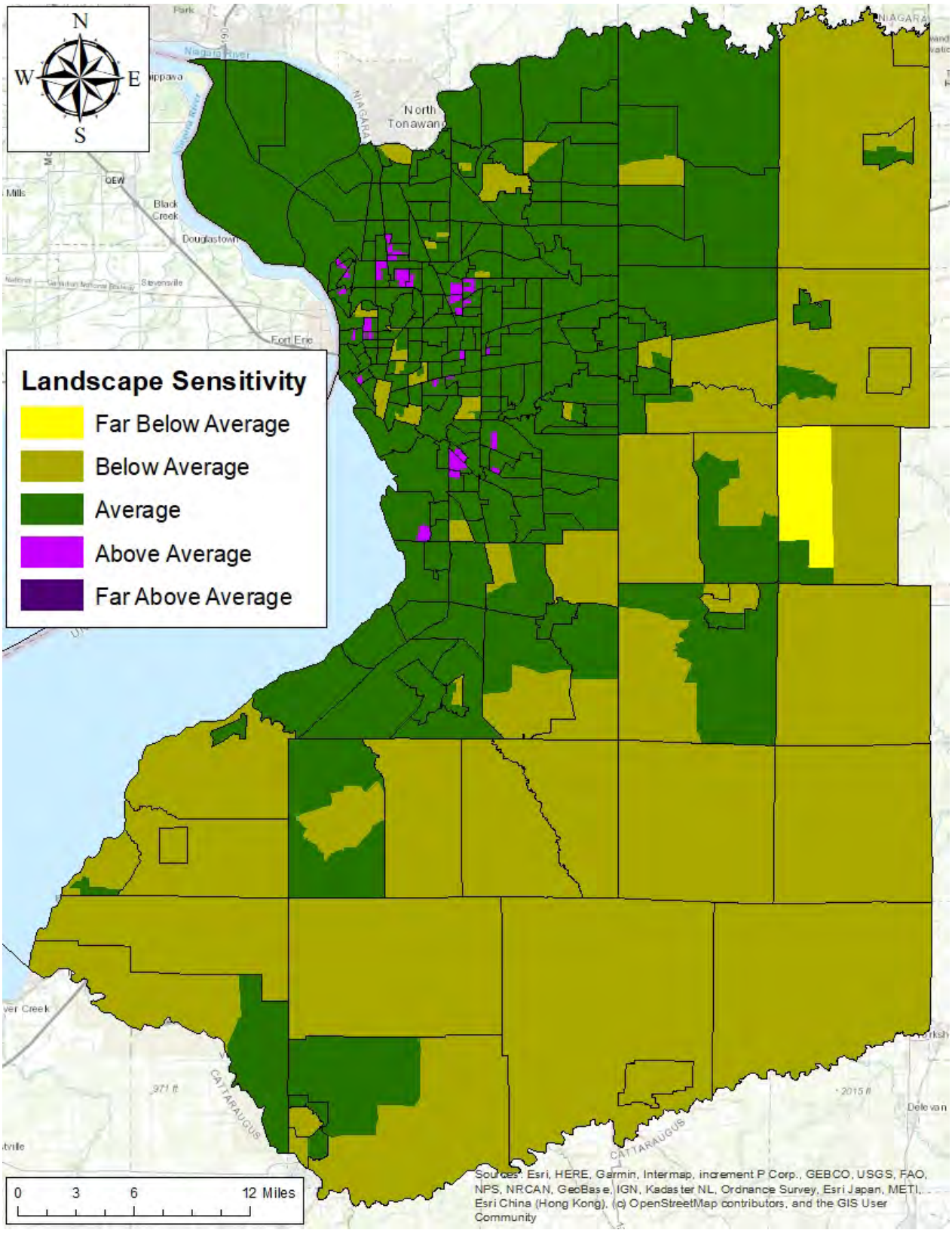



*Figure 2: Landscape Sensitivity to Extreme Heat*

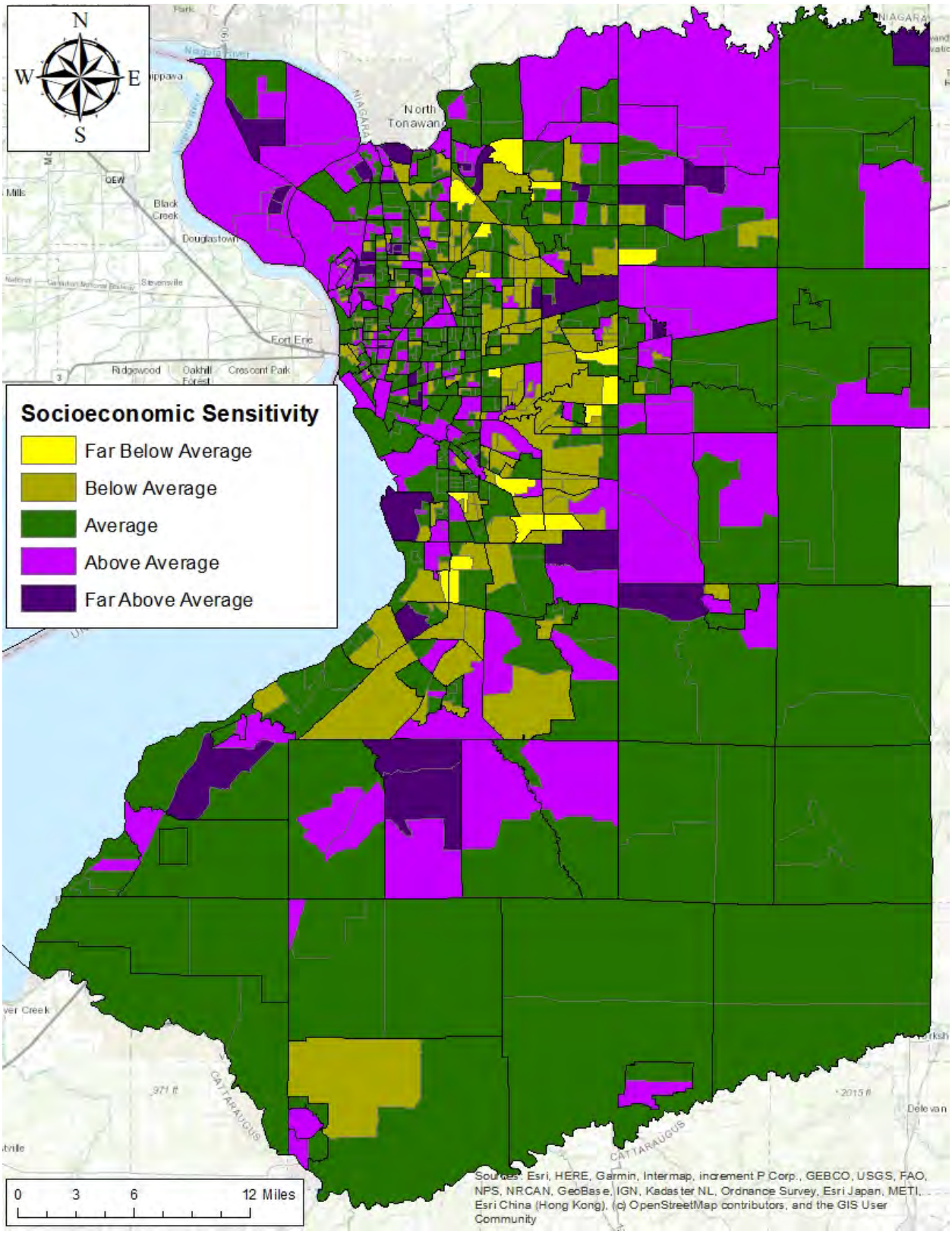



*Figure 3: Socioeconomic Sensitivity to extreme heat*

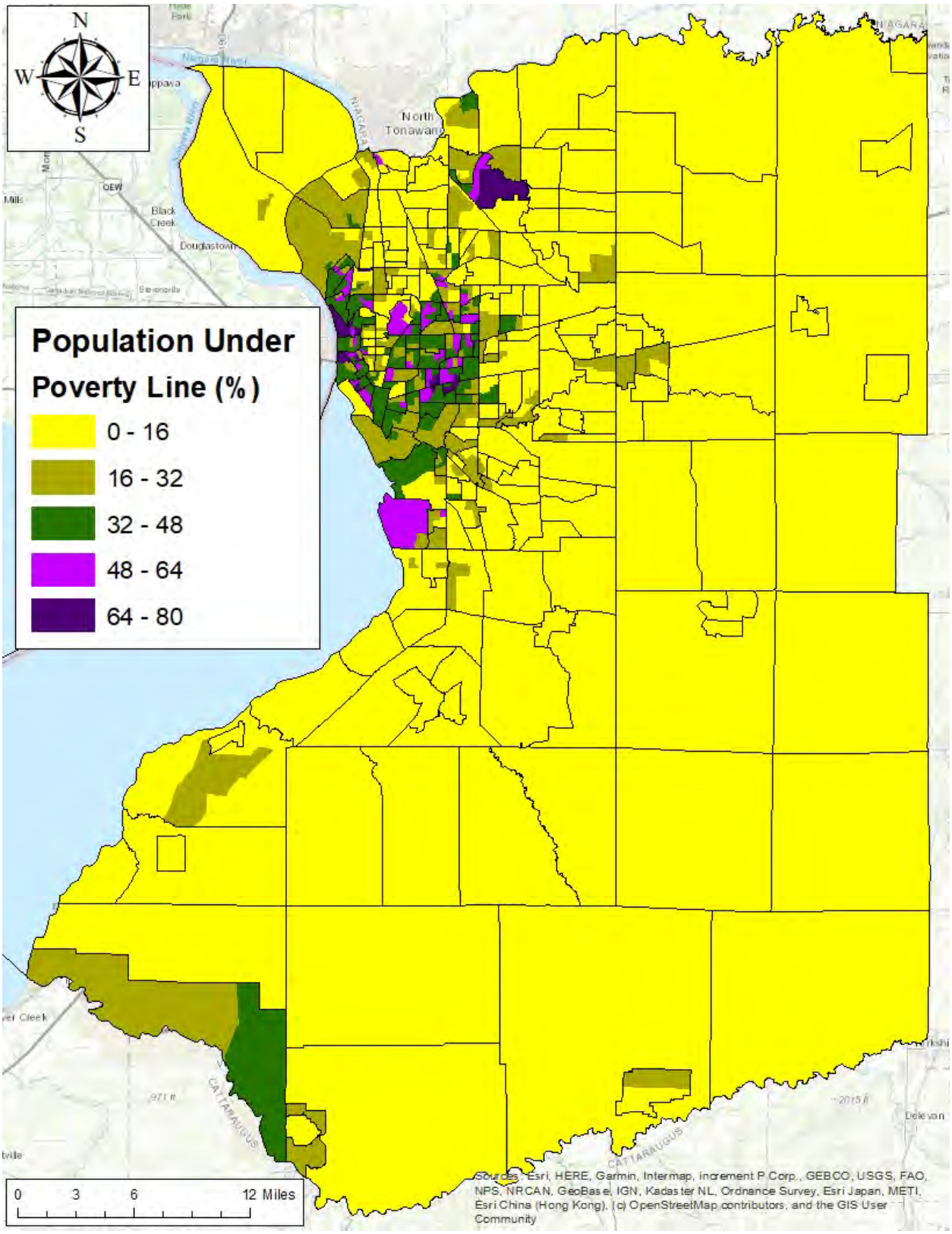



*Figure 4: Percent of Erie County population under the poverty line*

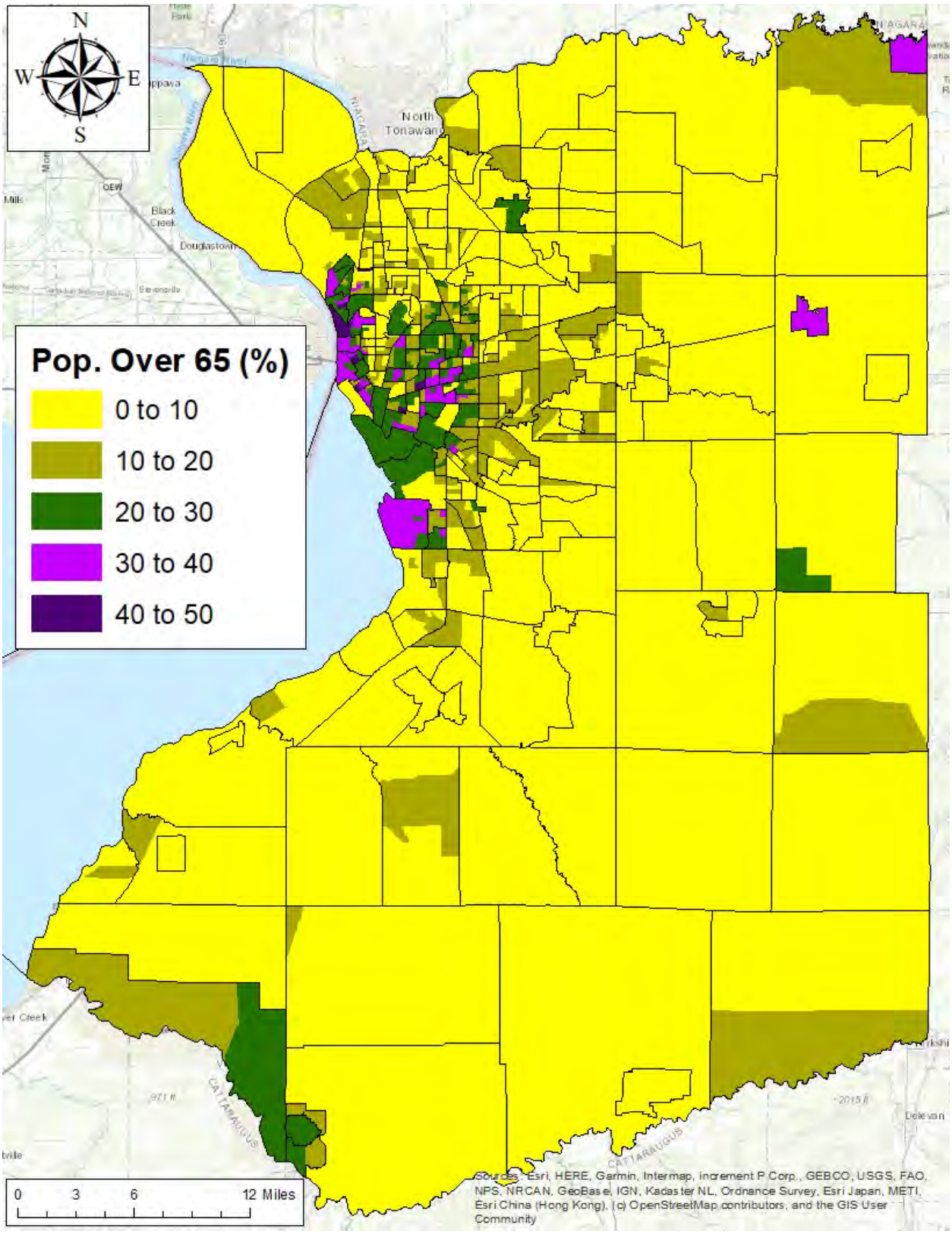



*Figure 5: Percent of Erie County population over the age of 65*

## Flooding

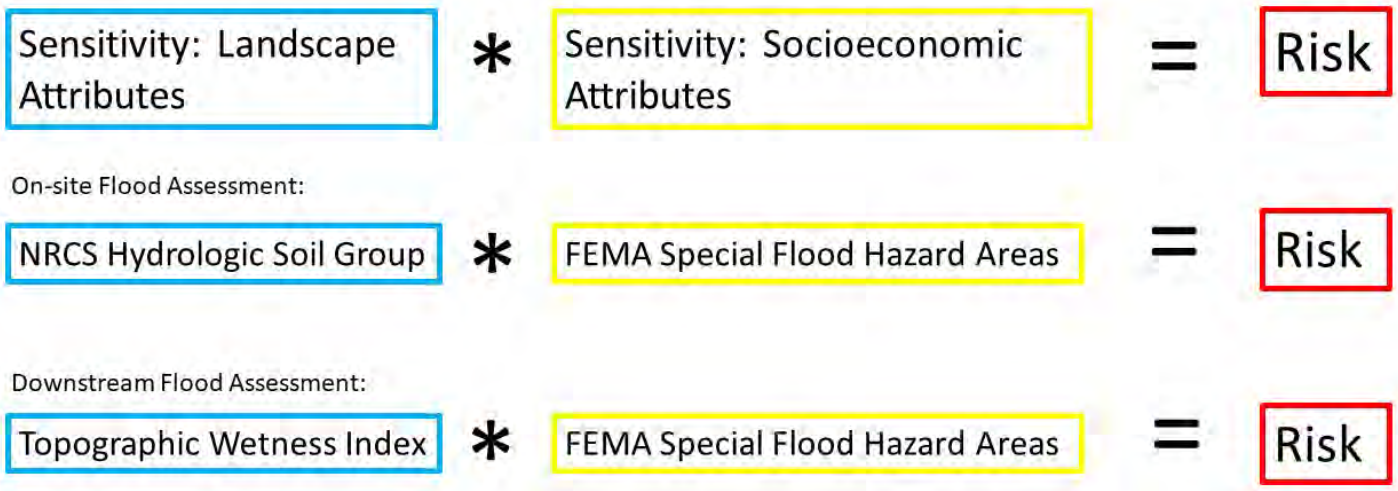



*Figure 6: Work flow for assessing sensitivity with respect to flooding*

*Table 2: Hydrologic Soil Groups, their respective properties, and numerical rank to be used in final sensitivity analysis.*

| **Current Conditions** | | | | **Improved Conditions** | | |
|---|---|---|---|---|---|---|
| **Group** | **Properties** | **Rank** | | **Group** | **Properties** | **Rank** |
| A | Rapid Infiltration | -0.75 | | A | Rapid Infiltration | -0.75 |
| A/D | A Conditions if altered | +0.5 | | A/D | A Conditions if altered | -0.75 |
| B | Weak Infiltration | -0.5 | | B | Weak Infiltration | -0.5 |
| B/D | B Conditions if altered | +0.5 | | B/D | B Conditions if altered | -0.5 |
| C | Low Infiltration | +0.25 | | C | Low Infiltration | +0.25 |
| C/D | C Conditions if altered | +0.5 | | C/D | C Conditions if altered | 0.25 |
| D | Very Little Infiltration | +0.75 | | D | Very Little Infiltration | +0.75 |
| U | Compacted Urban | +0.8 | | U | Compacted Urban | +0.8 |

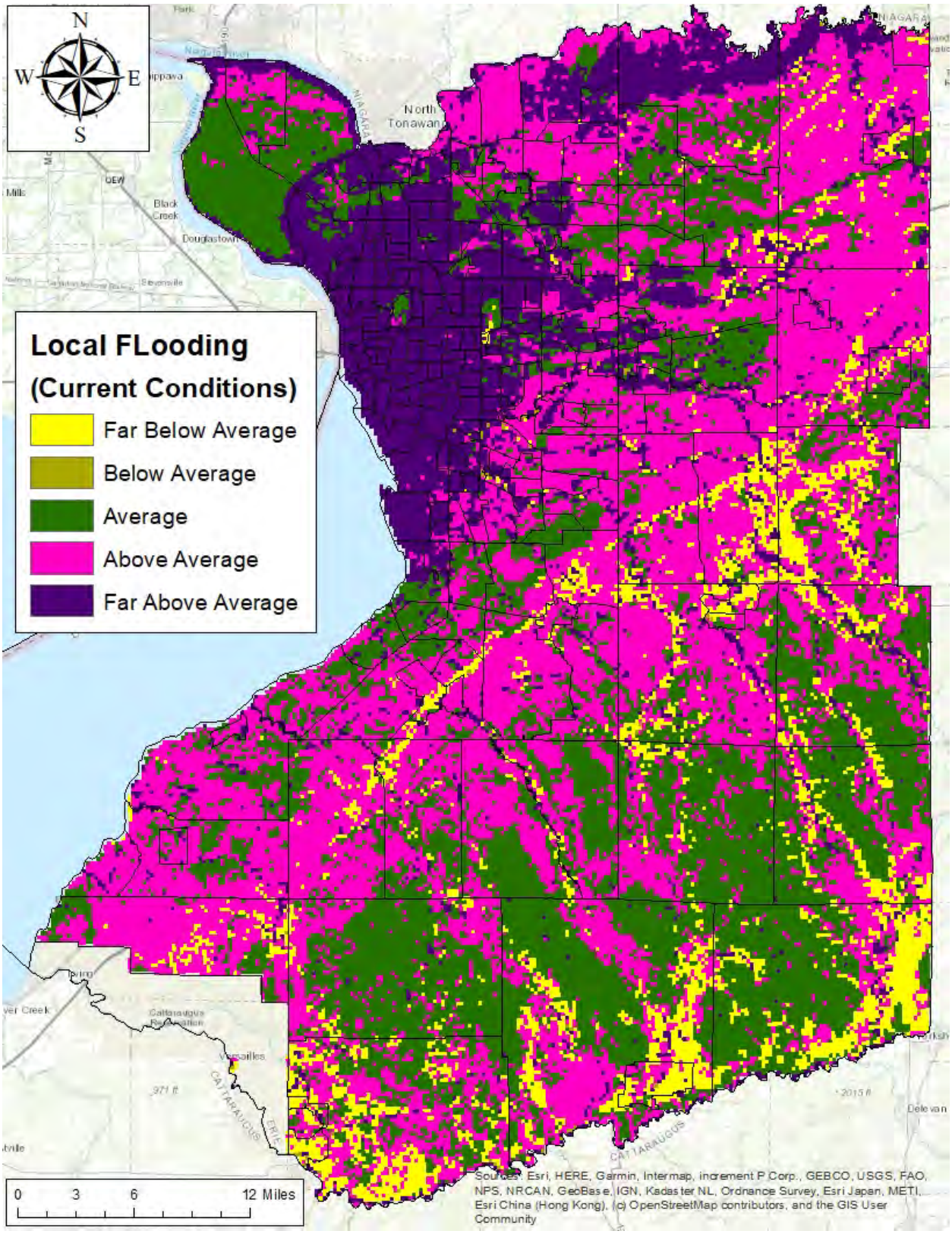



*Figure 7: Sensitivity to localized flooding in current soil conditions*

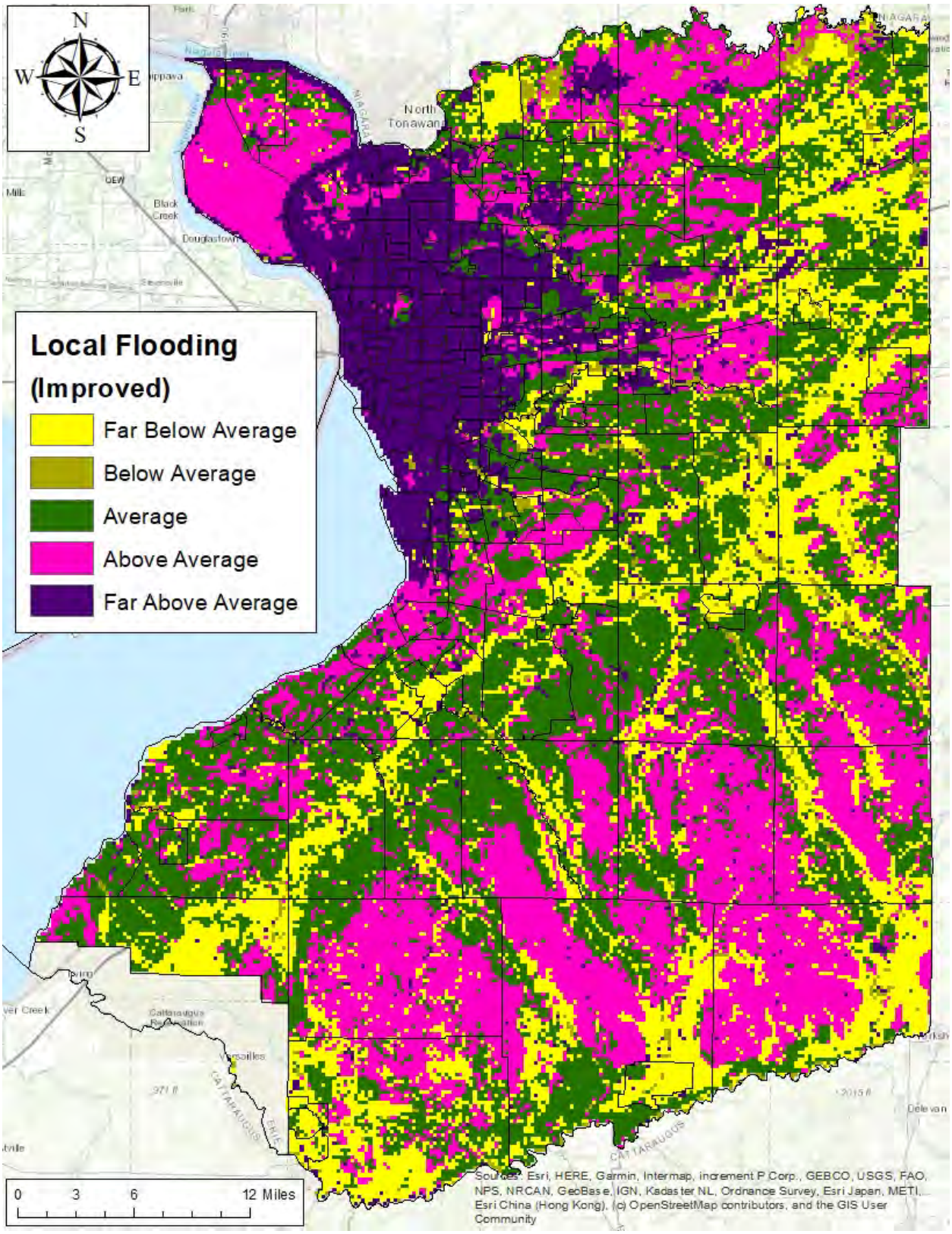



*Figure 8: Sensitivity to localized flooding in improved soil conditions*

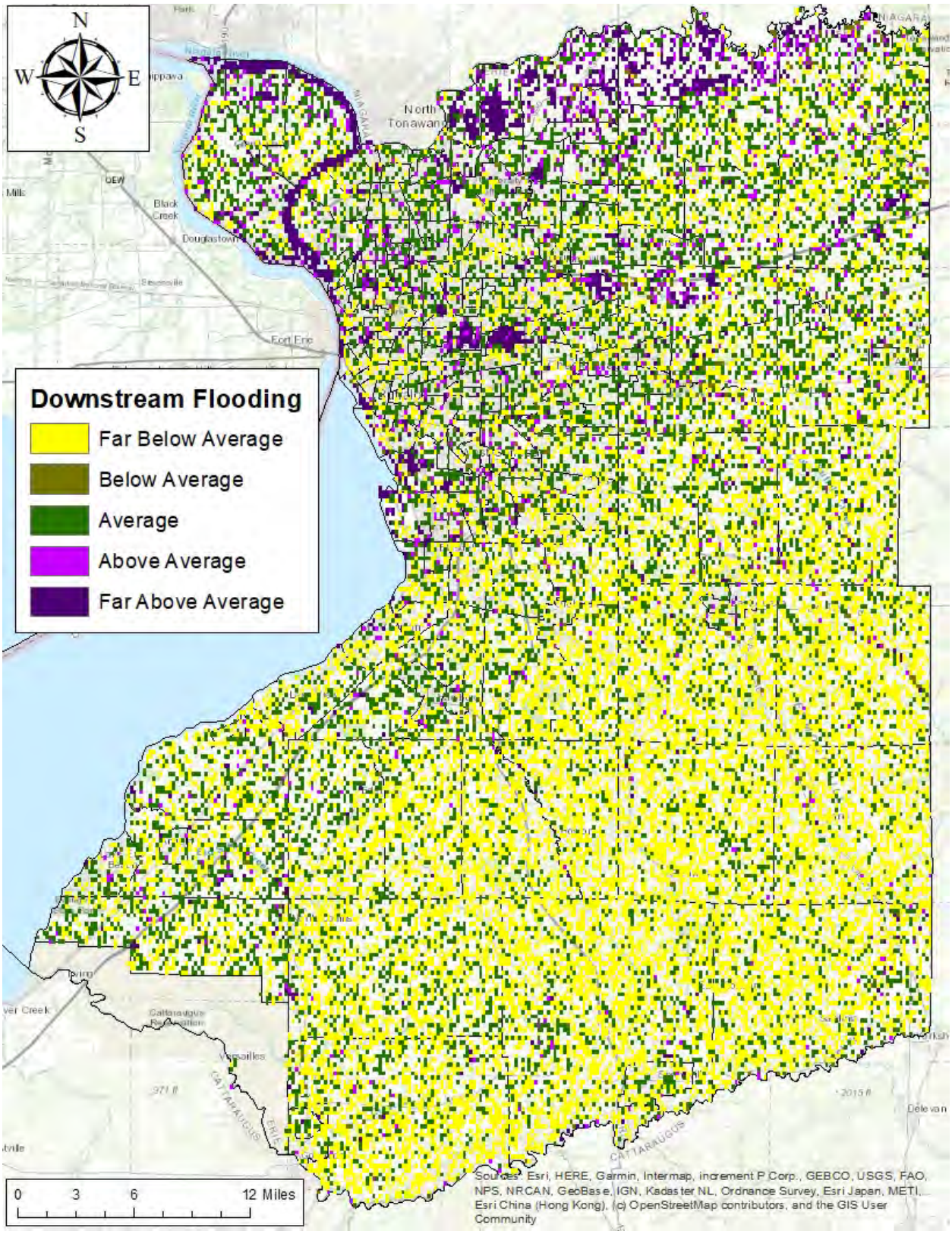



*Figure 9: Sensitivity to downstream or off-site flooding*

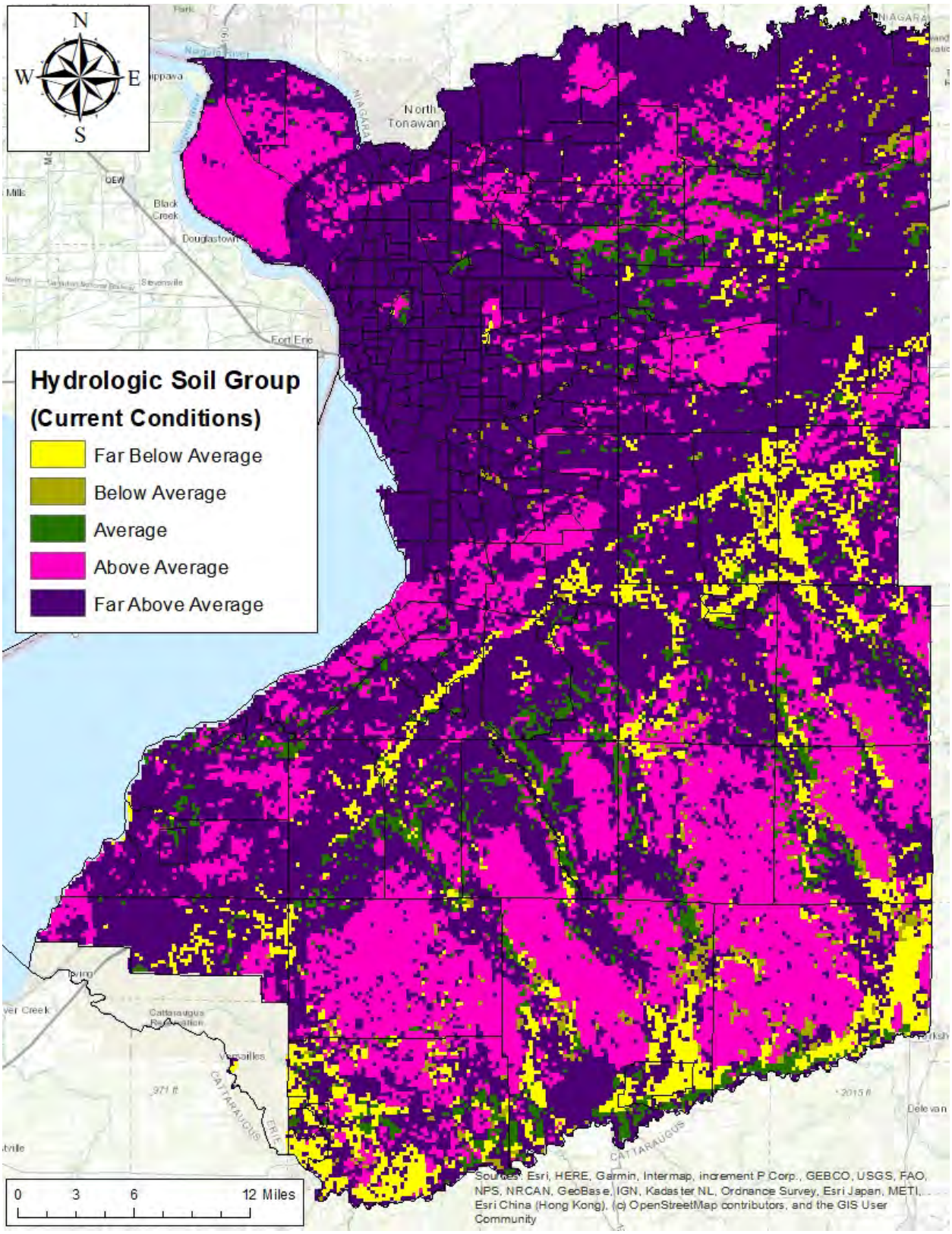



*Figure 10: Current conditions of Hydrologic Soil Group Units ranked by runoff potential*

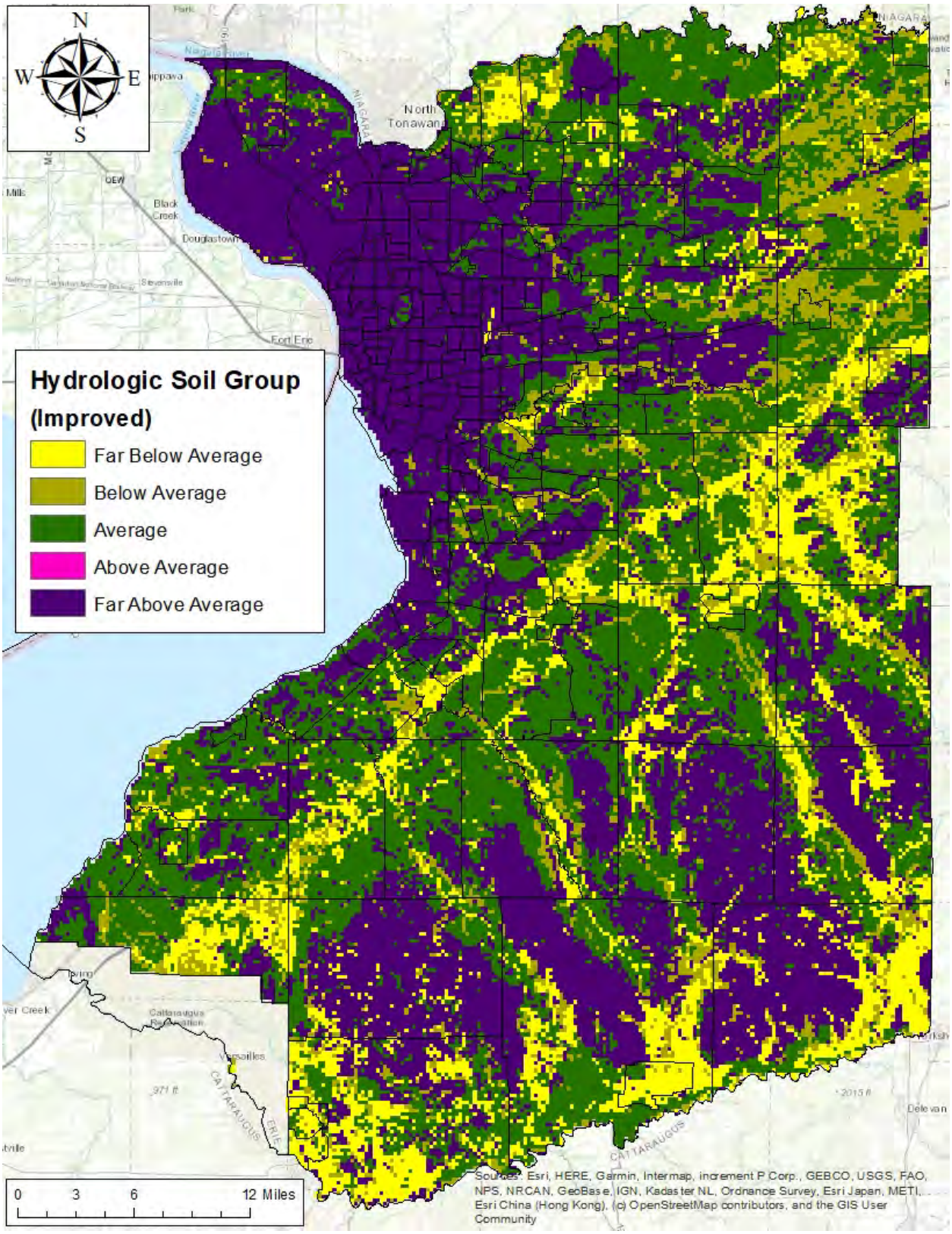



*Figure 11: Improved conditions of Hydrologic Soil Group Units ranked by runoff potential*

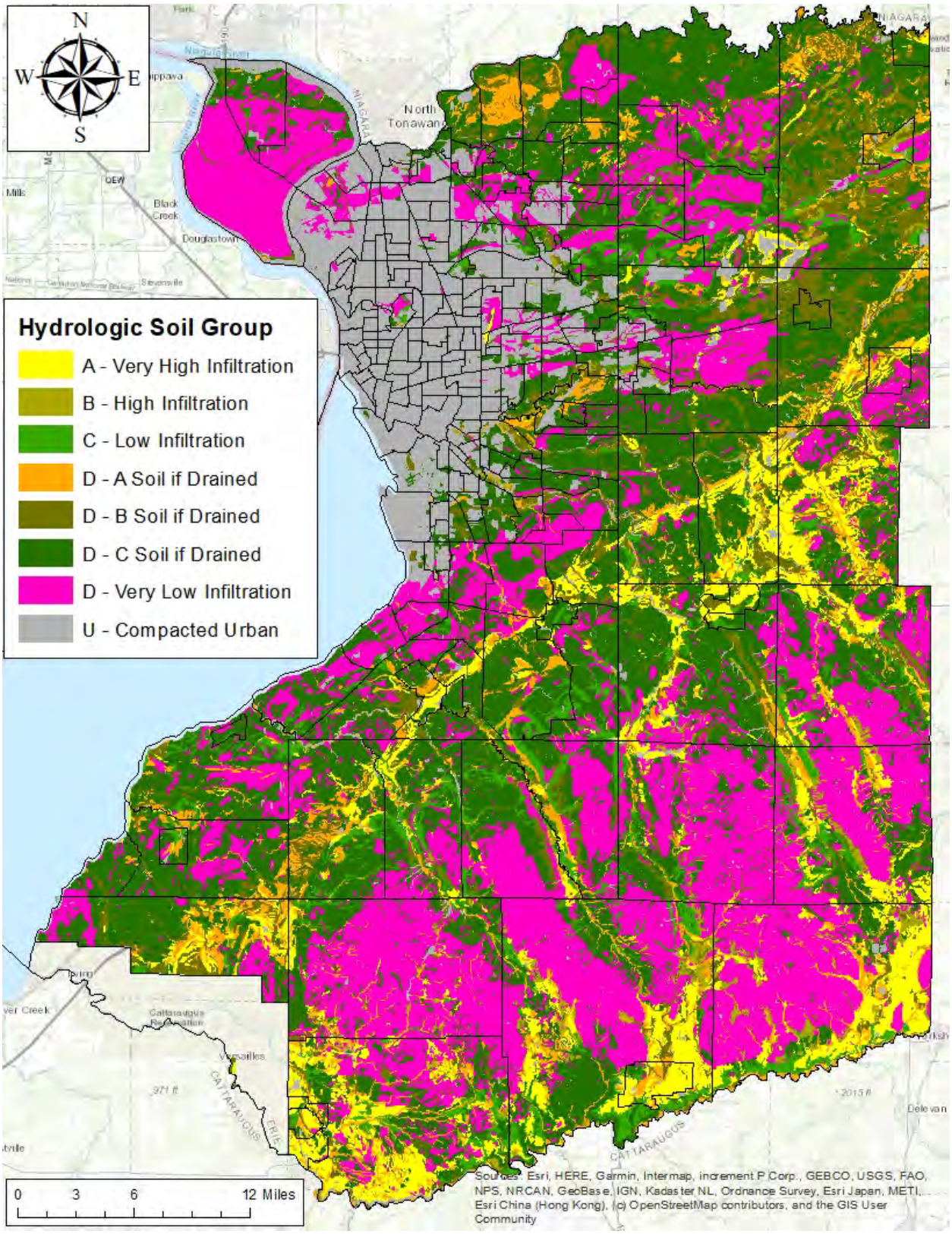



*Figure 12: Hydrologic Soil Group Units ranked by runoff potential*

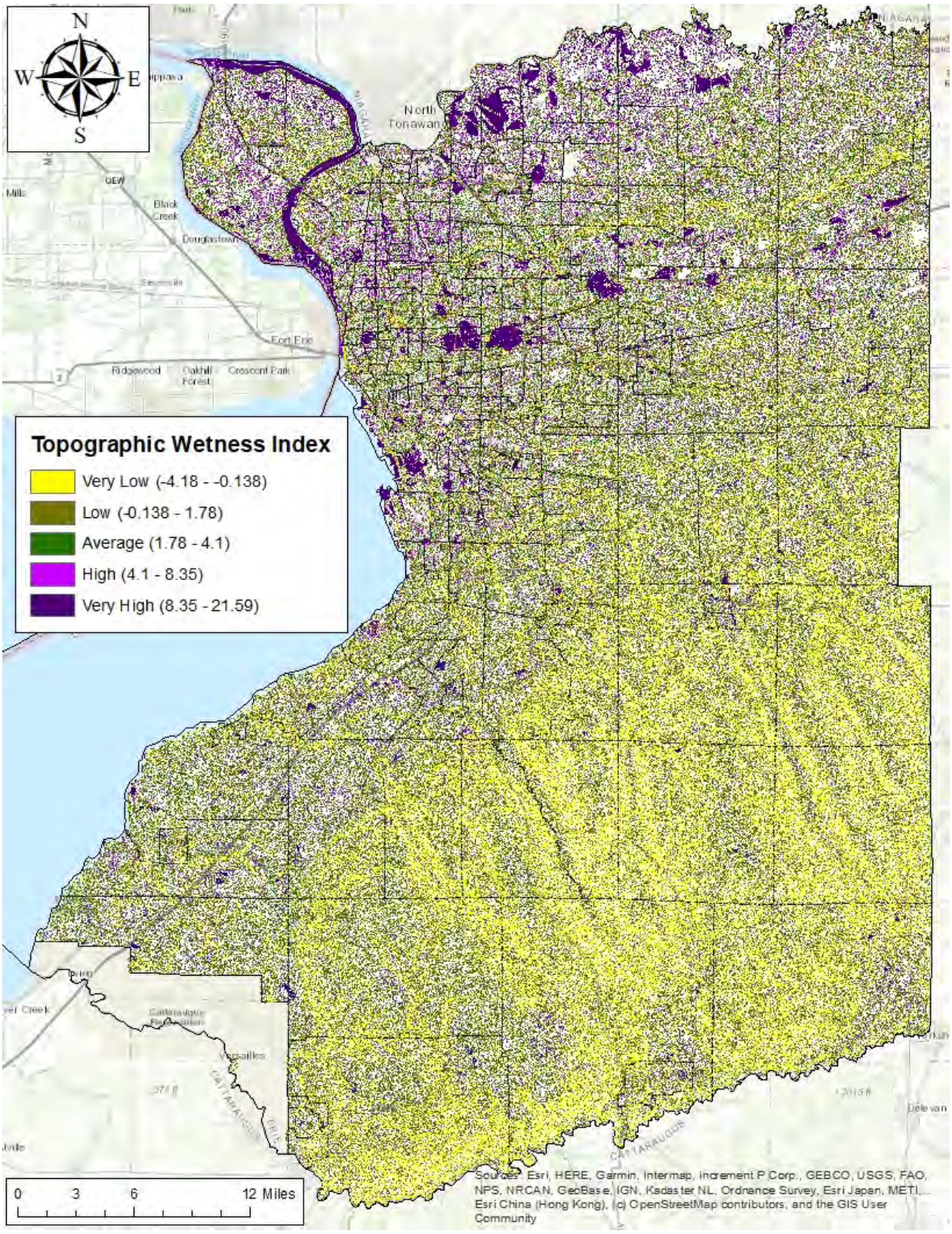



*Figure 13: Topographic Wetness Index created of Erie County representing low (purple), medium (green) and high (yellow) wetness potential. Units are displayed along with Erie County census tract blocks.*

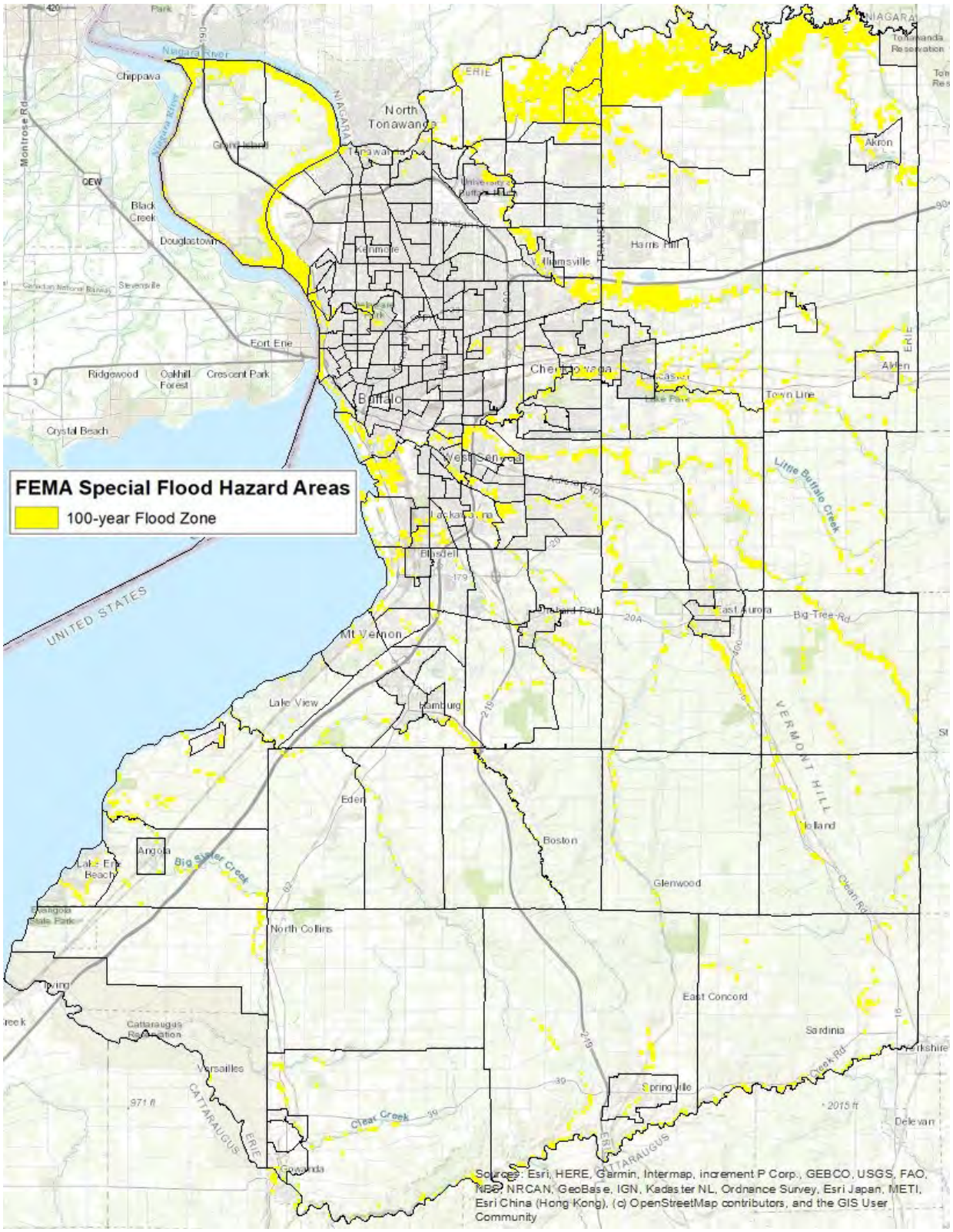



*Figure 14: Special Flood Hazard Areas as delineated by FEMA. These zones represent areas of "100-year flood risk". Zones are displayed along with Erie County census tract blocks.*

## Biological Threats

*Table 3: Species analyzed using USFWS RAMP tool in ArcMap GIS ( * denotes consideration as a key case study). Additional information available in the appendix of this report.*

| **Common Name** | **Species Name** | **Impact** |
|---|---|---|
| Hemlock Woolly Adelgid | *Adelges tsugae* | Invasive Species |
| Asian Tiger Mosquito* | *Aedes albopictus* | VBD/Invasive Species |
| Water Hyacinth | *Eichhornia crassipes* | Invasive Species |
| Goat's Rue | *Galega officinalis* | Invasive Species |
| Asian Longhorned Tick* | *Haemaphysalis longicornis* | VBD/Invasive Species |
| English Ivy | *Hedera helix* | Invasive Species |
| Himalayan Balsam | *Impatiens glandulifera* | Invasive Species |
| Deer/Black-legged Tick* | *Ixodes scapularis* | VBD |
| Spotted Lanternfly* | *Lycorma delicatula* | Invasive Species |
| Asian Swamp Eel* | *Monopterus albus* | Invasive Species |
| Wavyleaf Basketgrass | *Oplismenus undulatifolius* | Invasive Species |
| Asiatic Smartweed | *Persicaria perfoliata* | Invasive Species |
| Kudzu | *Pueraria montana* | Invasive Species |

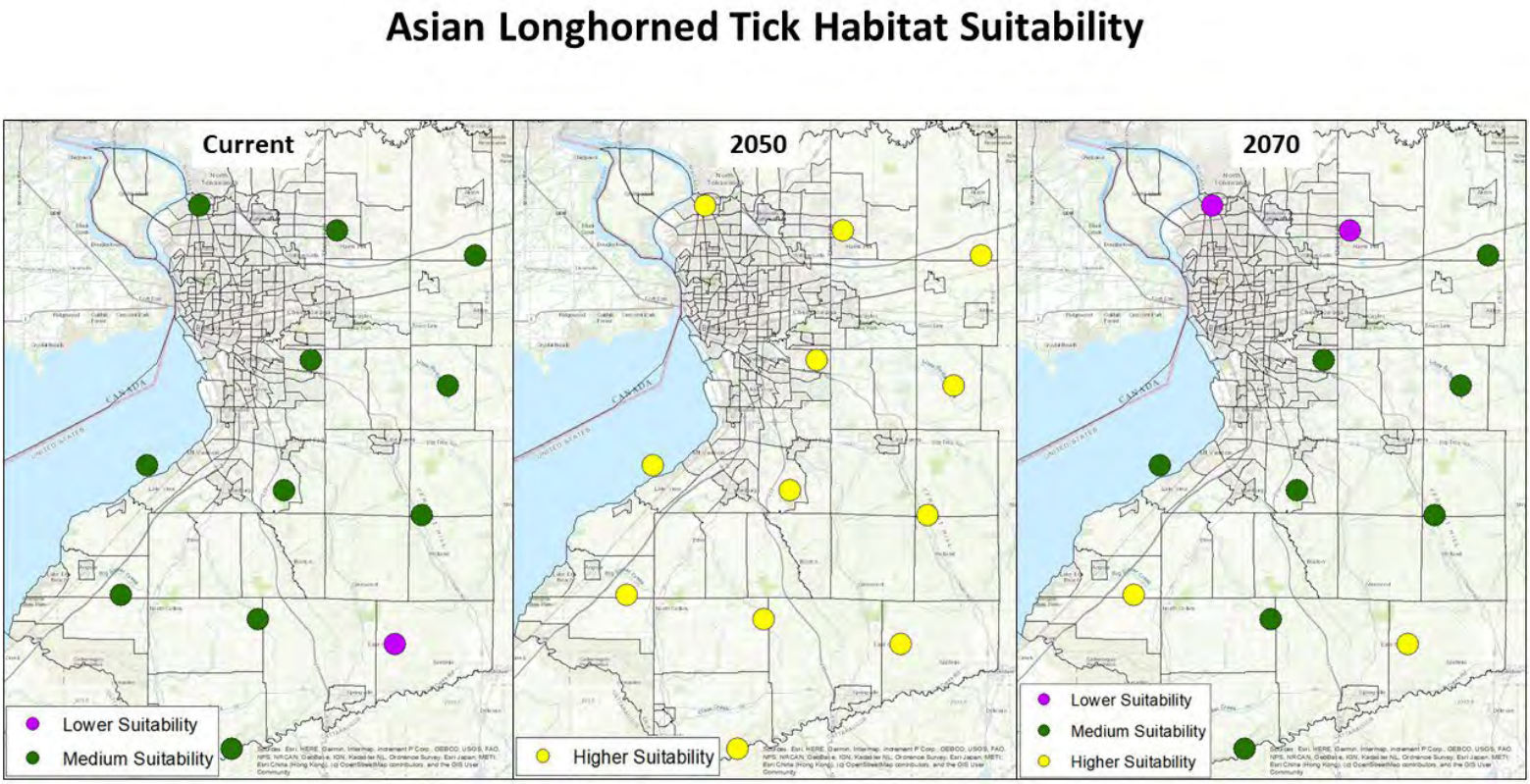



*Figure 15: Habitat suitability for the Asian longhorned tick in 3 time intervals using the RCP 4.5 scenario*

# Deer Tick Habitat Suitability

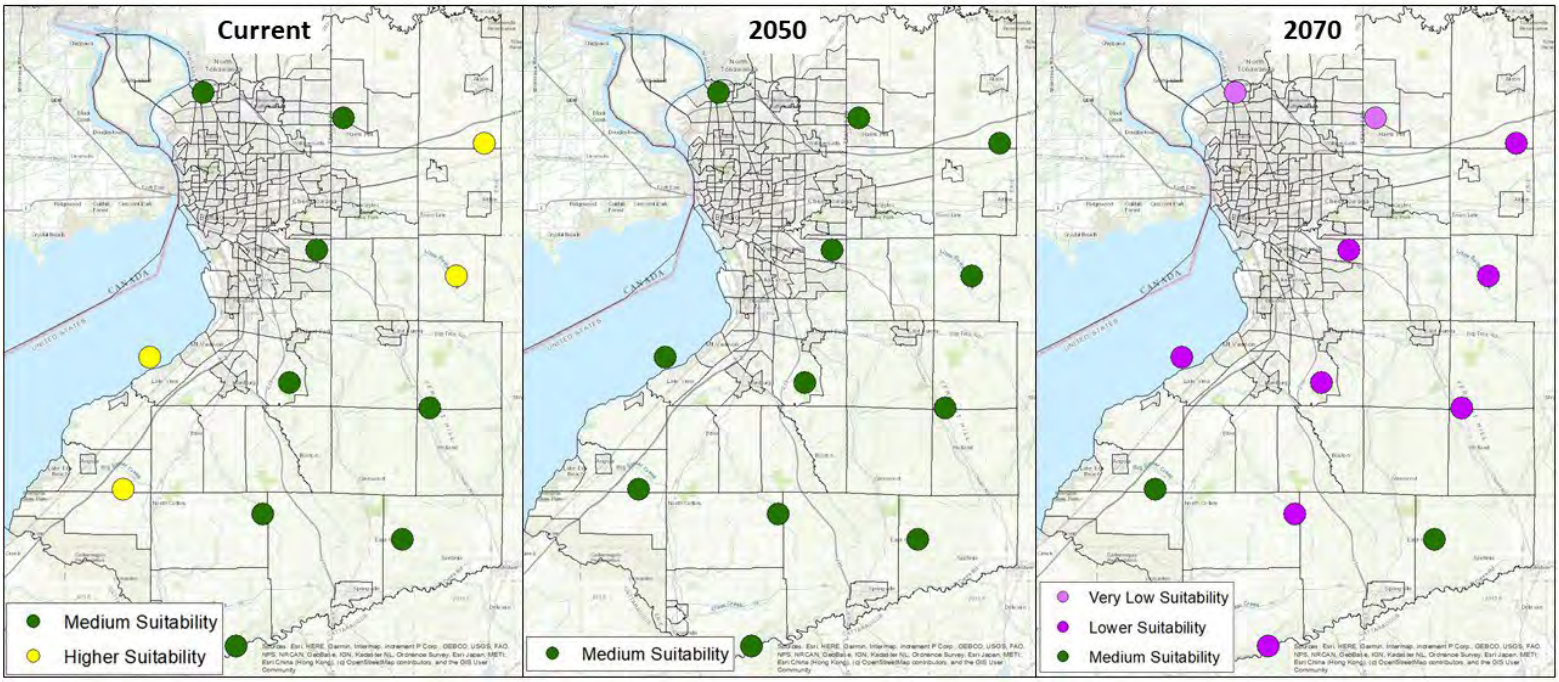



*Figure 16: Habitat suitability for the deer tick in 3 time intervals using the RCP 4.5 scenario*

## Wind

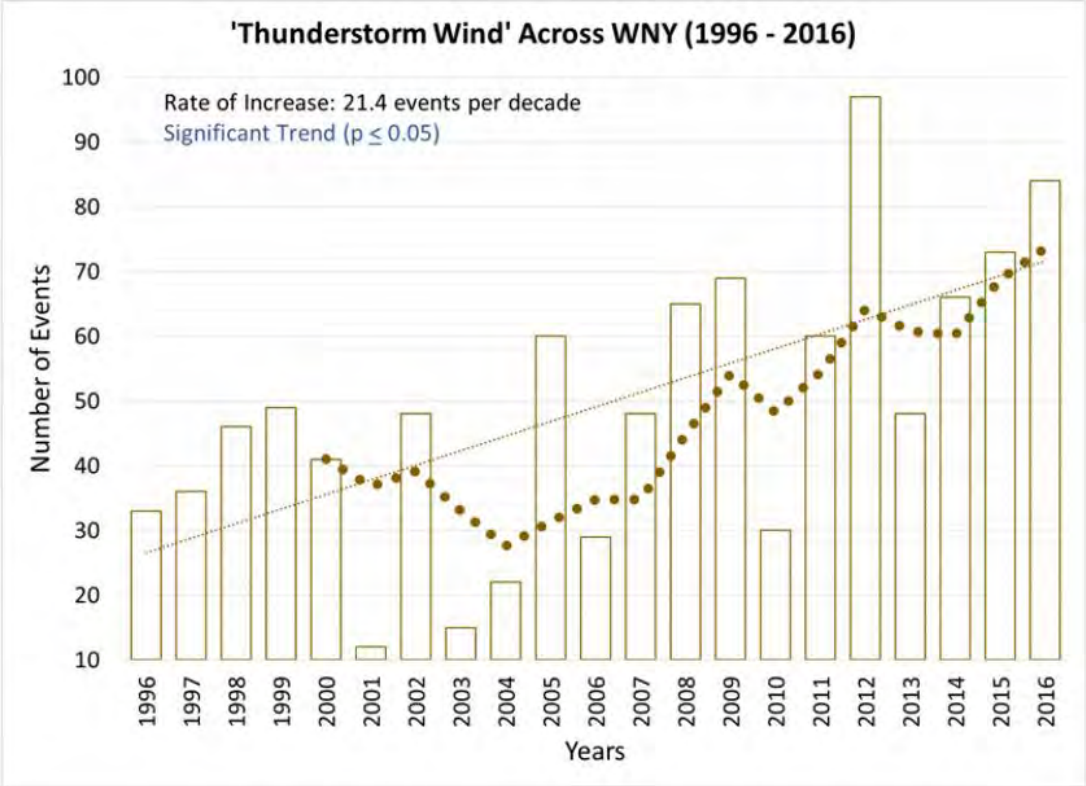
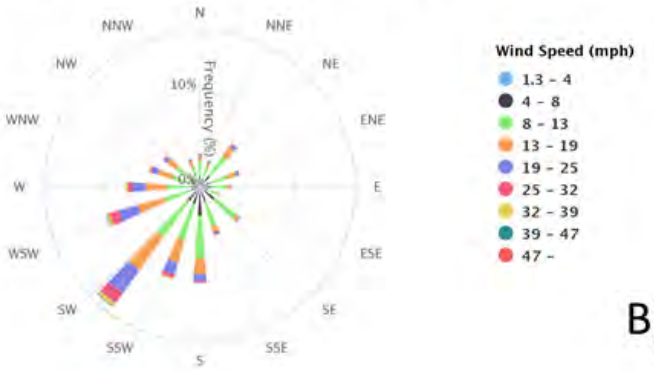
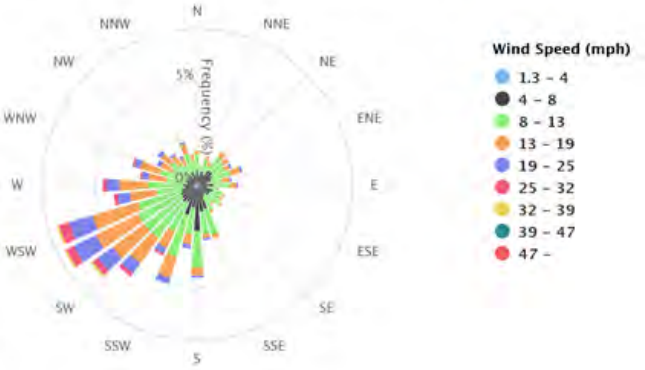



*Figure 17 : Frequency of thunderstorm wind events reported for WNY (1996-2016) (Vermette, 2017).*

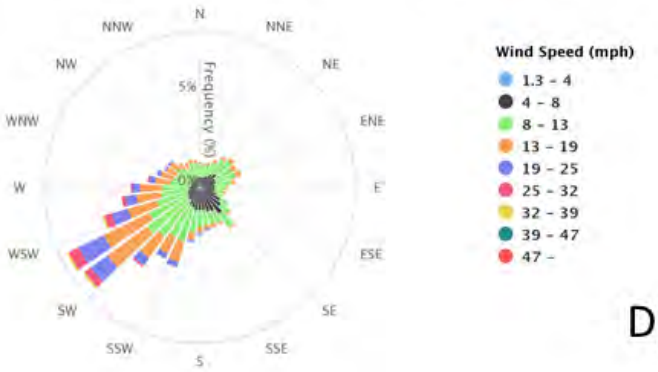
A) Wind rose for 1942 - 1962




B) Wind rose for 1962 - 1982




C) Wind rose for 1982 - 2002




D) Wind rose for 2002 - 2021

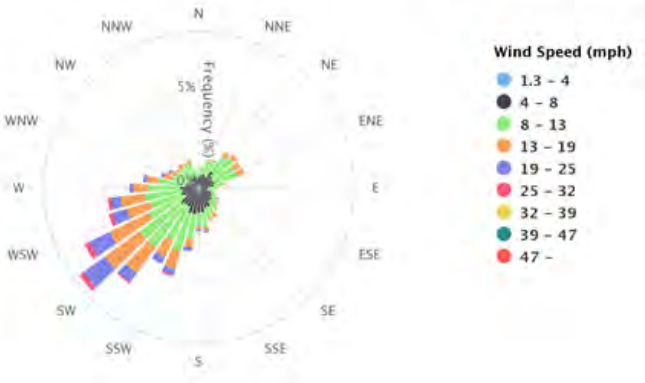



*Figure 18: Wind rose diagrams for the periods from 1942 - 2021 showing wind speed and direction in 20-year increments (NOAA, 2021).*

## Mobility

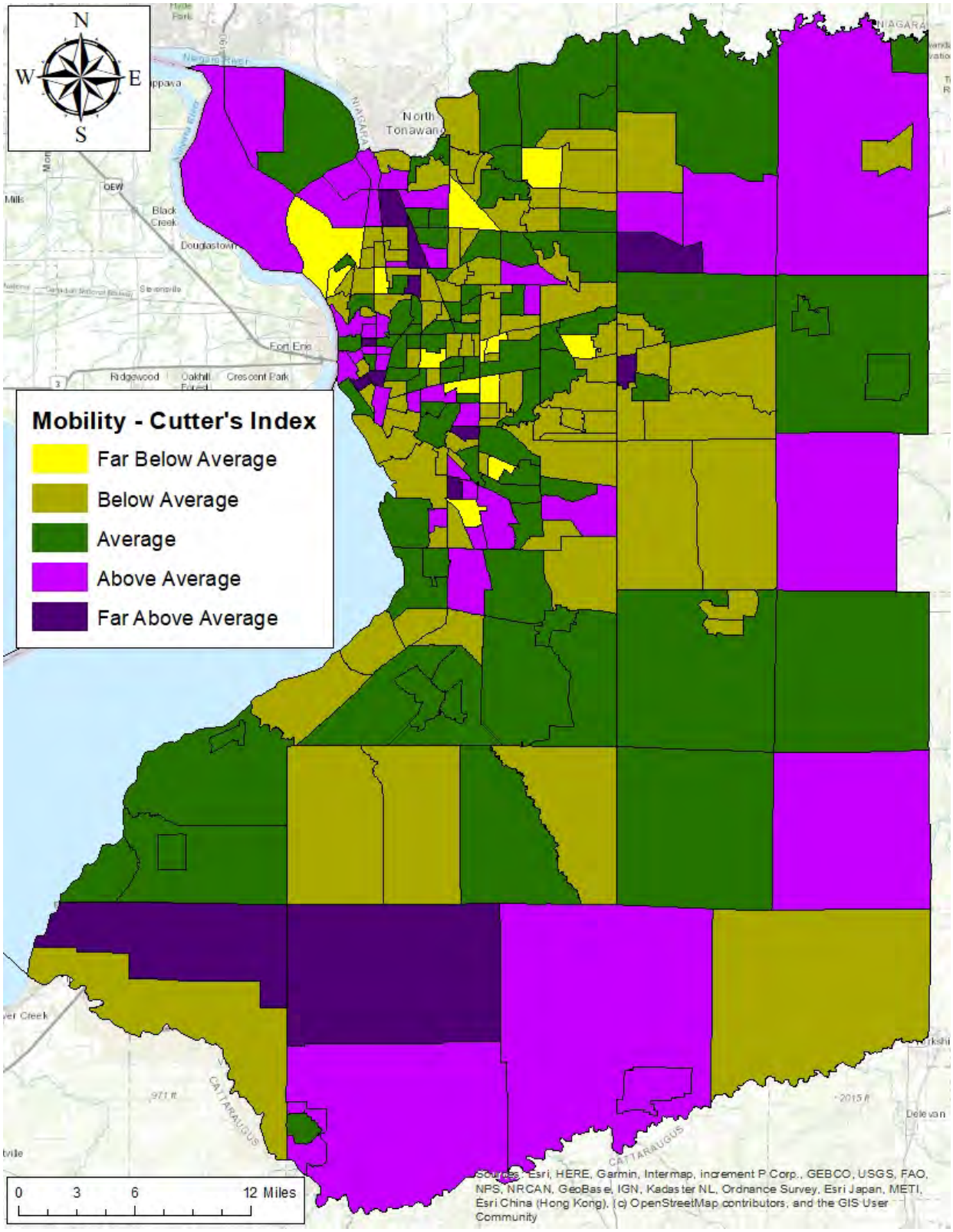



*Figure 19: Cutter's Resilience Index*

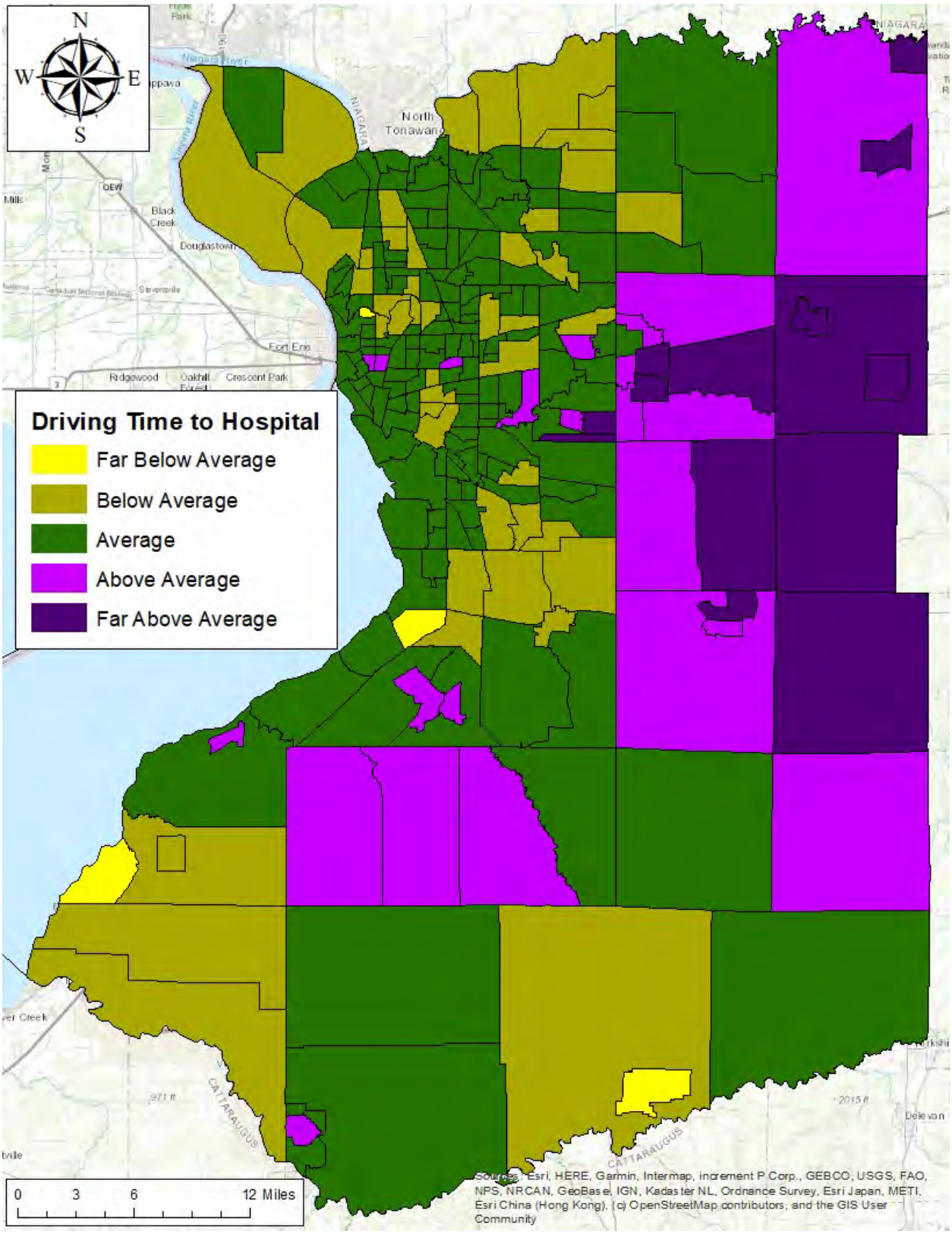



*Figure 20: Accessibility to Emergency Departments via driving*

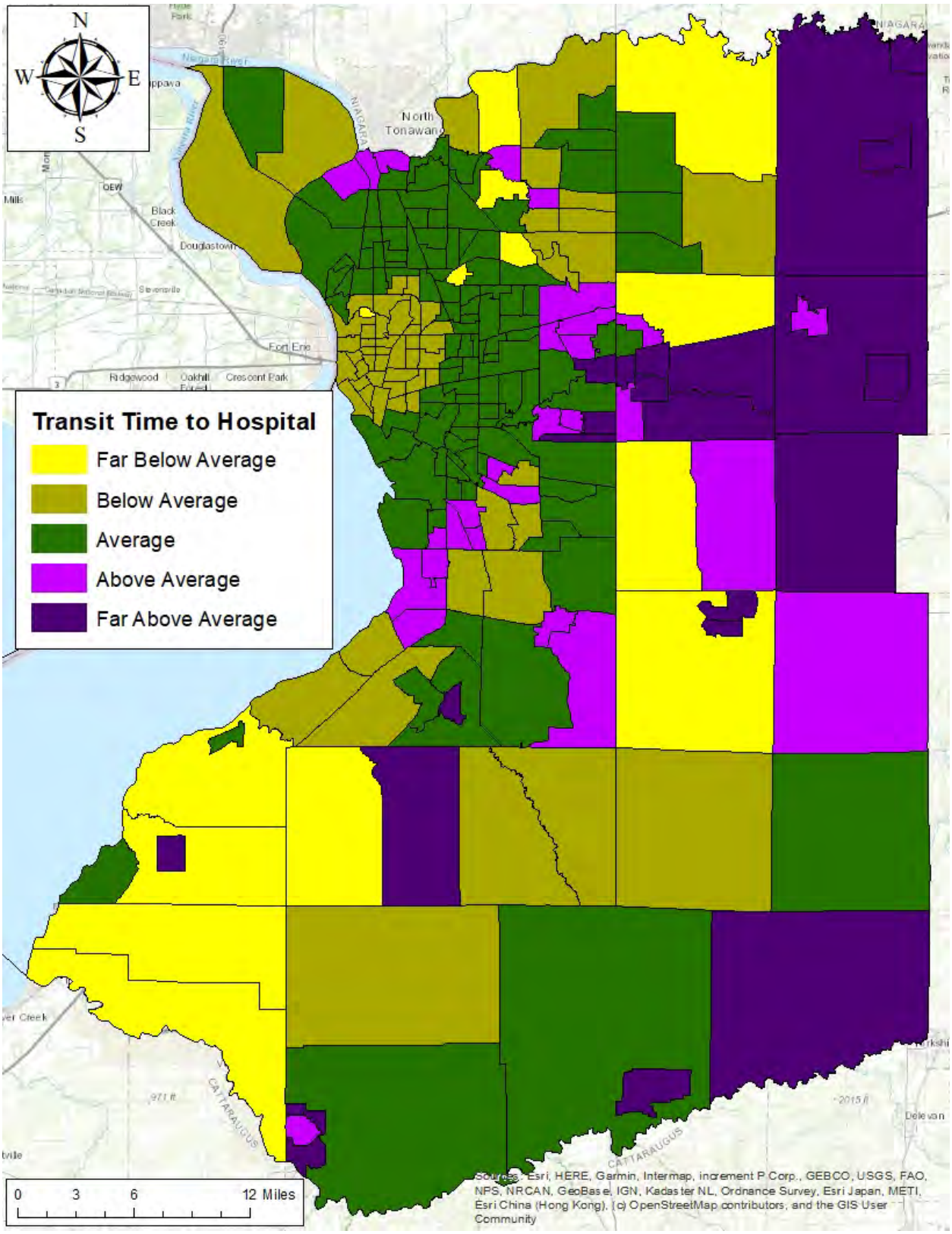



*Figure 21: Accessibility to Emergency Departments via transit*

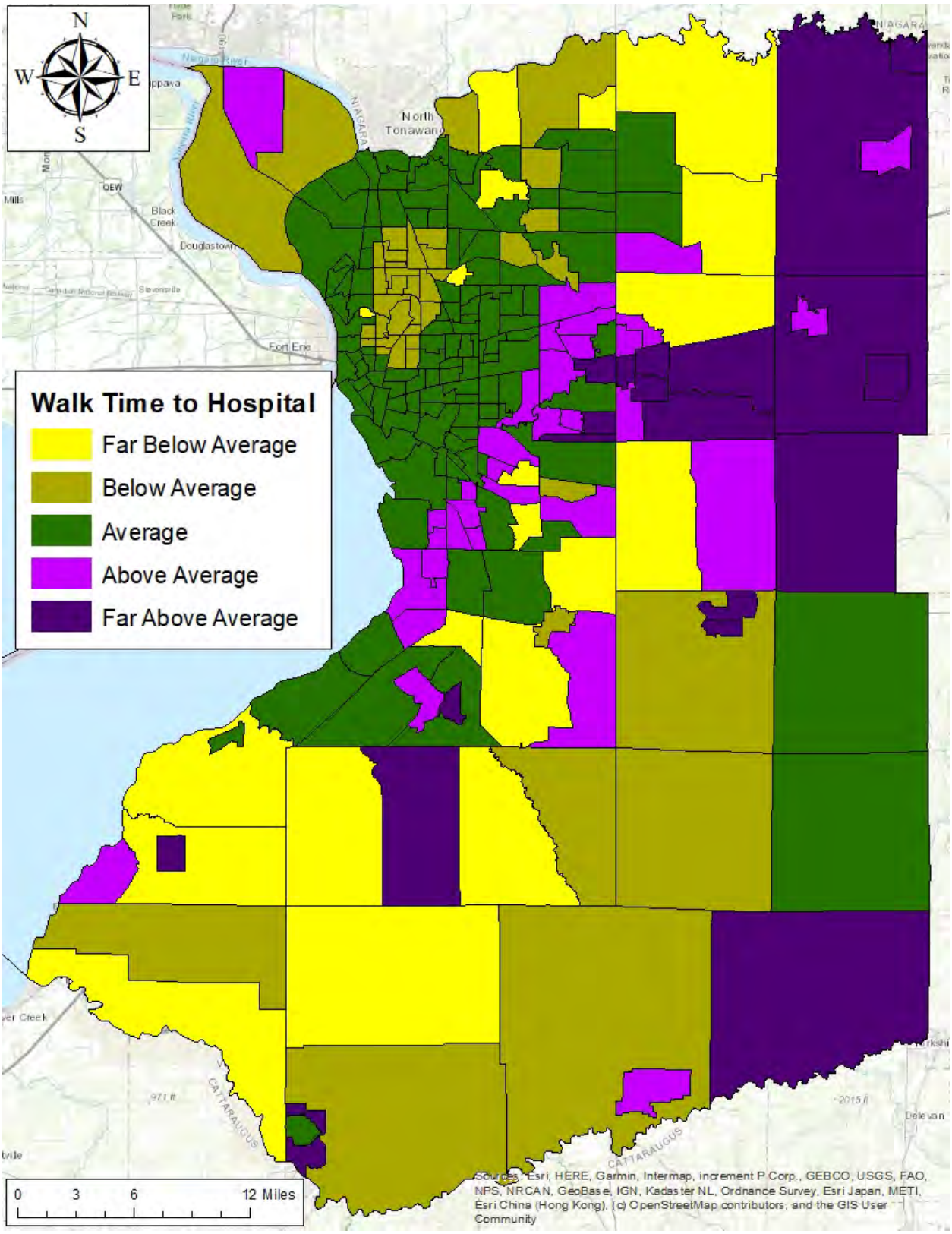



*Figure 22: Accessibility to Emergency Departments via walking*

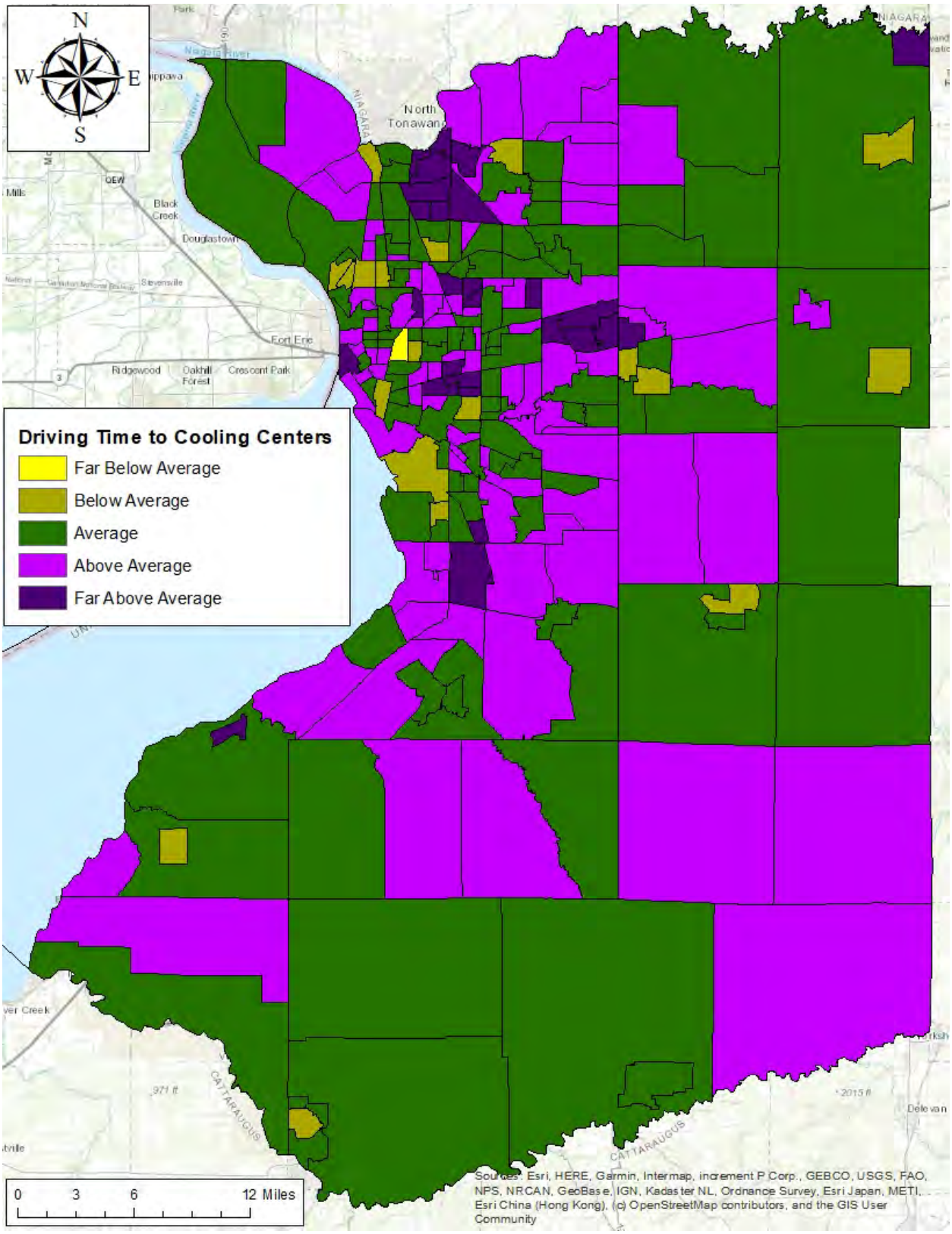



*Figure 23: Accessibility to Cooling Centers (libraries) via driving*

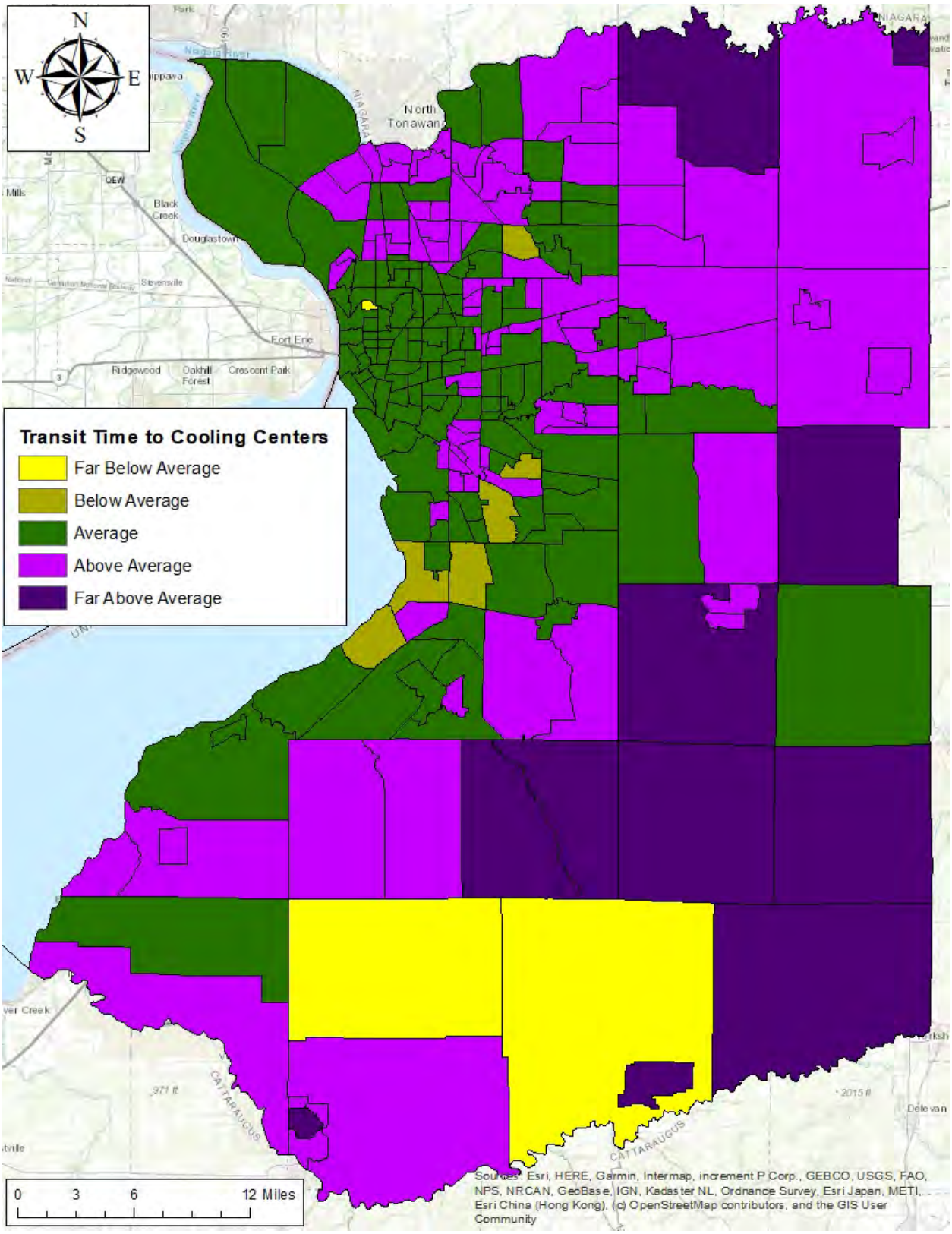



*Figure 24: Accessibility to Cooling Centers (libraries) via transit*

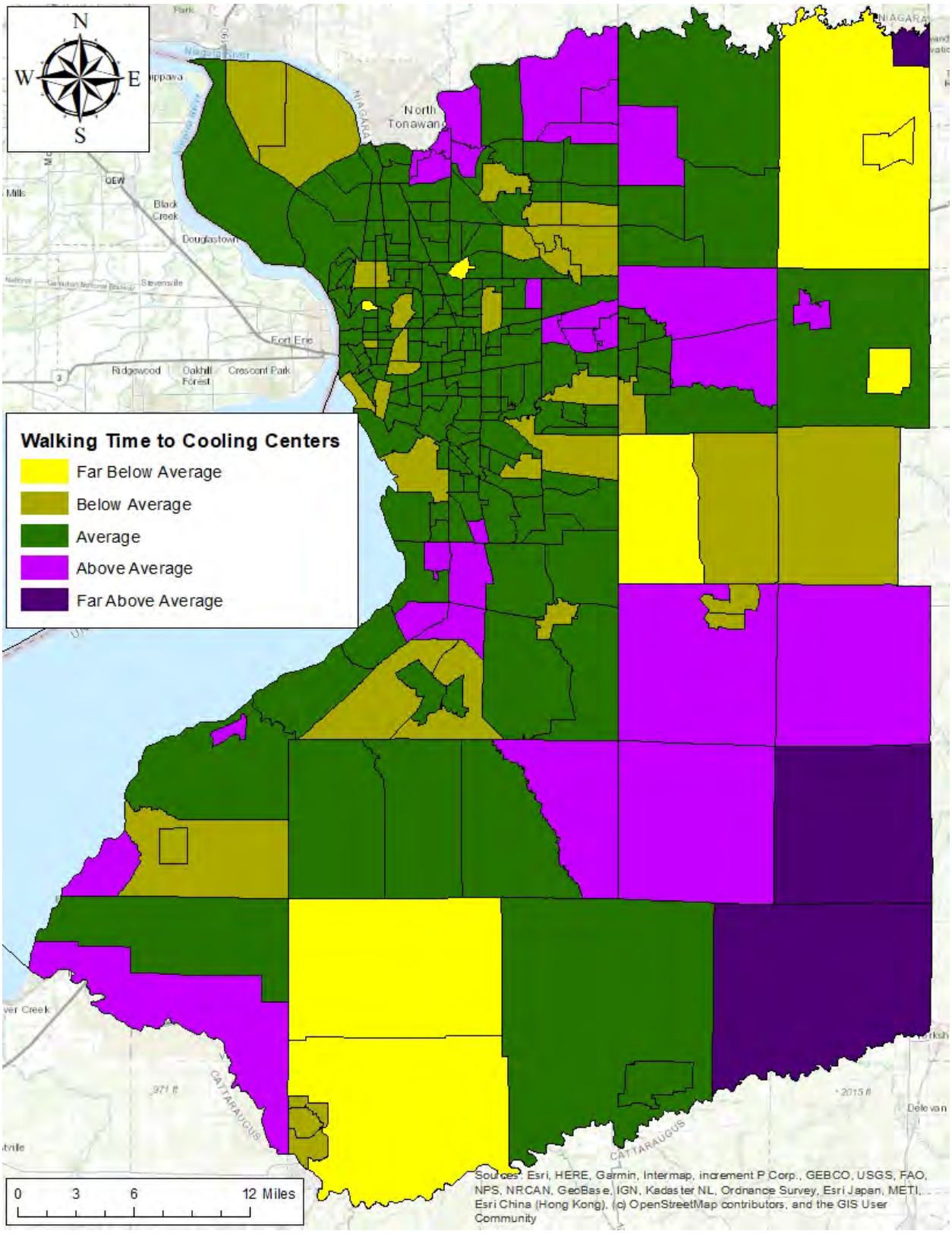



*Figure 25: Accessibility to Cooling Centers (libraries) via walking*