DRAFT-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, yellow-green indicates below average, green indicates average, pink 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:

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- 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.

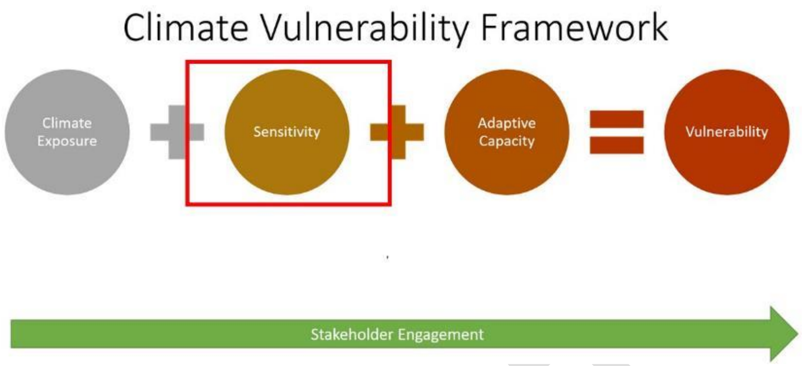


Figure 2: Climate Vulnerability Framework employed in this CVA process with Sensitivity highlighted as the aspect of vulnerability for which this report is focused.

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.

POPULATION AND DEMOGRAPHICS
Composition, Distribution, Socio-Economic status, etc.

ENVIRONMENTAL/ECOSYSTEM
Air quality, Soil, Biomass, Biodiversity, etc.

ORGANIZED GOVERNMENTAL SERVICES
Legal and security services, Health services, etc.

PHYSICAL INFRASTRUCTURE
Facilities, Lifelines, etc.

LIFESTYLE AND COMMUNITY COMPETENCE
Quality of Life, etc.

ECONOMIC DEVELOPMENT
Financial, Production, Employment distribution, etc.

SOCIAL-CULTURAL CAPITAL
Education services, Child and elderly care services, etc.

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
	% 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

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

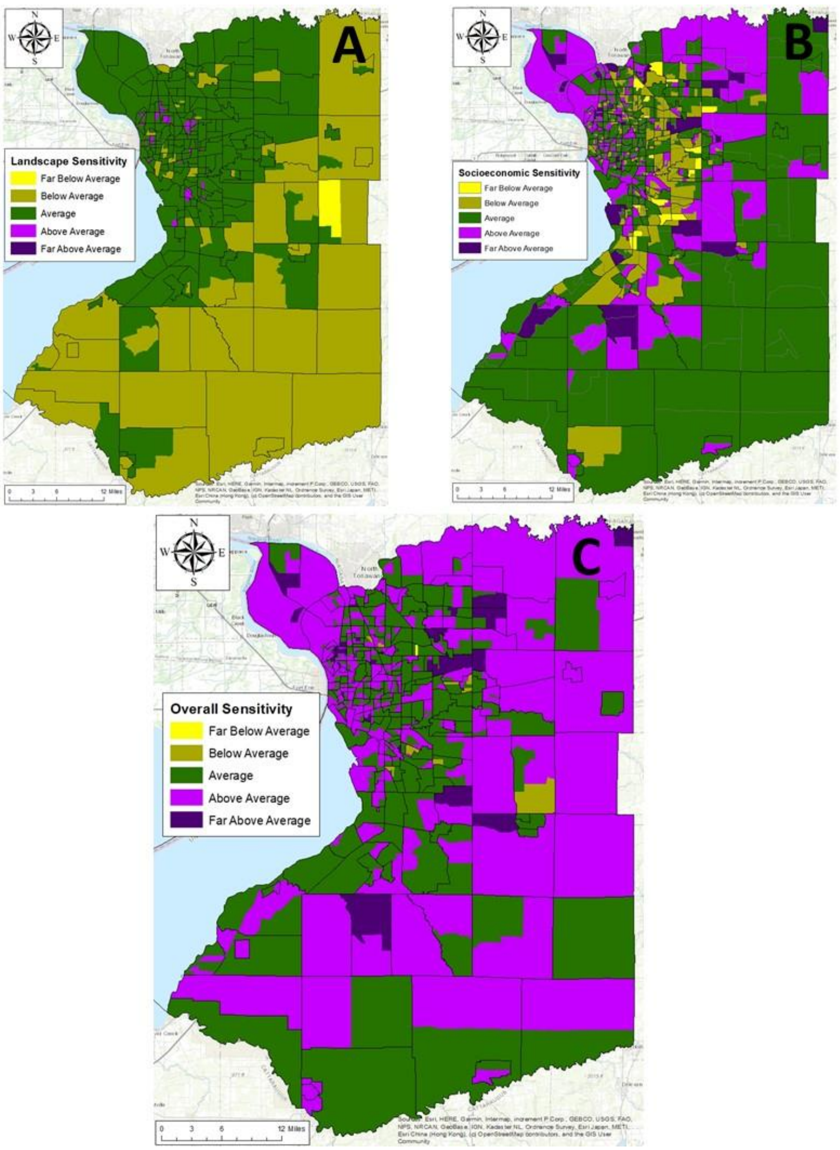


Figure 4: Overall sensitivity to extreme heat (c) derived from landscape (a) & socioeconomic variables (b)

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

Population and Demographics living in areas with a high sensitivity to the landscape are more at risk of extreme heat-related problems, even if they are not in a particularly sensitive population due to their socio-economic attributes. Likewise, sensitive populations are more at risk, even if they are not 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 Parks or forests in the county are very impactful concerning extreme heat. The trees contained within them are a part of exposure's heat sinks, which cool the area surrounding them. The shade they provide can be invaluable for sensitive populations in areas of extreme heat.). Accessibility to locations that can provide a climate-controlled is extremely important, whether their own home or a community or county run building, because not having access to this service makes people much more vulnerable 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 even 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 could be impacted by an extreme heat event, especially those in areas of high exposure. Physical infrastructure also impacts the microclimates surrounding it, with roadways and industrial parcels in particular being incorporated into the study as heat sources, and with buildings and asphalt in general contributing to the urban heat island effect discussed before.	**P**
Even not during 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.	**L**
An extreme heat event can impact both personal, corporate, and county **Economic Development**. On the personal end, cooling costs can increase during an extreme heat even. Corporate-wise, any 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. Finally, for the county, pipelines and other materials can shift during an extreme heat event.	**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. Both adding more emergency personnel and adding more shade to an event can put financial strains on event hosts.	**S**

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 the block group 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 does have 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

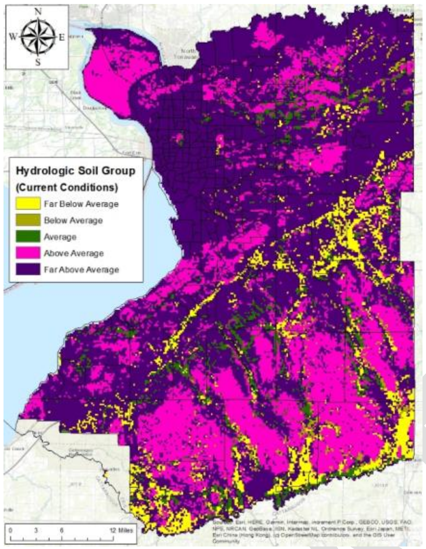
Group	Properties	Rank
A	Rapid Infiltration	-0.75
B	Weak Infiltration	-0.5
C	Low Infiltration	+0.25
D*	Undrained A-B-C Soils	+0.75
D	Very Little Infiltration	+0.75
U	Compacted Urban	+0.8

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.

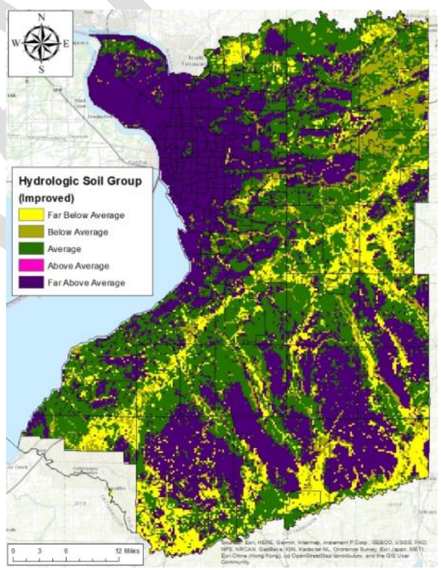
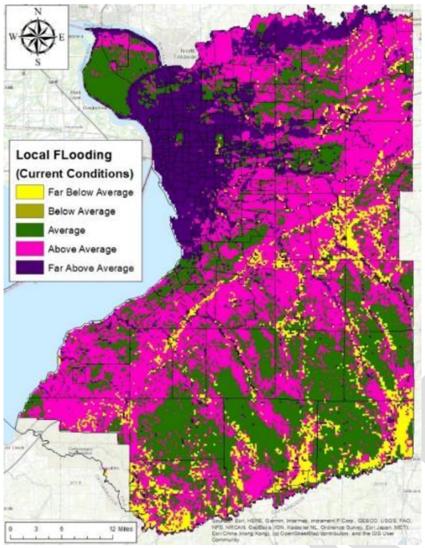


Figure 5: Infiltration capacity of soils (current versus improved drainage conditions)

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.

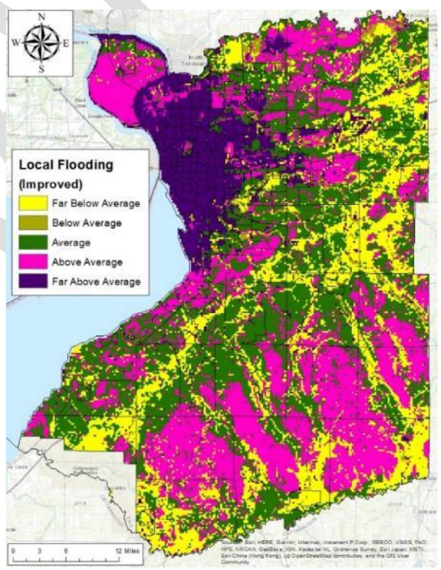


Figure 6: Sensitivity to local flooding (current versus improved drainage conditions)

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, potentially increasing risk of flooding.

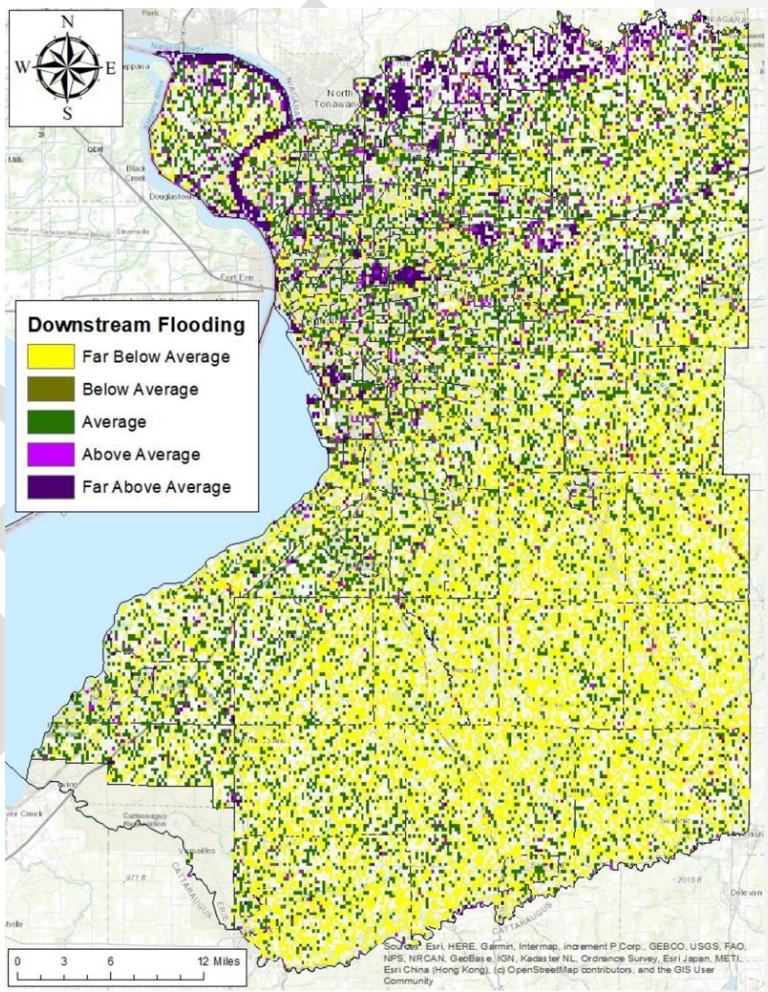


Figure 7: Sensitivity to downstream flooding from sources of runoff

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

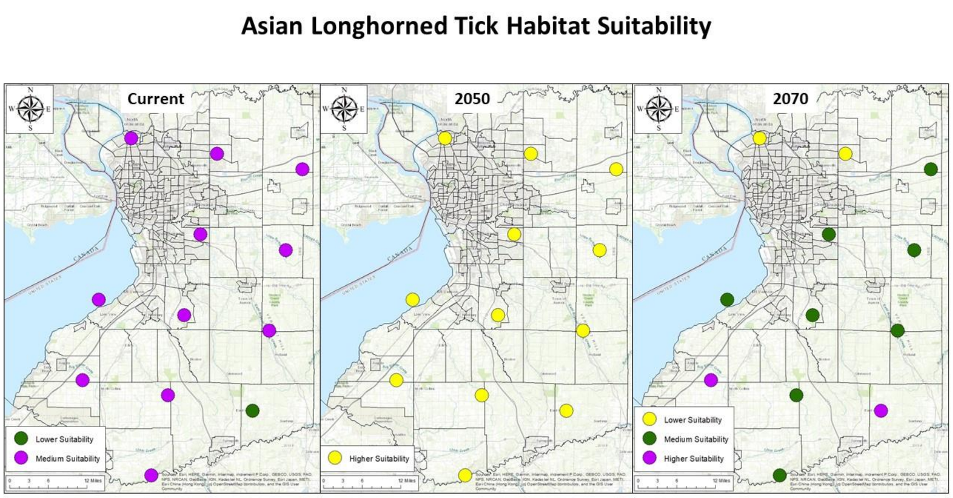
Populations and Demographics such as Erie County employees and vulnerable residents may be impacted by on-site flooding and runoff generation in a variety of ways. Erie County employees tasked with managing damage to infrastructure or risk to the public may be at risk of injury when managing extreme 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 an 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 provided by the County, the **Lifestyle & Community Competence** is impacted. This 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 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. To do this, 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



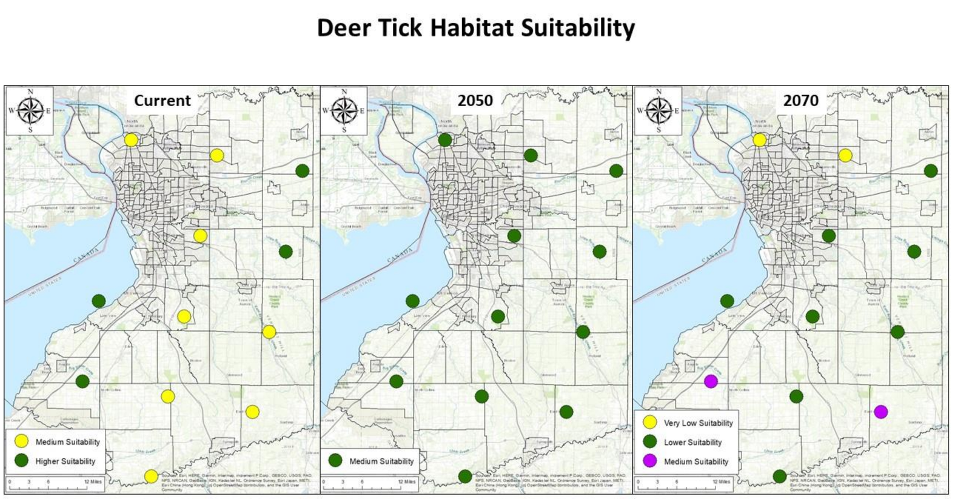


*Figure 10: Habitat suitability as modeled by USFWS Risk Assessment Mapping Tool (4.5 RCP scenario), showing suggested suitability in current conditions, 2050, and 2070. *Note differing color display in these maps where colors denote relative habitat suitability,*

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).

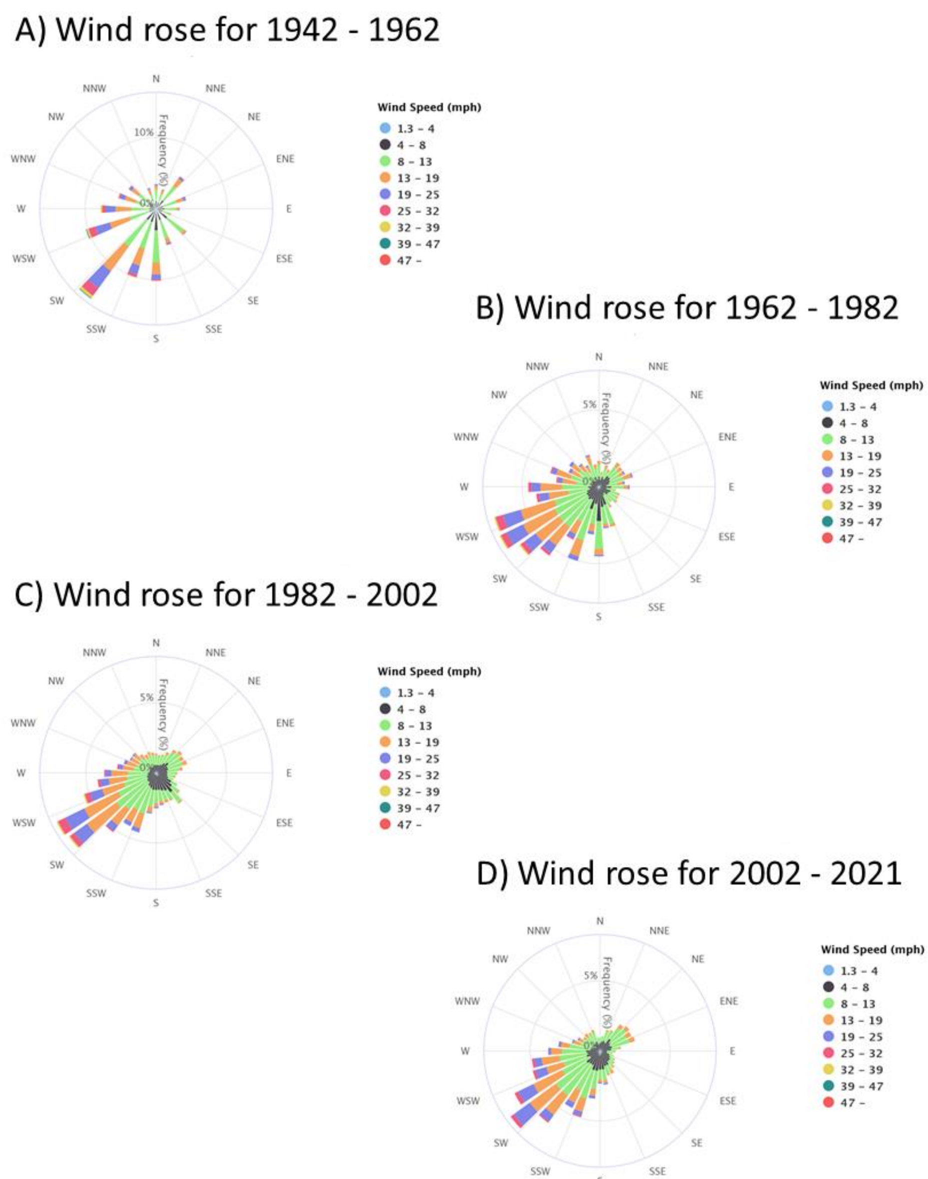


Figure 11: Wind rose diagram for the Western New York area. The diagrams show how wind speed and direction is beginning to shift.

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 these threats 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 amount of 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.

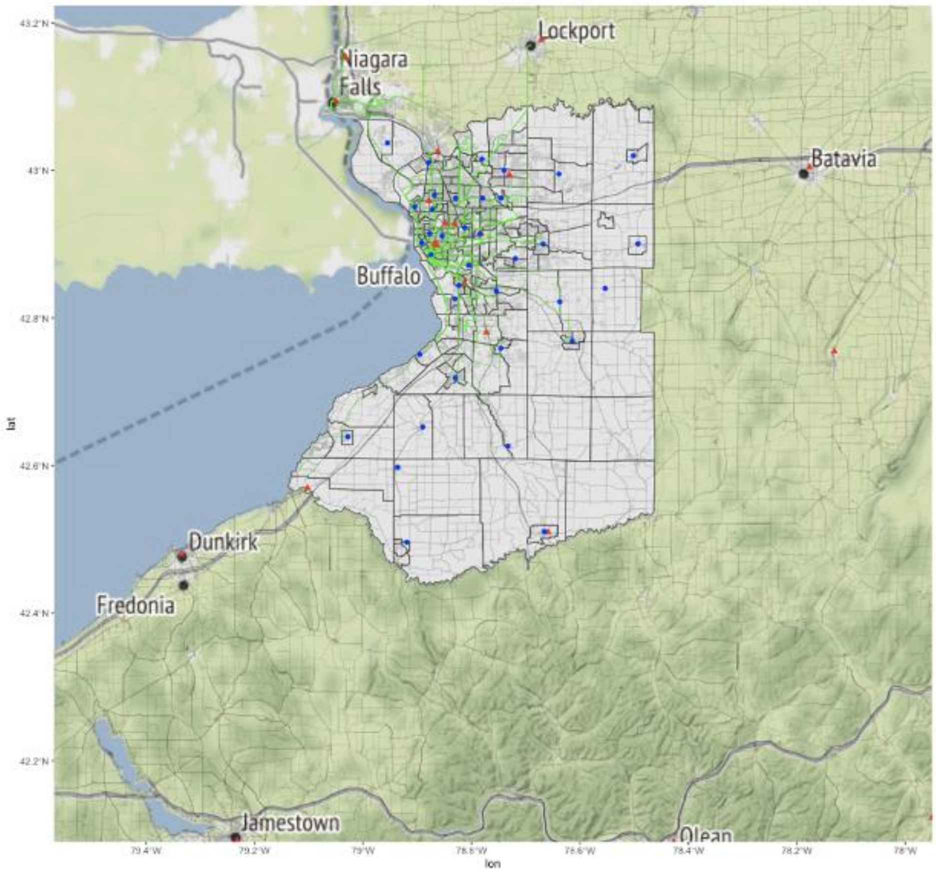


Figure 12: Erie and Surrounding Counties with Roads (grey), NFTA-Metro System (green), EDs (red), and CSs (blue)

Methodology

The methodology for this component of the Assessment was chosen to highlight the comparative accessibility of Western New York area hospitals with emergency departments (EDs) and 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

Commented [SC1]: any way to make this bigger? I don't think we need the lat and lon on the axis, you can't read them anyway.

Commented [JT2R1]: I am working with Michael to generate a better image 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 the 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 can investigate 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 for each transportation mode, each showing the minimum travel times by mode 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.

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 TRAVEL TIME

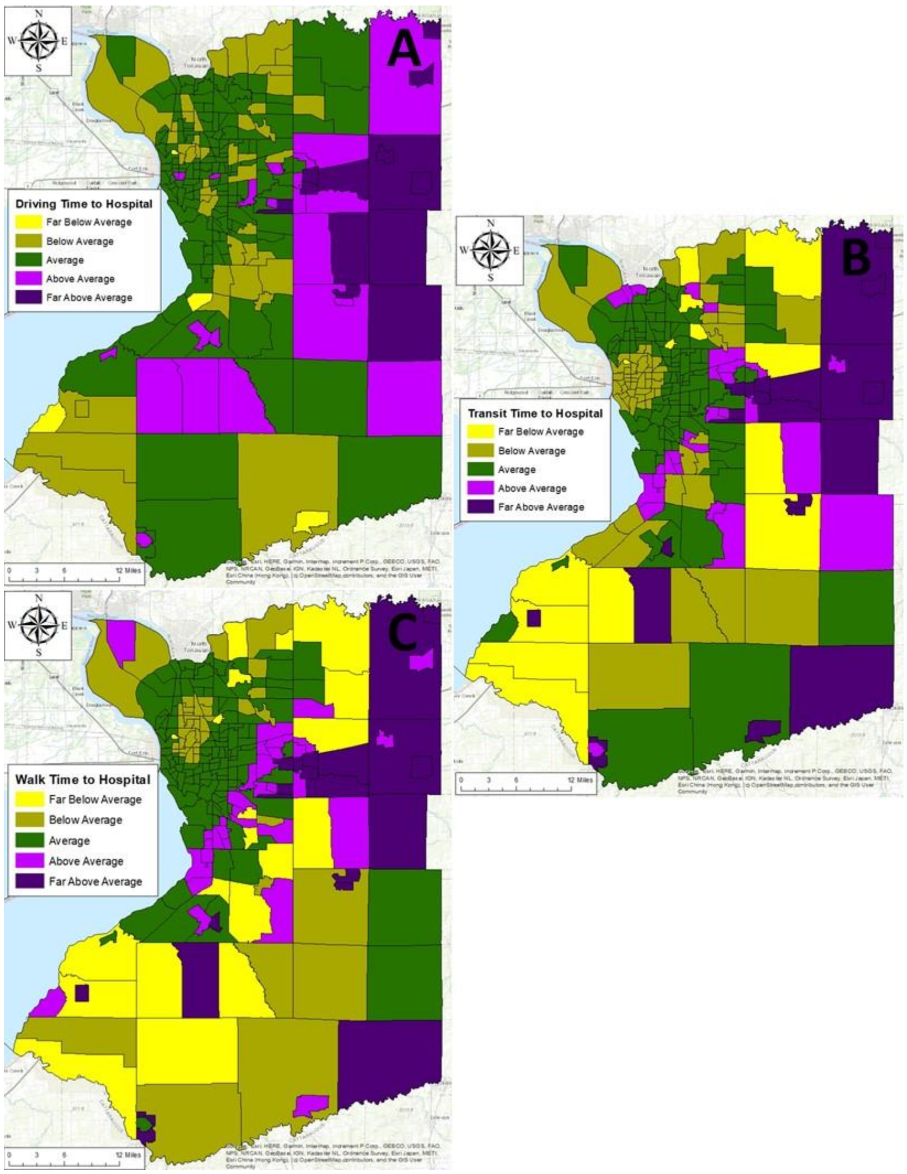


Figure 13: Accessibility of EDs via driving (a), transit (b) and walking (c).

ACCESSIBILITY OF COOLING CENTERS IN ERIE COUNTY BASED ON TRAVEL TIME

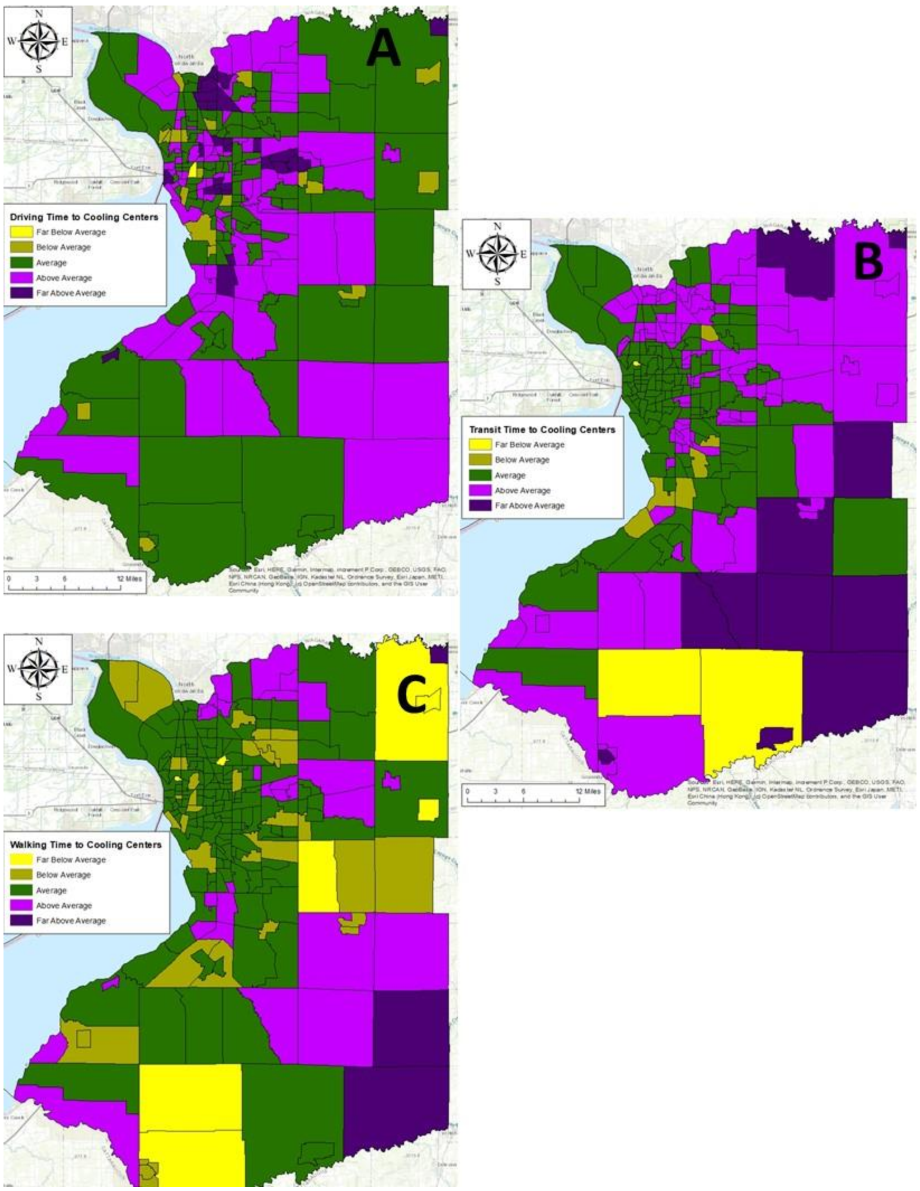


Figure 14: Accessibility of CS via driving (a), transit (b) and walking (c).

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 Travel 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 13(b) shows the comparative travel times by transit or public transportation. Here, the clustering in the urban areas and the eastern rural areas is much more pronounced. Some relative changes also occur in the southwestern portion of the county where many tracts display travel times even further below what is expected (compared to driving times), and a few actually switch from having shorter travel times than expected to having longer travel times than expected when comparing this map to the one for the driving time model. Note that it is these southwesterly tracts that have the greatest accessibility relative to their levels of vulnerability and resilience. Some changes are also visible in the eastern part of the county where some tracts go from above average travel times for drive times, to below average for transit times. The reason for these changes is likely to be driven by the geography of the NFTA-Metro lines. NFTA routes are clustered near Buffalo but a few lines run along the lake shore and out into the eastern parts of the county. Since this map only considers travel times via public transit, many of these changes make sense. For the most vulnerable tracts in Figure 13(b), the average travel time is approximately 196 minutes, or otherwise infeasible in the case of an emergency.

Finally, the Figure 13(c) displays the travel times if one were to walk to an ED or CS. By visual inspection, this map appears to be the most clustered. The lower than expected travel time cluster in the City of Buffalo is north and east of the one uncovered in the transit results. It is similarly surrounded by many average travel times. However, a southwest-northeast oriented area of higher than expected travel times is uncovered, nearly unbroken, just outside of Buffalo. Beyond these census tracts, these is a similarly-oriented region of tracts with walking travel times much lower than expected. Lastly, the most easterly part of the County again shows much higher relative travel times. Since absolute travel times are similar for many of these areas, the patterns displayed are likely induced by changes in vulnerability from Census tract to Census tract. It is also worth noting where some values that are near to average in the transit travel time results, become far below average for walking. These tracts mostly lie towards the

[1] Preliminary results pending further review

south and southeast of the City of Buffalo, indicating relatively more accessibility for those whom neither driving nor public transit would be an option for reaching a hospital. For the most vulnerable tracts in Figure 13(c), the average travel time is 212 minutes, or otherwise infeasible in the case of an emergency.

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.

Figure 14(b) displays the results for vulnerability in terms of accessibility to CSs via public transit. Here, the more rural tracts generally show the highest vulnerability in rural parts of the County where it is not feasible to use public transit to reach a CS. This makes sense. If transit lines are far away and public transit is the only means to reach a CS, then CSs will be inaccessible. Some interesting results lie in the Census tracts constituting Springville, Concord and North Collins. In these census tracts, where public transit is not available, travel times are initially assumed as being equivalent to walking the same distance. On average, as population density increases, travel times decrease. Therefore, Springville, with high population density, ought to have generally low travel times. However, without any transit lines, when the comparing Springville to other similar lcoations, the accessibility of CSs is comparatively much lower. The result is an increase in relative vulnerability. On the other hand, for Concord and North Collins, these tracts are among the least densely populated in the county. However, the large size of these tracts works in their favor as population density is low. To illustrate this, consider that Concord and the western tract of Boston have roughly the same population, but Concord is between two and three times the size of Boston's western tract. The result is that the population density of Boston's western tract is more than twice that of Concord. Being that this approach is relative, not absolute vulnerability, Concord is designated as a low vulnerability tract and the western tract of Boston is designated as a highly vulnerable tract. How high? For far above average tracts on this map, the mean travel time is approximately 87 minutes. In many cases, it would be infeasible to travel for 87 minutes to seek shelter from extreme heat. However, this is significantly lower than the 196 minutes needed for an individual to reach an ED via public transit from one the most vulnerable tracts in Figure 11(b).

Finally, Figure 14(c) displays the results for vulnerability in terms of accessibility to CSs when traveling by foot. These too are driven most strongly by population density and by absolute travel times. Likewise, the most vulnerable census tracts lie in the rural parts of the County, as well as near the airport and slightly to the east in Lancaster. For the suburban tracts, population density is high but roads are sparse, increasing walking times and therefore vulnerability. For the rural tracts, roads are sparse and travel times tend to be even longer, resulting in even higher overall vulnerability. Like the transit map, large rural tracts, with lower population density tend be less vulnerable as a whole, such as near North Collins and Collins center. The wide distribution of CSs however, increases accessibility overall. Even for the most vulnerable Census tracts in Figure 14(c), or those with the relative travel times farthest above average, the average absolute travel time is 35 minutes, which, in many case cases, might be feasible for accessing a CS during an extreme heat event.

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

Populations and Demographics living more distantly 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. Please refer to the sections on Thermal Vulnerability and Flooding.	**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. In the results above, travel times to EDs and CSs are shown relative to their level of social vulnerability are displayed. In the event of an extreme hazard, it is the citizens who live in the least accessibility tracts that will have risk exacerbated by the amount of time it will take to reach an ED or CS. Therefore, it may be useful for planners to keep a watchful eye on these tracts.	**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, transit time, and walk time models are all 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. 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. For all transportation modes, this tract is identified as having travel times above or far above average relative to its level~~s~~ of vulnerability and resilience. The accessibility of this area is seemingly poor because the nearest hospitals are quite far and 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.