DEVELOPMENT OF A SPATIAL MUNICIPAL VULNERABILITY INDEX

PHASE 2 REPORT: MVI FACTORS AND FRAMEWORK METHODS

FINAL REPORT

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Contents

List of Tables

List of Figures

1. Overview

1.1 Background

In September 2020, the Vermont legislature passed the Global Warming Solutions Act (GWSA) that requires the state to aggressively reduce its gross greenhouse gas emissions (GHGs) to at least 26 percent below 2005 levels by 2025, 40 percent below 1990 levels by 2030, and 80 percent below 1990 levels by 2050.[1] To help achieve these reductions, the GWSA created the Vermont Climate Council (VCC)[2] and charged them with developing a Climate Action Plan (the Plan) to provide a framework and planning process for reducing climate pollutants and preparing for the impacts of climate change.[3] The GWSA also required the VCC to create a specific set of subcommittees to assist in the Plan's development and carrying out related duties, including the Rural Resilience and Adaptation Subcommittee.[1]

The GWSA mandated the Rural Resilience and Adaptation Subcommittee to "focus on the pressures that climate change adaptation will impose on rural transportation, electricity, housing, emergency services, and communications infrastructure, and the difficulty of rural communities in meeting the needs of its citizens that sets greenhouse gas emission reduction requirements."[4] Moreover, the GWSA specifically requires that the Rural Resilience and Adaptation Subcommittee advance the development of a municipal vulnerability index that includes factors that measure the climate risks associated with "a municipality's population, average age, employment, and grand list trends; active public and civic organizations; and distance from emergency services and shelter."[5]

To advance the municipal vulnerability index, ERG is working with representatives from the State of Vermont (the Vermont state team) and members of the VCC municipal vulnerability index (MVI) Task Group[6] to develop the municipal vulnerability index, an online geospatial tool that is being designed for use by state, regional, and municipal agencies and organizations to identify community vulnerability to climate change based on a range of social, economic, ecological, land use, built environment, and hazard factors. The MVI is intended to help identify where Vermont communities are most vulnerable to climate change, with a focus on pressures that climate change will place on Vermont's people,

[1] Vermont Act 153 (2020): https://aoa.vermont.gov/sites/aoa/files/Boards/VCC/ACT153%20As%20Enacted.pdf

[2] The 23 member Vermont Climate Council is comprised of state administration officials, legislative appointees, and various sector representatives: https://climatechange.vermont.gov/about

[3] Vermont Climate Action Plan: https://climatechange.vermont.gov/readtheplan; VECAN "Vermont Global Warming Solutions Act" Webpage: https://vecan.net

[4] Vermont Act 153, Page 9.

[5] Vermont Act 153, Page 10.

[6] The MVI Task Group is comprised of VCC members who are focused on the development of the MVI/ The Task Group helped develop the tasks and principles in the RFP for this project, including the vision for stakeholder engagement and the end product.

transportation, electric grid, housing, emergency services, and communications infrastructure.[7] The MVI will provide information that will inform the challenges faced by rural communities across the state when addressing these pressures. Ultimately, the purpose of the MVI is to identify where vulnerabilities occur and the factors that contribute to those vulnerabilities to determine the actions needed to increase climate resilience in Vermont and its communities.

1.2 MVI Tool Purpose

ERG and the VT state team developed a statement of purpose for the MVI to provide a clear and stable definition of the tool's purpose, focus, and intended users. The statement of purpose is based on input and discussions with the VT state team and MVI Task Group as well as findings from three background research efforts conducted by ERG: 1) an evaluation of existing tools that can be used to inform the MVI, 2) document review and background research of Vermont's climate issues, and 3) engagement of key partners[8] to ensure the MVI reflects their experiences, expertise, and concerns related to climate vulnerability within their communities and organizations across Vermont. The resulting statement of purpose is as follows:

> The Vermont Municipal Vulnerability Index (MVI) is designed for use by Vermont State agencies, regional planning commissions, municipal staff, communities, and non-governmental organizations to measure vulnerability to climate change at the municipal level for the purposes of informing climate-related planning and decision-making and supporting the professional duties of tool users (e.g., grant-writing, development of local hazard mitigation plans, identification of climate vulnerability hot spots, disaster planning and response). The MVI will measure climate vulnerability based on a range of factors related to the built/physical environment (e.g., buildings, infrastructure), economy and jobs (e.g., unemployment, per capita income), hazards (e.g., flooding, extreme temperatures), natural environment (e.g., forest cover, ecosystem services), and social/community (e.g., sociodemographic factors, housing, access to emergency services).

MVI Tool Users

As described in the statement of purpose, the primary users of the MVI are municipalities, state agency staff, regional planning commissions (RPCs), non-governmental organizations, and community groups to better understand the climate vulnerability at a municipal scale and identify planning actions and strategies to reduce vulnerability and increase resilience.

[7] According to the Vermont Statutes Annotated (VSA), 1 VSA § 126, the term "municipality" includes "a city, town, town school district, incorporated school or fire district or incorporated village, and all other governmental incorporated units." The terms "town" and "municipality" are used interchangeably throughout this report.

[8] Engagement under this project includes the following groups: expected MVI tool users; entities, communities, or their representatives who will potentially be affected by the tool's use; entities whose work is parallel to, or overlaps with, the MVI tool, and there is a need to align efforts; and Vermont state staff assisting with the tool's development who will be responsible for updating and maintaining the tool over time.

MVI Tool Uses

The municipal climate vulnerability information generated by the MVI has a variety of applications, including (but not limited to):

- Developing local plans, such as local hazard mitigation, emergency preparedness and response, and climate action and adaptation plans.
- Guiding planning efforts, such as land use planning, capital planning, and infrastructure and utility planning and maintenance.
- Conducting vulnerability assessments and/or impact analyses that highlight vulnerabilities to and disproportionate impacts from climate change.
- Providing information needed to support grant writing/grant applications.
- Supplying key information needed for education and outreach efforts related to climate vulnerability.
- Helping direct technical support from state, regional, NGOs to communities and municipalities.

1.3 MVI Tool Development Phases

The process to develop the MVI tool includes three phases. The phases include:

- **Phase 1.** The first phase of the project included background research, assessment, and evaluation of existing tools within and outside of Vermont as well as interviews and small group meetings with key partners. The first phase also included meetings with the MVI Task Group to receive timely input and feedback on findings and next steps. The information gleaned from the review of existing tools and input from key partners and the MVI Task Group was used to identify a set preliminary factors of climate vulnerability within five domains that should be included in the tool. For the purposes of this project domains are broad categories including built and physical environment, economy and jobs, climate influenced hazards, natural environment, and society and community.[9] Factors are defined as characteristics within these domains that increase vulnerability to climate change. For example, people over 65 or under 5 are more vulnerable to most hazards, including extreme heat and flooding, two hazards that are projected to increase in Vermont. For more information on this phase, please refer to the Task 2 Report.
- **Phase 2.** The second phase of tool development included applying what was learned in the first phase to further refine the factors of climate vulnerability to be included in the tool and also develop a framework for the MVI, including the methods and approach for how the tool will communicate vulnerability and resilience to tool users, whether to use a fixed, scoring approach

[9] The domains are defined as follows: **Built/physical environment -** Information on transportation assets, buildings, infrastructure, and the electric grid; **Economic/jobs -** Information on unemployment, per capita income, and industry types; **Hazards -** Information on natural hazards such as flooding, extreme temperatures, or landslides; **Natural environment -** Information such as forest cover, conserved and protected lands, and river and stream protection; **Social/community -** Information on governance, sociodemographic factors, housing, access to emergency services, and active community organizations. This domain considers equity and just transitions, including challenges faced by rural communities across the state/region.

or allow users to guide their own use of the tool, and whether and how to weight the factors. During this phase, meetings were held with tool partners that manage similar tools within Vermont to determine how best to align with these tools, identify attractive features and approaches used in other tools, and apply lessons learned from the use of these tools over time.

- **Phase 3.** The third phase of the project (forthcoming) is the development of the geospatial tool itself, including gathering input and feedback on the draft tool, tool testing, and finalizing the tool.

This report represents the conclusion to the second phase of MVI tool development. The purpose of this report is to provide the details of the MVI tool and a roadmap for its design, including the data and scale available for the selected vulnerability factors, the conceptual framework for tool, methods to be used to represent climate vulnerability and climate resilience in the tool, and the tool components and outputs.[10]

In the sections that follow we describe each of these aspects of MVI tool development. The remainder of the report is laid out as follows:

- **Section 2** describes processes and considerations for selecting tool factors, framework, and methods for use in the MVI tool.
- **Section 3** describes the proposed factors, framework and methods for the MVI, along with data gaps and how to overcome them.

2. Identifying Tool Factors, Framework, and Methodology

The following section summarizes the processes and information used to identify the factors of climate vulnerability that are most relevant to Vermont, the conceptual framework underpinning the tool, and considerations for determining the methods used to indicate climate vulnerability within the MVI tool.

2.1 Factors of Climate Vulnerability

A key component of phase 2 of the tool development process was the identification of a broad range of climate vulnerability factors for each of the five domains. These factors were informed by:

- **Legislation:** The development of the MVI is outlined in the GWSA. The legislation specifies certain factors that should be included in the MVI.[11]
- **Existing tools:** Our team reviewed existing tools to understand factors that were used by similar tools that were designed to identify social vulnerability, ecological assets, transportation

[10] Tool components refer to the elements of the geospatial tool, such as the online tool user interface, design features or tool functions. Tool outputs refer to the information generated by the tool.

[11] The GWSA specifies that the MVI should include the following factors: municipality's population, average age, employment, grand list trends, active public and civic organizations, and distance from emergency services and shelter.

vulnerability to flooding, and other similar tools used by Vermont and areas outside of the Commonwealth.[12]

- **MVI Tool Engagement:** Our team engaged with subject matter experts and partners through MVI task group meetings, interviews, and small group meetings.[13] This process provided information on which factors were identified most often, which factors were identified as a priority, and examples provided of how certain characteristics contribute to vulnerability or resilience to climate change.
- **Background Research and Expert Opinion:** We drew on background research of the characteristics of vulnerability and resilience that have been identified in Vermont and adjacent states, and the hazards most likely and consequential to the Commonwealth's communities and assets. Additionally, we also used our team's expertise in the climate vulnerability to ensure we did not overlook any key vulnerability factors.

An overview of this process is presented in Figure 1 and is described in more detail below.

Figure 1. Process of MVI factor identification

From a broad range of over 100 factors, the team identified a focused list of factors for inclusion in the MVI based on the priorities identified during engagement, alignment with other Vermont tools, direction from the legislation, data availability, and experience with similar vulnerability tools and assessments. The process for selecting these factors is described in more detail below.

Process of Selecting MVI Factors

Upon compiling and reviewing a broad range of potential factors across the five domains, the team identified six key considerations to help refine the list of factors into those that most greatly influence climate vulnerability or that represent a priority for those we engaged or as described in the legislation. The key considerations are depicted in Figure 2 below and described further below.

Tool Statement of Purpose. A key component of the factor selection process was the tool's statement of purpose. We assessed the factors to ensure a focus on factors that "measure vulnerability to climate change at the municipal level for the purposes of informing climate-related planning and decision-making and supporting the professional duties of tool users", as specified in the statement of purpose.

[12] Examples of tools we reviewed include: Climate Vulnerability in Greater Boston, Maine Coastal Risk Explorer, California Climate Change & Health Vulnerability Indicators, and Vermont Flood Ready Atlas.

[13] As part of the stakeholder engagement process, our team spoke with representatives from the following groups: MVI tool users, affected populations, MVI tool partners, and Vermont State staff responsible for MVI tool design and maintenance.

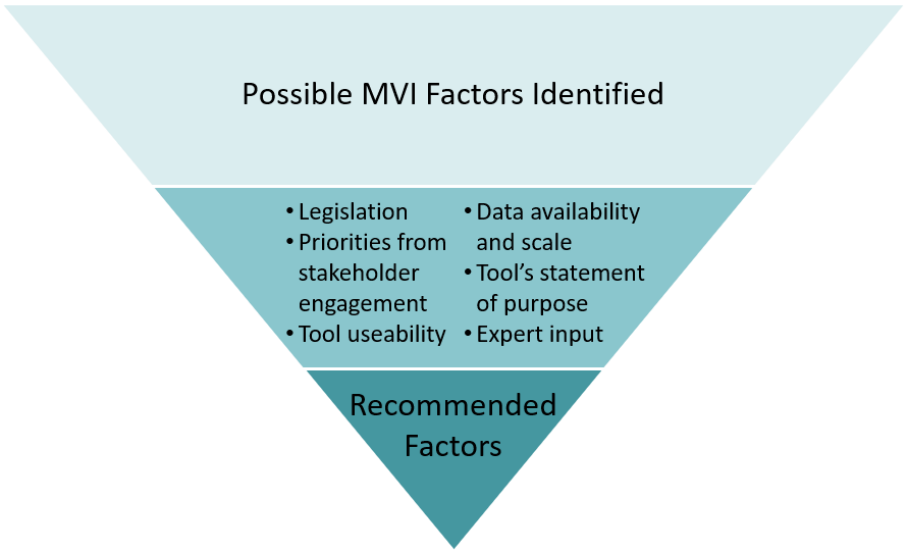

Figure 2: Overview of factor selection considerations

Legislation, Engagement, and Experience. In addition to prioritizing factors that clearly relate to the tool's statement of purpose, factors were prioritized if they were in the GWSA, were identified as a priority during the engagement process, or the team identified as high priority based on the team's expertise and experience with past tools and assessment. Prioritization also included considerations based on experiences from the July 2023 severe flooding in Vermont.[14]

Data availability. The team determined the data availability and scale for each of the priority factors identified through the process described above. For example, though "active public and civic organizations" were identified in the legislation as an important factor of resilience, there is no adequate geospatial data to support this factor. Rather than losing the important role that public and civic organizations play in supporting communities in preparing for and recovering from events due to a lack of available data, a narrative description will be included to describe the role it plays in community resilience. By including a narrative description for factors that lack adequate geospatial data, all high priority factors will be incorporated in some capacity within the tool.

Ease of Use. A key consideration of which factors to include was the need to balance the depth and breadth of data in the tool with the complexity that would be created by including too many factors. A common theme throughout the tool engagement process was that the MVI needs to be easy to use while still providing meaningful information. Additionally, those engaged raised the concern of the limited capacity for municipalities and RPCs to use the tool and the need for it to be simple, clear, and easy to use. To ensure that the tool fits these criteria, the number of factors needed to be limited to those with a clear link to climate change vulnerability or resilience. To help with this process, the team conducted an exercise to identify the direct connection between factors and climate vulnerability. Factors with limited or hard-to-identify relationships to climate vulnerability were not recommended for

[14] For more information on the July 2023 flooding in Vermont, read more from the NOAA National Weather Service here.

inclusion in the tool. This method allowed the team to balance the amount of data included in the tool with the tool's overall ease of use, simplicity, and clarity.

Data scale and data processing considerations. The scale of the data and data processing needs were important considerations when identifying data sources. Based on the team's experience with similar tools and assessments, as well as the preferences of those engaged in the process, it was clear that local data should be selected over regional or national datasets to ensure that the MVI is as specific and meaningful to each municipality as possible. Another consideration regarding data availability is the form that the current data is in and how much processing will be needed to include it in the MVI. This process is ongoing, and the team will continue to assess the level of effort to process datasets for use within the tool and balance the priority of the factor that the data represents with the level of effort needed to process the data.

Alignment with existing mapping tools. In order to better understand the relevant, existing tools in Vermont and ensure that the MVI is designed to align with these tools, the team met with tool partners and developers of existing Vermont tools. The discussions allowed the team to understand the opportunities for alignment across factors, methods, tool design; the data and analysis available in each tool; the challenges and lessons learned, and any recommendations for the MVI from each of the tool partners. Specifically, we engaged with partners familiar with the VT Social Vulnerability Index, Community Resilience Index, Transportation Resilience Planning Tool, and BioFinder. Below we provide key findings from our discussion with these tool partners, including development considerations for the MVI.

- **Social Vulnerability Index (SVI):** The Vermont Department of Health describes the SVI in the following way: social vulnerability refers to the resilience of communities when responding to or recovering from threats to public health. The Vermont Social Vulnerability Index is a planning tool to evaluate the relative social vulnerability across the state. It can be used if there is a disease outbreak or in the event of an emergency—either natural or human-caused—to identify populations that may need more help. The SVI draws together 16 different measures of vulnerability in three different themes: socioeconomic, demographic, and housing/transportation. ***Alignment with the MVI:*** The SVI shares similar themes with the MVI and provides elements of a vulnerability analysis that can be used to inform the design of the MVI. The SVI provides a simple approach of flagging characteristics of communities within municipalities that may make those communities more vulnerable. ***Development considerations:*** The SVI was modelled after a similar tool developed in New Hampshire. It uses the American Survey Community Data and identifies relative vulnerability, flagging the 10 most vulnerable census tracts for each measure. This approach results in a lack of data for communities that are not the 10 most vulnerable for that measure.
- **Community Resilience Index (CRI):** The CRI (currently under development), is intended to be a health disparity tool that will allow health officials to assess factors across the state that affect a community's resilience. All the data within the CRI is from the American Community Survey, published by the U.S. Census Bureau. The CRI is based on a set of indicators (including economic, education, language proficiency, and vehicle access) and population characteristics (including age, disabilities, and race). There is significant overlap between the factors recommended for inclusion in the MVI and those included in the CRI. Similar to the SVI, the CRI was used as a guide

to identify the factors of social vulnerability and resilience in Vermont. ***Development considerations:*** The CRI was developed with the intention of making it as accessible and "slim" as possible.

- **Transportation Resilience Planning Tool (TRPT):** The State of Vermont Agency of Transportation describes the TRPT as a web-based application that identifies bridges, culverts, and road embankments that are vulnerable to damage from floods, estimates risk based on the vulnerability, and criticality of roadway segments, and identifies potential mitigation measures based on the factors driving the vulnerability. The TRPT combines river science, hydraulics and transportation planning methods and is applied at a watershed scale. The TRPT has been developed for the entire state and is ready to be applied to inform project scoping, capital programming, and hazard mitigation planning for state and local highways. ***Alignment with the MVI.*** The MVI team determined that some of the data layers from the TRPT, such as those of the roads, bridges, and culverts and some information about critical assets and lack of redundancy should be included in the MVI. ***Development considerations:*** The TRPT tool is intended to help prioritize funding decisions at the state level. Development of the tool included input from several state agencies including the Agency of Natural Resources and Vermont Emergency Management as well as subject matter experts including the state climatologist, University of Vermont researchers, and RPCs. The TRPT is a tool that conducts a vulnerability assessment within the tool which is made easier by its focus on a single hazard, flooding, and its impacts to a single asset category, transportation. It is a difficult model for the MVI to use given the MVI's need to be a multi-hazard and multi-asset tool.
- **BioFinder:** As described on its website, BioFinder is a database and mapping tool for identifying Vermont's lands and waters that support important ecosystems, natural communities, habitats, and species. It features Vermont Conservation Design and was developed by the Agency of Natural Resources and partners to support stewardship, conservation, and land-use planning. BioFinder highlights networks of forests, streams and other features that together create the heart and backbone of Vermont's landscape and biodiversity**.** The many data layers within BioFinder, and the different types of geospatial data incorporated, provide a robust tool with a range of data that allows for different types of analysis and evaluations. ***Alignment with the MVI:*** BioFinder is a good example of a complex tool that allows users to explore the data and use the tool to support analysis, evaluations, and plan development. Future updates to the MVI may consider incorporating the priority ecosystem areas identified by BioFinder once the update to BioFinder is complete. ***Development considerations:*** BioFinder is a complex tool that includes a range of data and information and allows users to conduct assessments and analysis based on their own needs, as well as identifying priorities within the tool. In these ways, it is a good model for the MVI.

Recommendations to close data gaps in future tool updates. Data availability is a common challenge among climate tool development projects such as the MVI. One area for improvement is data consolidation/processing. We identified data sources that could have been included in the MVI, however the level of effort to process the data into a useable format was prohibitive given the resources

available at this time.[15] Another key data gap is publicly available geospatial projections of climate hazards specific to Vermont (i.e., not generalized from national projections) over the next 100 years which would inform the MVI and other climate change-related work in the state.

2.2 Conceptual Framework

The framework of the MVI is the structure and methods that provide the conceptual basis for the building of the MVI tool – that is, the way in which the tool assesses municipal vulnerability and presents that information to the user. Based on input from engagement, our experience with similar tools and assessments, and the characteristics of existing tools in Vermont that the MVI should align with, we evaluated several approaches to the MVI including two distinct approaches: 1) fixed output approach and 2) flexible, user guided approach (See Table 1). We considered the benefits and challenges to each approach within the context of the tool's statement of purpose as well as preferences expressed during the MVI tool engagement process. Key considerations include the need to balance municipal and regional capacity with tool complexity, the need for the MVI outputs to be clear and transparent, the importance of simple outputs, and the multi-hazard and multi-domain nature of the MVI. Table 1 summarizes each approach, including the benefits and limitations or challenges of each within the context of the purpose and goals of the MVI tool. We recommend using the flexible, user-guided approach as the core MVI tool, with an additional scoring system to support comparisons across municipalities, as further described in Section 5.

Table 1. Summary of framework options

Fixed Output Approach
Output type: Fixed output that does not change based on user selections. Possible output forms include a numeric value (0 to 5), a high/medium/low ranking, or some other fixed measure of vulnerability. **Examples:** VT Social Vulnerability Index, VT Community Resilience Index (currently under development), VT Transportation Resilience Planning Tool, Rural Capacity Index. **Benefits:** With a fixed output, it is **possible to compare** the vulnerability to climate across municipalities. This is a benefit to users who are looking to understand vulnerability across the entire state of VT but may not help municipalities with climate-related planning and decision making. Another benefit of a fixed output approach is that the tool conducts the first steps of a vulnerability assessment, providing the user with high-level information about how vulnerable a jurisdiction may be to climate change based on each factor. Additionally, priorities can be advanced through weighting some factors as having a greater role in contributing to vulnerability or to identify critical assets and issues important to Vermont.

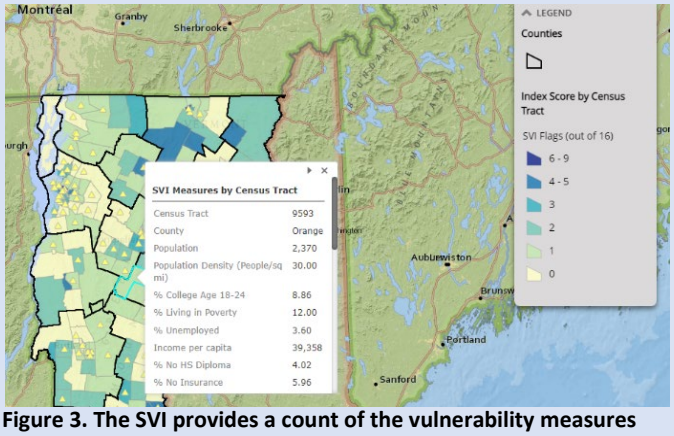

Figure 3. The SVI provides a count of the vulnerability measures (1–16) and provides a chart that shows the vulnerability percentiles of each of the 16 vulnerabilities for the census tract selected.

[15] Examples include local emergency evacuation routes, construction methods, and cultural resources documented in the Vermont Architectural Resource Inventory (VARI).

Challenges and Limitations: A fixed output is easier to employ when measuring vulnerability to a **single hazard** (e.g., flood vulnerability) or when **focusing on a single asset or domain** (e.g., transportation assets, social vulnerability). Conducting a high level vulnerability assessment within a tool for a single hazard is based on the sensitivity of the assets to that hazard. For example, while electric power and energy infrastructure is vulnerable to high heat, wildfire, flooding, and wind, different components of the infrastructure are vulnerable and in a different way for each hazard. Given that the MVI will measure vulnerability from multiple hazards, a fixed output would be difficult to develop without spending significant time and resources to capture the different vulnerabilities associated with each hazard. Capturing the different types of vulnerability by hazard for each of the asset types or domains would require significant time and resources. In addition, a fixed-output tool can be **challenging to update and difficult to use**. For example, if new factors or priorities are added it would require the index value to be recalculated (whether that be a 0 to 1 value, or a high/medium/low ranking). Updates to the hazard layers as new information and science becomes available would also be more complex and challenging.

Flexible, User-Guided Approach

Output type: Provides geospatial information to help users understand areas of vulnerability within their municipality and can be used to support hazard and climate plan development and provide for a broader range of self-directed analysis.

Examples: VT BioFinder, NOAA Coastal Flood Exposure Mapper, Climate Change & Health Vulnerability Indicators for California Visualizer, Maine Coastal Risk Explorer

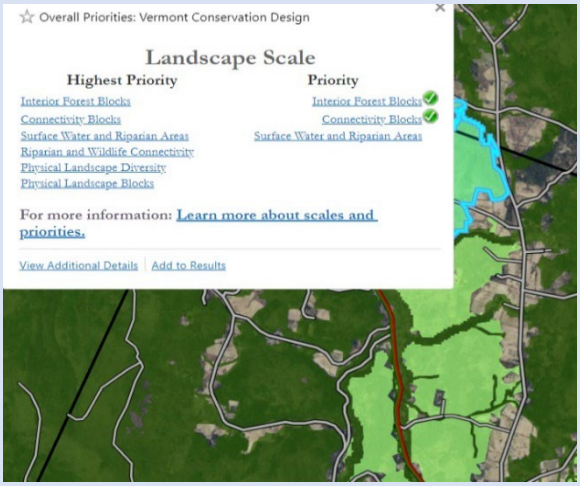

Figure 4. BioFinder allows users to overlay conservation priority areas with the Vermont SVI. An explanation of how to interpret the data is provided on a separate webpage.

Pros: This approach is often used in **multi-hazard and multi-asset tools** and allows for more self-directed analysis and evaluation. For example, a municipal user can use such a tool to identify where electric power infrastructure is located within a flood zone by using the geospatial data available. They can add social vulnerability factors to their analysis to determine where power infrastructure is at risk of flooding in neighborhoods with characteristics of social vulnerability. If they're interested in what electric power infrastructure is vulnerable to high winds, they could layer information related to above-ground infrastructure and wind speeds to determine areas of highest vulnerability to winds. In addition to representing hazard-specific vulnerabilities, this method also helps users understand **specific locations of vulnerabilities** within a municipality. This local level information can help municipalities with climate-related planning and decision-making, and can support grant proposal efforts, development of local hazard mitigation plans, identification of climate vulnerability hot spots, and disaster planning and response (all of which are specified in the tool's statement of purpose). An additional benefit is that this approach **is often easier to update and maintain** when new data is available, projects are implemented that change the risks, or conditions or priorities change within municipalities.

Cons: Though a flexible, user-guided approach can often provide a better understanding of climate vulnerability at the municipal level and allow for more user directed analysis and evaluation, the approach usually requires **more effort for users to determine the analysis that should be conducted and to interpret the information** provided in the tool and understand the areas of highest vulnerability. This issue can be overcome by information provided in the user guide, support provided by regional and state agencies, and often this is addressed by providing guidance on how to use and interpret the factors available in the tool and the role they play in climate vulnerability.

2.3 Tool Methodology

In addition to considering the type of conceptual framework for the tool, the project team also considered what methods for determining and/or depicting climate vulnerability using the selected climate vulnerability factors and corresponding data should be used in the MVI. There are multiple ways to process social, economic, and environmental factors to develop a climate vulnerability tool. Each of these methods is briefly described below:

Providing Component Factors for Users

Users are provided the data layers that represent the factors of vulnerability across Vermont and are able to select a location and conduct their own assessment of vulnerability against each of the hazards. Since the factors themselves are factors of vulnerability or resilience, the presence of the factor in an area affected by a hazard indicates some level of vulnerability. For example, users could toggle on and off layers about demographics or infrastructure and compare this data to hazard layers or community vulnerability layers to determine risks to community members directly from hazards such as flooding or extreme heat, or indirectly due to risks to utilities and infrastructure from the same hazards. The National Oceanic and Atmospheric Administration's (NOAA) Coastal Flood Exposure Mapper provides an example of providing the data to conduct an assessment without assigning a score or an index. The NOAA tool provides users with a range of flooding layers they can select to assess vulnerability to a selected geography.

This method gives the user agency to look at the data that most interests them and apply local conditions and priorities when assessing vulnerability based on the data available. It also gives users a high degree of customization in which to tailor their experience with the tool. However, the same quality that gives users a high degree of customization can make it more difficult for some users conduct analysis or to draw conclusions related to the scale of the vulnerability.

Creating an Index or Score

With this method, individual factors are compiled together to create an overall index or score of vulnerability. There are several ways to do this, including using:

- **Percentile ranks:** To do this, factors for each municipality can be compared across each other such that each municipality's percentile for a factor is used to create a rank or score. These factor scores can then be added or averaged together to get an overall vulnerability score for that municipality. This is similar to the methodology employed in the development of the VT CRI. This provides a way to compare areas to one another if that is desirable.

- **Thresholds:** A threshold can also be used to assign each factor a vulnerability "flag". For example, the SVI uses the 90th percentile in the state as a threshold for factors. If a municipality is above the 90th percentile for a certain factor, it receives a vulnerability flag. Then the number of flags for each municipality are summed to create a score for each municipality.

Weighting

To create a composite index, individual factors can be treated equally or be given weights. For example, the community and project team may decide that one factor is more reflective of vulnerability than another and assign it a higher score. Alternatively, the team can decide to assign a higher score to factors that are of greater priority or significance than other factors. Whereas an index that is weighted equally might be calculated by simply summing scores (Factor X + Factor Y), weighting these factors might look like: 0.7*Factor X + 0.3*Factor Y.

While this weighting process could, in theory, create an index that is most reflective of the actual importance of the different factors, deciding what weights to give each factor can be an arduous process that can require many rounds of engagement with community members, partners, agencies, municipalities, subject matter experts, and others to ensure that the weights are reflective of a range of perspectives. Weighting can result in outcomes that are less clear to users and harder to communicate to decision-makers and the public. Also, the index could be highly sensitive to small changes in weighting, such that a robust sensitivity analysis of the weighting chosen for all the factors would also need to be conducted. Neither the SVI nor the CRI included weighting in their indices in an effort to reduce tool development costs and keep methods simple and easy to understand. However, if there is the desire to prioritize specific factors, weighting is an effective way to do so and can be less challenging to implement if used in a focused and limited way.

3. Proposed Framework, Factors, and Components

This section presents the proposed framework, factors, methodological approach, and components for inclusion based on Phases 1 and 2 of the MVI tool development process. The section also outlines known data gaps and suggestions for overcoming them.

3.1 Tool Components and Outputs

MVI Tool Functions and Outputs

The MVI tool will be an online geospatial tool composed of data layers that can be manipulated and filtered to analyze and evaluate the presence of vulnerability and resilience factors in Vermont's municipalities to the most likely and consequential climate hazards in the state. The tool will include both geospatial and narrative descriptions of the selected vulnerability and resilience factors and the hazard data and climate projections at the most local scale available. The tool will allow users to select these factors from the five available domains– built and physical environment, economy and jobs, climate influenced hazards, natural environment, and society and community–and perform analysis of the most likely and consequential vulnerabilities, as well as factors of resilience, within each municipality. The tool will provide other functions including the ability to clip and print maps to include in reports and plans, allow for data to be exported for use in specific projects and efforts, and the ability to query across hazards, locations, and factors to understand vulnerability across Vermont, as well as

within each municipality. Users will be able to select hazards separately to assess vulnerability of different factors from each hazard, identifying how vulnerability differs across hazards and asset (Described further in Section 3.1 below).

The MVI functions and outputs will include a blend between the outputs provided in several of the tools that Vermont already uses, such as the BioFinder tool which allows users to conduct their own analysis and evaluations, and the SVI, which provides information on vulnerability by flagging locations that are vulnerable due to the social vulnerability characteristics present. To be most useful to municipal and regional users, the MVI will also allow for users to conduct their own analysis of the underlying data. For example, a municipality may be flagged for having three hospitals within five miles which could indicate resilience, as well as being flagged for having two hospitals in a flood zone which indicates vulnerability. Upon analysis of the data layers and maps, a municipality could determine which hospitals are at risk and which are not.

MVI Tool Interface

The MVI tool will have a public user interface that includes a landing page with a user guide and information on the purpose of the MVI, the functions of the tool, the outputs of the tool, links to related programs, data and tools, and definitions of climate vulnerability, and climate resilience. The user guide will include information on the methods used to develop the tool, the engagement that informed the tool, the tool development process, and step by step instructions of different ways to use the tool, including the scoring system that identifies the vulnerabilities within each municipality and the ability to conduct a separate analysis based on the data available within the tool. The tool interface will allow for users to access the underlying data and export that data to use in their own projects.

While the MVI is a geospatial tool, there will also be pages which include non-geospatial information such as qualitative information to help users comprehensively understand climate vulnerability, explanations of climate projections, fact sheets or data summaries that municipalities could use to help communicate climate vulnerability to residents. There will also be a section of the MVI interface which includes links to other tools that could help users understand social or climate vulnerability such as the Vermont SVI or the CRI (when it is completed), the TRPT, and information on actions and adaptations that can reduce vulnerabilities, including the Vermont Climate Action Toolkit.

3.2 Factors, Framework, and Methods

Based on engagement with the VT state team and MVI Task Group, tool engagement efforts, discussions with tool partners as well as the review of documentation and existing tools review, the project team developed the final list of factors of climate vulnerability presented in Appendix A. In addition, the team recommends the following framework and methodological considerations for the tool:

- **Flexible, User-Guided Approach:** The main priority of the tool is to drive municipal action to reduce risks through climate planning, decision-making, and implementation. A flexible, user-guided approach best serves this purpose as it allows users to understand specific locations and details of vulnerabilities, as well as provides an assessment of vulnerabilities of multiple climate hazards across multiple asset types. Figure 5 shows a rough mock-up of a user guided approach, in which the user selects a hazard (e.g., “inundation flooding”) and factor or set of factors (e.g., the community vulnerability of “designated areas”) of interest. In the figure, the area of

inundation flooding is depicted in the light grey box on the map, and the designated area is highlighted in red; allowing the user to see what portion of a designated area falls within the inundation flood area.

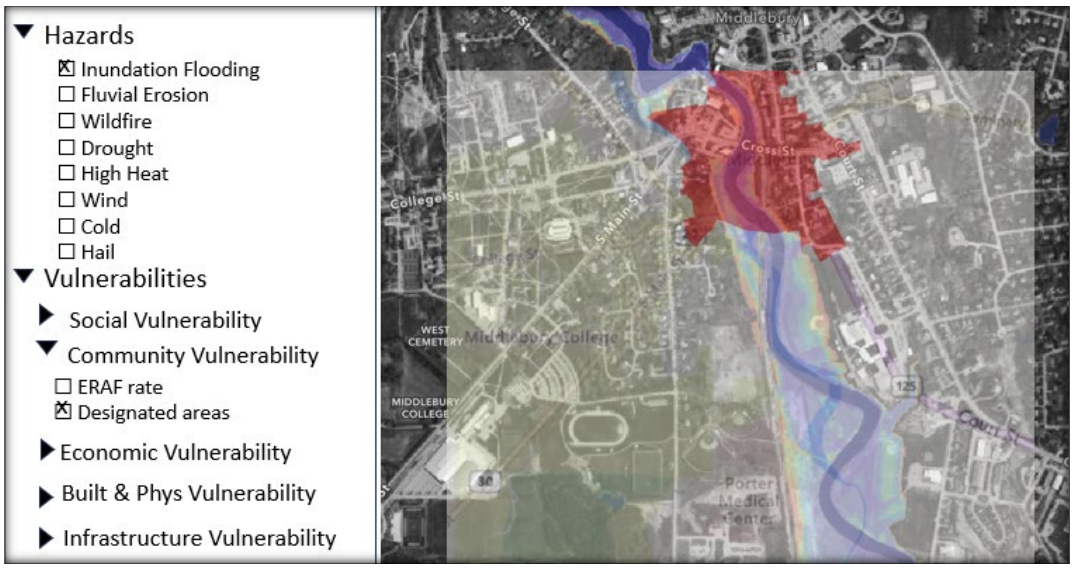

Figure 5: Example output visual of factor and hazard selection

- **Ability to Compare Vulnerability Across Municipalities:** Though the main purpose of the tool is to drive municipal action, a secondary goal of the tool is to support State priorities. Therefore, the ability to compare vulnerabilities across municipalities will inform State priorities and actions. While the proposed approach to the MVI will not produce a single vulnerability score for each municipality, it will allow the user to compare vulnerability across municipalities in two ways. First, the tool will provide a visual way to compare vulnerabilities across municipalities within the same hazards and factors. A second way of comparing vulnerabilities across municipalities will be possible using a flagging system. A subset of critical factors will be selected to be flagged when a municipality or census tract is over a certain threshold or amount. For example, a critical factor is considered to be the percentage of population above the age of 65, and a threshold of greater than 20 percent of the population above the age of 65 is determined to indicate a key climate vulnerability, the geographic unit within the municipality associated with that vulnerability (e.g., census tract) would receive a flag. The tool will then include a feature, such as a pop-up box, that will indicate the type and number flags within a given municipality or census tract. This flagging of critical vulnerabilities will allow for comparison across municipalities.
- **No Weighting of Factors:** Though weighting factors can be appropriate for some tools, the MVI should not explicitly weight factors. This aligns with other State tools such as the SVI and CRI, and it aligns with the user-guided approach. Though factors will not be explicitly weighted, there remains the opportunity to "fix" specific geospatial layers such that users will always view them and that they will be considered during every use of the tool. This is an alternative method to the traditional "weighting" that is sometimes applied to tools. Decisions as to which, if any, geospatial layers should be fixed within the tool will occur during the tool development phase

but would be those factors that Vermont wants to prioritize for action and ensure are always accounted for in assessing climate vulnerability.

- **Use Local Data Sources when Possible:** Due to the need to understand local conditions and hazards, it is important to include local data sources whenever possible. The project team is committed to using local data sources if they fit the needs and constraints of the project (e.g., minimal data processing required, suitable geographic scale).

Developing the MVI with the above key considerations in mind will ensure that the tool accomplishes its main goals and objectives. Specifically, the final framework and list of factors (See Appendix A) are intended to address each of the following:

- **Purpose Statement and Other Goals and Objectives:** The purpose statement and other goals and objectives as informed by engagement and the legislation and existing documents and plans was used to determine the factors and their priority, as well as to indicate the best framework design for the MVI.
- **Engagement:** Factors and framework were directly influenced by engagement, including from the MVI Task Group, interviews, subject matter experts, small group meetings, tool partner and other discussions.
- **Existing Document and Tool Review:** Document and tool review provided valuable insight into data availability, Vermont priorities, considerations for tool development, and identified challenges and opportunities for online tool development.
- **Vermont Priorities:** The work conducted to date on the MVI has provided a better understanding of Vermont's priorities, including concerns over flooding, issues related to housing affordability, disproportionate impacts on rural communities and those with social vulnerability characteristics that make them more at risk from climate change, as well as the importance of Vermont's natural resources.
- **Best Practices from Other Locations:** The framework and factors that we have identified for the MVI are aligned with other assessments and tools such as SVI, CRI, BioFinder, CalAdapt, NOAA Coastal Flood Exposure Mapper, FEMA National Risk Index, and others. We considered best practices from tools and assessments that were reviewed for this project as well as past projects and efforts, when considering the development of the MVI.

Data Gaps, Needs, and How to Overcome Them

Hazard Data. The MVI is a tool to evaluate vulnerability to climate hazards. Therefore, accurate climate hazard data is essential to the usefulness of the tool. As previously discussed, local data sources are preferred for inclusion in the MVI. Though there are national level geospatial datasets related to various climate hazards (e.g., U.S. Forest Service's Wildfire Hazard Potential), there is limited geospatial data that has been developed specifically for Vermont. Additionally, given that the climate is nonstationary, traditional historic climate information is becoming a less accurate indicator of future climate-forced hazard consequence. Therefore, climate hazard data that incorporates climate projections is needed to provide a more accurate understanding of climate related vulnerabilities. The MVI will use climate hazard data from local datasets and those with climate projections whenever possible and will incorporate regional or national data as required. Vermont is not alone in lacking authoritative peer-reviewed local and state data for climate projections, particularly in a geospatial form. Partnering with

local universities on applied research that results in Vermont-level geospatial data for specific climate influenced hazards would be a good next step. An all-hazards approach would be unrealistic, therefore, prioritizing the hazard(s) with the greatest consequences may be a preferred approach.

Factors Identified by Legislation. Though data exists for some of the factors identified by the GWSA, other factors do not have sufficient data available to include directly within the geospatial tool. Below is an outline of the recommended approach for each factor identified in the legislation, as well as provide recommendations for how future efforts can help to overcome these barriers.

- ***Active public and civic organizations.*** Suitable data to determine active public and civic organizations is not available. Vermont should prioritize collecting these data so that future updates to the MVI can include this information. To overcome this, the MVI will include a description of this factor and describe the importance of public and civic organizations through a narrative that summarizes how they can reduce the vulnerability, or increase the resilience, of a community.
- ***Distance from emergency services.*** Data on the distance from emergency services is not readily available.16 Given that the MVI tool will present geospatial data within the flexible, user-guided approach, the maps will include point locations of emergency services. Readily measurable metrics such as the number of hospitals per square mile may be included to support vulnerability comparisons across municipalities.
- ***Population.*** Population size will be represented at the census tract level.
- ***Average Age.*** The GWSA identifies that the average age should be measured. Average age does not inherently communicate climate vulnerability and is not generally used in climate vulnerability tools. Instead, the MVI will present the population for children aged 5 and under and adults aged 65 or older at the census tract level as these represent ages that are particularly vulnerable to climate hazards.
- ***Employment.*** The GWSA identifies that employment should be measured. To ensure that the tool focuses on climate vulnerabilities, the number of people employed in industries that are particularly susceptible to climate hazards within a geospatial area will be depicted. Given data availability limitations, this will be limited to specific occupation categories, preliminarily envisioned to include: Protective service (i.e., firefighting and prevention, law enforcement workers); building and ground cleaning and maintenance; and natural resources, construction, and maintenance. Data will be presented at the census tract level.
- ***Grand list trends.*** The GWSA identifies that grand list trends should be measured. Grand list information is available at, and will be presented at, the town level, as a measure of a municipality's financial capacity. Specifically, the 2023 equalized municipal grand list value published by the Vermont Department of Taxes will be used.

[16] The TRPT does not consider travel time between points, and therefore cannot be used to determine travel time from emergency services. Though the TRPT does include data that could be used to calculate routes that are not susceptible to flooding, this would require additional data processing which is beyond the resources available for this effort.

- ***Factors Not Represented Geospatially.*** In addition to active public and civic organizations already identified in the section above, there are other factors that were identified as a priority that will not be represented in a geospatial format due to lack of available data. In these instances, written narratives will be available to the user that describe how the factor contributes to climate vulnerability or resilience. These factors are denoted in Table 2 by the Data Source column showing "DATA GAP – written narrative".

Appendix A: Final Climate Vulnerability Factors

The table below summarizes the priority factors for inclusion in the MVI, the data sources, and the scale at which they are available. Factors that do not have sufficient data (either no or very limited data is available, or it is not available at an appropriate geographic level) will be addressed through the MVI tool with a narrative description, as indicated within the table.

Table 2. Summary of factor data availability, sources, and scale by factor category

Factor	Data Source	Data Scale (Geographic Level)
Social Vulnerability		
Population	U.S. Census Bureau (ACS)	Census Tract
Income[17]	U.S. Census Bureau (ACS)	Census Tract
Elderly residents	U.S. Census Bureau (ACS)	Census Tract
Children	U.S. Census Bureau (ACS)	Census Tract
People with disabilities	U.S. Census Bureau (ACS)	Census Tract
Single parent households	U.S. Census Bureau (ACS)	Census Tract
Linguistic Isolation	U.S. Census Bureau (ACS)	Census Tract
No vehicle	U.S. Census Bureau (ACS)	Census Tract
No internet	U.S. Census Bureau (ACS)	Census Tract
Rentership	Written narrative	N/A
No high school diploma	Written narrative	N/A
Preexisting health conditions	DATA GAP – written narrative	N/A
Asian/Asian Americans	U.S. Census Bureau (ACS)	Census Tract
Black/African Americans	U.S. Census Bureau (ACS)	Census Tract
Indigenous Americans/Alaskans	U.S. Census Bureau (ACS)	Census Tract
Indigenous Hawaiians/Pacific Islanders	U.S. Census Bureau (ACS)	Census Tract
Multiracial Groups	U.S. Census Bureau (ACS)	Census Tract
White/European Americans	U.S. Census Bureau (ACS)	Census Tract
Additional Racial Groups	U.S. Census Bureau (ACS)	Census Tract
Hispanic/Latino	U.S. Census Bureau (ACS)	Census Tract
Energy and transportation burden	Efficiency Vermont (Appendix A)	Municipality
Housing cost burden	Vermont Housing Finance Agency	Municipality
Access to healthy foods	Written narrative	N/A
Community Vulnerability		
Limited municipal staff capacity	DATA GAP – written narrative[a]	N/A
Limited municipal financial capacity	State of Vermont Equalized Grand List	Town
ERAF rate	State of Vermont Agency of Natural Resources	Town/Community

[17] Income vulnerability will be measured based on the percent of people whose income is less than 2 times the federal poverty rate.

Factor	Data Source	Data Scale (Geographic Level)
Mitigation measures	State of Vermont Agency of Natural Resources	Town/Community
Public and civic organizations	DATA GAP – written narrative	N/A
Designated areas	Vermont Agency of Commerce and Community Development	Town/Community
Cultural resources	DATA GAP – written narrative	N/A
Plan and regulation status	Vermont Planning Atlas	Town/Community
Economic & Job Vulnerability		
Vulnerable employment	U.S. Bureau of Labor Statistics and U.S. Census Bureau	Census Tract
Agriculture	Vermont Open Geodata Portal	0.5 Meter Grid
Tourism industry	U.S. Census Bureau Decennial Census (PCT086)	Census Tract
Timber industry	DATA GAP – written narrative	N/A
Expected annual loss from natural disasters	Written narrative	N/A
Small businesses	DATA GAP – written narrative	N/A
Built & Physical Environment Vulnerability (excluding infrastructure vulnerability)		
Wildfire mitigation	DATA GAP – written narrative	N/A
Wells at risk of drying up	DATA GAP – written narrative	N/A
Emergency services	Vermont Open Geodata Portal (E911 data)	Point Data
Heating and cooling centers	DATA GAP – written narrative	N/A
Mobile homes	U.S. Census Bureau (ACS)	Census Tract
Housing materials, age, construction methods, maintenance	DATA GAP – written narrative	N/A
Critical assets (libraries**, schools**, buildings, houses)	Vermont Open Geodata Portal (Libraries, Schools, other buildings and houses)	Point Data
Manufactured home communities in flood hazard areas	Written narrative	N/A
Infrastructure Vulnerability		
Roads, bridges, and culverts vulnerability to flooding and other hazards	VT TRPT	Point Data
Airports	Vermont Open Geodata Portal	Point Data
Public transit routes	Vermont Open Geodata Portal	Line Data
Power lines	Vermont Open Geodata Portal (WEC Utility Lines, Green Mountain Power Lines, VEC "spans" data)	Point Data
Drinking water infrastructure	Vermont Open Geodata Portal	Feature Layer
Wastewater infrastructure	Vermont Open Geodata Portal	Point Data
Electric substations	Vermont Open Geodata Portal	Point Data

Factor	Data Source	Data Scale (Geographic Level)
Underground electric infrastructure	Written narrative	N/A
Power plants	Power Plants and Neighboring Communities Mapping Tool	Point Data
Natural Environment Vulnerability		
Tree canopy	Vermont Open Geodata Portal	0.5 Meter Grid
Toxic or contaminated sites	Vermont Agency of Natural Resources	Town/Municipality
Conserved and protected lands	Vermont Open Geodata Portal	Shape Data
River and stream protection	Vermont Agency of Natural Resources	Shape Data
Impervious surfaces	Vermont Open Geodata Portal	0.5 Meter Grid
Air quality	Written narrative	N/A
Critical habitat	Written narrative	N/A
Biodiversity	Vermont Open Geodata Portal	Shape Data
Hazards		
Inundation flooding	1. FEMA National Flood Hazard Layer 2. VT Venter for Geographic Information (Lake Champlain Basin)	1. Regional (based on local topography) 2. Lake Champlain Basin (based on local topography)
Fluvial erosion	VT ANR River Corridors	Shape Data
Wildfire	U.S. Forest Service[18]	30m Resolution
Drought	U.S. Drought Monitor	County
High heat	LOCA Statistical Downscaling[b]	6km Grid
Extreme precipitation	LOCA Statistical Downscaling[b]	6km Grid
Wind	First Street Foundation[c]	Census Tract
Cold	LOCA Statistical Downscaling[b]	6km Grid
Hail	NOAA NCEI Storm Events Database[d]	County
Snow	NOAA NCEI Storm Events Database[d]	County
Ice	NOAA NCEI Storm Events Database[d]	County
Landslides	USGS	Point Data
Invasive species	Vermont Open Geodata Portal	Point Data

[a] Though a list of cities with a municipal manager or administrator is available from the Vermont Town and City Management Association, this is likely not a complete list of municipal management or administration. Therefore, we recommend addressing this factor through a written narrative.
[b] LOCA data will require data manipulation as it provides minimum and maximum daily temperature and precipitation from 1950-2100.
[c] First Street Foundation's data includes climate projections.
[d] The NOAA Storm Events Database provides the number of events, or the number of days with event, in a county.

[18] If Northeastmidwestwildfirerisk.com has readily available data, we will use it.