Mitig Adapt Strateg Glob Change
DOI 10.1007/s11027-015-9672-x

ORIGINAL ARTICLE

Adapting bridge infrastructure to climate change: institutionalizing resilience in intergovernmental transportation planning processes in the Northeastern USA

Anna Schulz[1] · **Asim Zia**[1] · **Christopher Koliba**[1]

Received: 9 March 2015 / Accepted: 8 July 2015

Abstract Multi-level governance networks provide both opportunities and challenges to mainstream climate change adaptation due to their routine decision-making and coordination processes. This paper explores institutionalizing resilience and adaptation to climate change in the intergovernmental transportation planning processes that address bridge infrastructure in the Northeastern United States (USA), specifically in Vermont and Maine. The research presented here relies on nine interviews with policy-makers and planners, a survey of transportation project prioritization criteria, development of a longitudinal bridge funding database, and its integration with publicly available geospatial data. It presents a novel spatial analysis methodology, a modified version of which could be adopted by transportation agencies for prioritizing scarce adaptation funds. Although transportation agencies are undertaking a variety of mitigation activities to address business-as-usual needs, climate change adaptation and resilience efforts remain underprioritized. Adaptation is a global concern, but impacts vary dramatically between regions and require localized solutions. Bridges and culverts, which are especially vulnerable to climate-induced flooding impacts, have complex maintenance and design processes and are subject to convoluted adaptation planning procedures. Critical gaps in resources and knowledge are barriers to improved adaptation planning. Restructuring the transportation project prioritization procedures used by planning organizations to explicitly include adaptation may provide a novel strategy to institutionalize resilience in transportation. These procedures must be considered in the context of the intergovernmental networks that exist to support transportation infrastructure. Although these networks will likely vary across countries, the approaches introduced here to study and address transportation infrastructure adaptation may be applied to many settings.

✉ Anna Schulz
Anna.Schulz@uvm.edu

[1] Department of Community Development and Applied Economics, University of Vermont, Morrill Hall 102, 146 University Place, Burlington, VT 05405, USA

Published online: 23 September 2015

Keywords Adaptation · Bridge infrastructure · Climate change · Geospatial analysis · Multi-level governance · Transportation planning · Resilience to extreme events · Institutional design

1 Introduction

Extreme events induced by global climate change, such as more persistent rainfall leading to flooding or more intense tropical storms, pose ominous risks to transportation infrastructure across the globe (Jaroszweski et al. 2010). The majority of the literature on transportation and climate change focuses on mitigation (e.g., the role of transportation in carbon reduction) (Schmidt and Meyer 2009). More research is needed on the impacts of global climate change on transportation infrastructure (e.g., see Hunt and Watkiss 2011) and, consequently, on transportation system adaptation and resilience as well. This paper employs the following definitions of key terms relevant to the impacts of climate change on transportation infrastructure: *resilience* is "the capacity of a system to absorb disturbances and retain essential processes" (Savonis et al. 2008), and *adaptation*, which is specific to the processes that are undertaken to result in system resilience, is defined here as "the development, modification, maintenance, and renewal of transportation infrastructure, operations, and policy to moderate the impacts of climate change" (Oswald and McNeil 2013). In the Intergovernmental Panel on Climate Change's (IPCC's) Fifth Assessment Report, Revi et al. (2014, p. 562) concluded that transportation systems are "a difficult sector to adapt due to large existing stock, especially in cities in developed countries, leading to potentially large secondary economic impacts with regional and potentially global consequences for trade and business. Emergency response requires well-functioning transport infrastructure." The IPCC synthesis team concluded (Revi et al. 2014, p. 563) that there is relatively less literature available on understanding the role of "local government decisions to include adaptation in plans and investment programs." The local government decisions are, however, typically embedded in intergovernmental networks, some of which extend beyond public–public intergovernmental configuration, into governance networks comprised of public, private, and civil society actors (Koliba et al. 2010). Coordination among national, regional, and local level agencies in such governance networks is critical for implementing adaptation strategies in the transport sector, as climate change impacts are widespread and extend across scales (Regmi and Hanaoka 2011).

Multi-level governance systems provide both opportunities and challenges to mainstream/integrate adaptation in their routine decision-making and coordination processes. While some international studies (Lowe et al. 2009; Kehew et al. 2013) have found that mainstreaming adaptation into urban, regional and transportation planning, land use management, and legal and regulatory frameworks is critical for successful adaptation, other studies have found that many of these multi-level governance networks are intergovernmental, cross-institutional, and complex, operating at vastly different scales and timelines with often conflicting stakeholders and high uncertainty (Roberts and O'Donoghue 2013). In this paper, we explore the potential of institutionalizing resilience and adaptation into the transportation planning processes. We focus on investigating the potential of adaptation to climate change integration in the intergovernmental planning processes that address bridge infrastructure maintenance and development in the Northeastern USA.

Increasing trends in mean and extreme precipitation have been relatively large in the Northeastern United States (USA) compared to other regions. Sea levels in the northeast have already risen by roughly 1 ft and are on track to rise another 1 to 4 ft further by the end of the century (Horton et al. 2014). Annual precipitation has increased by 8 % since 1991 relative to 1901–1960, while extreme precipitation, defined as the 1 % of rainiest days, has increased over 50 % 2001–2012 relative to 1901–1960 (Walsh et al. 2014). This observed increase in mean and extreme precipitation across the Northeast USA is projected to continue into the future. For example, the current 1 in 20-year (1981–2000) storm is expected to occur three to four times more often by the end of the century under Representative Concentration Pathway (RCP) 8.5 (Walsh et al. 2014). The state of Vermont received disaster relief funds from the Federal Emergency Management Agency (FEMA) a record 11 times in the 5 years between 2007 and 2011, almost double that of any other 5-year period since 1962 (Johnson 2012). Thus, the measures that northeastern states take to address the role of climate change impacts on its transportation infrastructure can serve as important guideposts for other jurisdictions across the globe facing similar, increased high precipitation extreme events.

The implications of climate change for transportation are varied and complex. Higher temperatures may cause asphalt to wear faster and expansion joints to suffer. Heavier rainfall and more storms are indicative of more runoff and flooding, both of which have the potential to stress bridges, culverts, and low-lying roadways. Rising seas will force the elevation of coastal infrastructure. All of the above, taken together, present high risk and exposure and a persuasive argument for adaptation.

This paper focuses on two very important features of designing resilient and adaptive transportation infrastructure, namely, how and to what extent are the intergovernmental networks in selected regions undertaking planning and implementation practices to adapt transportation infrastructure, specifically bridge infrastructure, to the threats posed by climate change? And how does spatial scale, scope of the landscape, and other features affect local jurisdictions' exposure to flooding risk for sustaining bridge infrastructure in the face of climate change and can such risk assessment methods at higher governance level (e.g., state) be used to prioritize bridge adaptation funding?

In the USA, transportation governance follows a very hierarchical/multi-level structure. The federal (national) level is responsible for crafting major legislation, distributing funding, and imposing requirements on the states. Each of the 50 states has its own Department of Transportation (DOT), which coordinates overall state transportation policies, assembles comprehensive state-wide plans, and oversees projects within state boundaries. Within states, there are even smaller organizations as well: Metropolitan Planning Organizations (MPOs) manage transportation planning in urban areas, while Regional Planning Commissions (RPCs) are responsible for more rural areas. The geographic scope of the USA results in differing adaptation needs across and sometimes within states. Political control and recent experiences with disaster may also influence states' adaptation priorities.

The Northeastern USA has suffered from recent storms that point toward a need for improved resilience. In August of 2011, Vermont was hit especially hard by Tropical Storm Irene, which caused an estimated $250 million of damage to transportation infrastructure alone. In addition to the approximately 200 bridges that were damaged on state roads, municipalities had to repair or replace another 280 bridges and 960 culverts (Johnson 2012). The Vermont Agency of Transportation (known as VTrans) responded quickly to rebuild, but as importantly, the disaster spurred the agency—as a state-level organization—to formalize its stance on climate change adaptation. In a white paper released a year after Tropical Storm Irene, VTrans outlines its goals and procedures for adaptation and also notes roadblocks and potential improvement actions. Among the roadblocks are regulatory constraints, forecasting difficulties, political tensions, and, above all, budgetary restrictions. Some noted opportunities for improvement include standardization and digitization of records, infrastructure resilience monitoring, the expansion of asset inventories, and updating project prioritization guidelines (Johnson 2012). Not long after Tropical Storm Irene, in 2012, Super Storm Sandy caused approximately $5.7 billion worth of damage to transportation infrastructure in the states of New Jersey and New York alone, a figure that does not include the costs associated with the multi-day paralysis of the transportation network in America's most populous region (US Government Accountability Office 2014). Devastating storms may force transportation agencies to reconsider the risks posed to infrastructure and the potential costs of infrastructure failure. Funding constraints, however, may dictate priorities.

As of the writing of this article, the USA awaits passage of a federal transportation funding authorization, with the current funding set to expire at the end of July 2015. The previous bill, titled "Moving Ahead for Progress in the 21st Century" (abbreviated "MAP-21"), barely touches upon the issue of resilience and adaptation. While the US transportation budget is constrained, mere maintenance of the existing infrastructure with existing specifications threatens the system's long-term sustainability. Even keeping the system intact in its current form is growing more expensive in the face of climate change: as extreme weather becomes more frequent and more severe, state-level DOTs report that maintenance costs continue to rise (Venner and Zamurs 2012).

Research suggests that, in the absence of federal requirements for integrating adaptation into planning, both some state DOTs and regional MPOs are beginning to tackle the task on their own, particularly in areas that are seeing impacts (Gallivan et al. 2009; McBeath 2003; Walker et al. 2011). The absence of explicit language encouraging adaptation certainly does not prohibit organizations from interpreting mandated actions (such as increasing the safety and security of the system) to include climate-related factors. Some agencies have begun to incorporate climate planning through long-range transportation plans, which are mandated by the federal government and have a 20-year timeframe. A 2009 study of a dozen proactive organizations, all of which explicitly included climate change in their long-range transportation plans, yielded mixed results: some only addressed mitigation, while others referred to adaptation as a vague goal without specific steps (Gallivan et al. 2009).

A study conducted in 2011 focused on the northwestern corner of the USA and the state of Alaska. It examined both long-range transportation plans and climate action plans, which have been developed by many cities, counties, and states. In general, the region was found to be ahead of the national trend, with almost all agencies having completed climate action plans and many touching on the idea of adaptation (Walker et al. 2011). Similar to other regions, however, the long-range transportation plans tended to skip discussion of climate change entirely, focus exclusively on mitigation, or only briefly mention adaptation in a non-action-oriented context (Walker et al. 2011). Despite an awareness of the potential impacts of climate change, agencies did not present strategies to adapt transportation infrastructure. The research highlighted a fundamental disconnect between climate planning and transportation planning.

The USA is not alone in its struggle to incorporate climate adaptation measures into transportation planning. Many of Asia's coastal and island nations are already struggling with the effects of climate change, but studies relating to adaptation measures are limited. A 2009 survey assessed various factors relating to transportation adaptation in Asia, including levels of awareness, coordination and response to climate emergencies, adequacy of design standards, and adequacy of current policies (Regmi and Hanaoka 2011). The respondents, transportation professionals from 21 widely dispersed Asian nations, cited a need for improved awareness of the transportation challenges posed by climate change, a desire for better inter-agency collaboration, and concerns over both funding and technical support for adaptation planning and implementation (Regmi and Hanaoka 2011).

Perhaps the most comprehensive assessment to date of literature on adapting transportation to climate change was authored by Eisenack et al. (2012). They note that while extensive research has been done regarding the influence of climate change on ecosystem, little literature focuses on the adaptation needs of the transportation sector and what literature does exist ends to be impractically specific or overly broad. The authors ultimately determine that there may be a need for adaptation actions that can bridge the difference between those categories and begin to provide insight toward best practices (Eisenack et al. 2012).

In 2013, a review of climate adaptation activities across the USA identified seven primary barriers to adaptation planning and implementation: uncertainty in the decision-making process about climate change; lack of resources; fragmented decision-making; institutional constraints; lack of leadership; and divergent perceptions relating to risk, cultures, and values (Bierbaum et al. 2013). Ultimately, the review recommended pursuing low-risk strategies, engagement of stakeholders, and sharing of best practices (Bierbaum et al. 2013). Another analysis comparing state-level climate action plans across the USA and examining potential influencing factors found that most states have yet to incorporate adaptation planning and, even among the 13 most forward-thinking states, only 3 (Connecticut, Minnesota, and New York) formally addressed transportation in their adaptation planning efforts (Lysák and Bugge-Henricksen 2014). Influencing factors were shown to include political affiliation of state leadership, state gross domestic product (GDP), and coastal population levels.

In the USA, a growing body of literature provides suggestions on how state and local organizations could integrate adaptation into transportation planning. The National Transportation Policy Project released a white paper on transportation adaptation to climate change that lists a number of specific strategies for integrating climate change adaptation into current US policy, all of which fall into one of five main categories: research; planning; design standards; project delivery and the environmental review process; and funding, performance, and accountability (Cambridge Systematics 2009). Most of the recommended policies target the federal legislature. Federal policies can have broad-reaching effects, making them well-suited to mitigation, which needs to be addressed at as large a scale as possible to effectively combat collective greenhouse gas emissions. Adaptation, however, is not only a global- or federal-scale issue: the variability of climate-related impacts in any given region requires regionally tailored approaches to appropriately address specific needs (IPCC 2013). State and regional policies and planning processes provide smaller-scale adjustments through which adaptation could be addressed. Long-range transportation plans developed at the regional level can formalize adaptation methodologies that are replicable from region-to-region and have step-by-step processes that include capacity analysis, risk assessment, inventory evaluation, and monitoring, among other techniques (Oswald and McNeil 2013). Some suggested frameworks are more conceptual, with broader, more flexible steps that allow planning to be tailored to a wider variety of organizations and plan types (Schmidt and Meyer 2009). Others suggest that adaptation hinges on national priorities, the education of policy-makers, performance-based planning, land use concerns, and communication and collaboration (Plumeau and Lawe 2009).

A less-studied strategy for incorporating adaptation is through the modification of prioritization procedures used by MPOs and state DOTs for selecting transportation projects for funding. Because transportation funding is so limited and the number of prospective projects is so great, MPOs and state DOTs are forced to prioritize which projects are most necessary each year (or two, depending on the location). MPOs have substantial control over which projects are funded within their boundaries; state DOTs are responsible for selecting projects from non-metropolitan regions with limited input from local planning commissions. Each MPO and state has its own procedures for selecting which projects to include. Factors such as safety, pavement condition, and average daily traffic are among the criteria commonly incorporated into prioritization procedures. Some states and MPOs employ highly quantitative methods that assign points if a project meets specific criteria, while others employ less formal, more qualitative methods.

The Boston Region MPO, which oversees transportation in one of the northeast's biggest cities, is one of the few organizations that include adaptation-related components in their actual project prioritization procedures. Out of a total possible 154 points, projects can earn up to 6 points for their "ability to respond to extreme conditions," with two of those points relating directly to sea level-rise and flooding (Boston Region 2013). Another 25 points can be earned for mitigation-related components. In that prioritization scheme, adaptation is still weighted far less heavily than mitigation, but it at least earns mention. The explicit inclusion of both mitigation and adaptation in Boston MPO's prioritization scheme was driven by the Massachusetts Global Warming Solutions Act of 2008. In consultation with other agencies, the MPO worked to implement policies that would help meet greenhouse gas emissions targets as well as improve system resilience (S. Pfalzer, Boston MPO, unpublished data).

Increasingly, states and MPOs are able to use specific tools to aid in transportation planning. The use of Geographic Information Systems (GIS) has proven to be valuable for transportation planning in many ways, from mapping daily traffic loads to determining route distances. It is now being applied to various strategies for adaptation, too. In 2009, a county in Washington State employed GIS to map different sea level rises and compare the scenarios' effects on coastal roads (Federal Highway Administration [FHWA], 2011). On the east coast, the New England Environmental Finance Center, in partnership with the University of Southern Maine, has developed a tool called "Coastal Adaptation to Sea Level Rise Tool" (COAST), which helps towns or organizations to calculate the potential economic costs associated with different climate scenarios (FHWA 2011). In the state of North Carolina, Buncombe County worked with the University of North Carolina-Asheville to develop a Multi-Hazard Risk Tool, which enables users to layer data from various sources in map-form, then analyze it using certain GIS-specific tools (FHWA 2011). A study in the state of Virginia used transportation data, climate projections, and existing demographic data (including population density data) to map risk relative to various factors (Wu et al. 2013). Its approach was fairly novel because it magnified the risk according to the presence of important transportation infrastructure or population centers; it did not simply map areas susceptible to flooding. In Vermont, different organizations have begun to consider ways to use GIS to identify vulnerabilities, particularly since Tropical Storm Irene. Shortly after the storm, geologists from Vermont's Norwich University used GIS to map the impacts, which may provide insight toward future adaptation activities (Springston and Underwood 2012). Currently, the Vermont Department of Environmental Conservation is working on a project to map full natural corridors of the all state's rivers, which would help identify areas not to build.

The Federal Highway Administration, which is an agency within the federal DOT that supports state- and local-level transportation initiatives, evaluates climate change-related risk to infrastructure based on two primary factors: first, the exposure to threats, and second, the consequences associated with failed or compromised structures (FHWA 2012). Low spending on infrastructure that typically requires maintenance is in itself considered an indicator of risk exposure. While there are many environmental factors that influence structure vulnerability, major concerns for bridges include precipitation levels and slope angles (FHWA 2012).

This paper seeks to build on prior research and literature regarding transportation adaptation to climate change. It examines current practices, project prioritization procedures, and allocated funding trends in the northeastern states of Vermont and Maine and employs geospatial analysis to highlight the challenges posed by the straightforward integration of adaptation in the transportation project prioritization processes. The states are used as case studies that provide insight into two research questions: first, how and to what extent are the intergovernmental networks in Vermont and Maine undertaking planning and implementation practices to adapt transportation infrastructure, specifically bridge infrastructure, to the threats posed by climate change? Second, how do spatial scale, scope of the landscape, and other features affect local jurisdictions' exposure to flooding risk for sustaining bridge infrastructure in the face of climate change and can such risk assessment methods be used at higher governance levels (such as the state level) to prioritize bridge adaptation funding? The research presented here addresses the second question using a demonstrative spatial analysis to map bridge funding priorities based on assessments of vulnerability at the town level in Vermont, then examines those spending patterns relative to potential risks, including precipitation levels and slope. Future extensions of this methodology can include more sophisticated approaches to measure the structural risk to bridges. The integration of funding data with geospatial analysis creates a novel approach. Basic demographic data—population and income—are also included in the analysis. The goal is to assess whether such risk assessment approaches can be embedded in multi-level governance systems for prioritizing future bridge adaptation funding. Section 2 presents the methodological details; Section 3 presents results from the Northeastern USA; Section 4 discusses gaps in adaptation planning in the US context and discusses the implications of these findings for multi-level institutional designs; and Section 5 concludes with recommendations.

2 Background and methodology

Vermont and Maine were chosen as case study states for their limited geographic size, the readily available planning data, and the extreme events of recent history. Having recently recovered from the impacts of Tropical Storm Irene, Vermont is a unique state for evaluating transportation adaptation planning. While Irene, like Katrina, is impossible to attribute to climate change, the storm displayed many of the climate change-related characteristics that threaten the northeast: heavy rain, an exceptionally intense storm, and massive flooding. Tropical Storm Irene highlighted resilient and unresilient portions of the transportation infrastructure. Maine, which is similar to Vermont in its rural nature and northeastern location, is used for context and comparison throughout much of this paper. Unlike Vermont, Maine was largely missed by Tropical Storm Irene, which veered through only the northwestern corner of the state (Russell et al. 2011). The scale of rebuilding due to Tropical Storm Irene performed by the Maine Department of Transportation (MaineDOT) was a small fraction of that done by VTrans. According to the director of MaineDOT's environmental office, Maine has not suffered from any storms on the scale of Irene in recent history, which may be one of the reasons that Maine has only recently begun to focus on adaptation (J. Gates, MaineDOT, unpublished data). It is not altogether surprising that a state recovering from an extreme storm, like Vermont, might find the need for adaptation more pressing than a state with differing experiences.

Four main processes contributed to the research presented in this paper: (1) interviews and qualitative research, (2) analysis of state prioritization procedures, (3) compilation and assessment of bridge and culvert funding data, and (4) using geospatial analysis to map potentially vulnerable localities. Maine was researched comparatively for multi-level planning regimes. We triangulate both qualitative and quantitative/geospatial approaches to address the research questions posed above.

2.1 Interviews and qualitative research

The first stage relied primarily on interviews conducted in 2014 with key informants to provide background information on existing adaptation practices. Eleven different individuals from seven different organizations contributed insight either via phone or email.[1] Online data mining and a survey of existing literature also contributed context necessary to pursue additional research.

2.2 Project prioritization procedure assessment

In the second step, state project prioritization procedures were assessed for the inclusion of adaptation-specific components. Project prioritization procedures are essentially rubrics that guide how an agency goes about choosing certain transportation projects over others to allocate limited funding. These procedures, which are readily available to the public, can vary widely from state to state.

2.3 Funding allocation analysis

The third phase of research focused on compiling funding data dating back to the year 2000 into a Vermont Bridge Funding Table. This required the acquisition of Vermont's Capital Programs from VTrans. For Maine, the best available funding plans were Statewide Transportation Improvement Programs (STIPs). It should be noted that while the two plan types are closely related, they do have distinct differences: Capital Programs are more representative of the budget, while STIPs are plans used for committing federal funds. Capital Programs also tend to operate on the state fiscal year, while STIPs align with the federal fiscal year. In the case of both plan types, specific projects often fall behind schedule or are delayed for another year. As a result, some projects can reappear in plans for several consecutive years even if they are not actually active, which leads to funds being overcounted (M. Langham, VTrans, unpublished data). Capital Programs are also produced annually, while STIPs are produced biennially, meaning that in the STIPs, the second year is typically a much rougher estimate of allocated funding.

The Capital Programs and STIPs were used to build a project database that included all available information about a given project. For the purposes of this research, only bridge and culvert projects were included. VTrans divides its projects into specific programs: those projects belonging to the "Interstate Bridges," "State Highway Bridges," and "Town Highway

[1] The organizations from which participants were interviewed are the VTrans, the MaineDOT, Chittenden County Regional Planning Commission (CCRPC), Boston MPO, Kittery Area Comprehensive Transportation System (KACTS), Portland Area Comprehensive Transportation System (PACTS), and Bangor Area Comprehensive Transportation System (BACTS).

Bridges" categories were included in the database. For plans produced in 2006 and later, maintenance projects were segregated into a separate "Bridge Maintenance" category; those were included as well. MaineDOT does not subdivide bridge projects into program classes as neatly as VTrans, which made the funding allocations less clear: projects were selected if their descriptions explicitly stated that they were bridge or culvert projects. These processes resulted in the selection of 1,682 projects in Vermont for the period 2000 to 2015 and 1,418 projects in Maine for a comparable period (MaineDOT 2000-2014; VTrans 2000-2015).

2.4 Geospatial analysis

For the fourth stage, spatial analysis was conducted with GIS software to link spending patterns to variables potentially associated with bridge vulnerability and, consequently, provide insight toward the complexities associated with identifying risk. Mean values were calculated for slope, precipitation, bridge count, and bridge funding. These attributes were used to identify potential hot spot towns, defined as towns that had higher than average precipitation, steeper than average slope, a greater than average number of bridges, and sub-average levels of funding. The selected towns were also then compared against population and income. This proposed approach of identifying hot spot towns is merely for illustration purposes to highlight that complexities that arise from varied sloping landscape and socioeconomic conditions within and across towns, regions, and states in multi-level governance systems. Future studies can improve the methodology for identifying "hot spot" towns; we recognize that the slope, without consideration of the soil or rock conditions, does not define stability or the relationship between precipitation and runoff. Due to issues with data availability and consistency, this stage of analysis was conducted for Vermont but not for Maine. Table 1 provides background on the data used.

VTrans maintains publicly available data that maps out bridge location, along with other components such as date built. For the purposes of this research, only state system-level bridges were used. Both long (over 20 ft in length) and short (6–20 ft in length) state-system bridges were included, for a total of approximately 4,000 unique structures. Funding data are not part of the VTrans spatial data; the funding information used in this step was taken from the bridge funding database discussed in Section 2.3. Because the bridge location data provided in the funding documents were insufficiently detailed to assign to specific points, bridge funding information was aggregated by town. Individual bridges were also aggregated by town to achieve a total count for each town.

The environmental factors that have the potential to impact flooding and compromise bridges are myriad. For the purposes of this analysis, slope and precipitation were chosen as experimental variables. To add a small degree of depth to the analysis, basic demographic data were added to the map as well, in the form of both population and income. The higher an area's population, the more people will feel impacts from a washed out bridge and, historically, low-income populations are disproportionately affected by natural disasters (Masozeraa et al. 2007).

3 Results

Analysis of current practices, project prioritization procedures, bridge and culvert funding data, and geospatial patterns indicates that VTrans is not thoroughly incorporating adaptation

Table 1 Basic data information

Name	Data type	Source	Scale/ resolution	Publication date	Attributes used
Vermont RPC, County, and Town Boundaries	Polygon	VCGI	Various	2012	Names and spatial boundaries of RPCs, counties, and towns
VTrans Bridge and Culvert Inventory	Point	VCGI/VTrans	1:5,000 and GPS	2014	Long and short structures: town name and count
USGS National Elevation Data set 30 m	Raster	VCGI/USGS	30 m	2002	Elevation (ft)
Mean annual precipitation data for Vermont (1971–2000)	Raster	VCGI/NRCS	800 m	2008	Precipitation (in.)
Vermont Town Population Statistics, 1790–2000	Polygon	VCGI/UVM Center for Rural Studies	1:5,000	2014	Estimated 2008 population
Vermont Town Economic Statistics	Vector digital	VCGI/UVM Center for Rural Studies	1:5,000	2004	Estimated 2008 average annual wages
Vermont Bridge Funding Table	Table	UVM Transportation Research Center	N/A	Unpublished; compiled in 2014	N/A

practices into planning processes. The comparative assessments with Maine's intergovernmental planning system indicate the MaineDOT is also likely falling short on adaptation planning, which is consistent with national and international research on this topic as synthesized by Revi et al. (2014). Transportation officials from both states agree that a scarcity of funding forces many bridge projects to go unaddressed until near-failure (J. Gates, MaineDOT, N. Wark, VTrans, unpublished data).

3.1 Current intergovernmental planning practices for adaptation in transport sector

In Vermont, VTrans is aware of the need for adaptation: Capital Programs produced after Tropical Storm Irene include a resiliency and adaptation section as an emphasis area in the plans' introductions. Improving the state's bridges is also listed as a priority. Despite the emphasis, very few adaptation-specific actions are actually being undertaken. One important existing practice, which is not found in the planning documents, is the construction of stream crossings to bank full width.

In early 2014, the Vermont Agency of Natural Resources (ANR) updated its permitting process for stream alterations, which include transportation-related structures that bridge perennial streams, such as bridges and culverts (VT ANR 2014). The changes mandated that new structures be built to at least bank full width, which is "the top surface width of the stream channel at a discharge corresponding to a water stage that occurs at a frequency of every one to two years" (VT ANR 2014, page 1). Prior to this mandate, stream crossings were often sized smaller than the channel, which led to a number of problems. Constricting the channel can alter water speed and direction, causing erosion. During periods of high water, undersized crossings cannot accommodate flow and can also become easily blocked with debris, leading to flooding and washouts.

Another major problem with undersized stream crossings is that they often become impassable for fish and other aquatic life. In Vermont, as in many other states, the push for bank full width crossings came predominately from environmentalists and natural resource advocates, not from the transportation community. Despite the move to bank full width design being instituted on behalf of fish, it has important implications for transportation adaptation as well. A VTrans hydraulic engineer noted that, anecdotally, he could not think of any bank full width structures that had failed in the last 10 years (N. Wark, VTrans, unpublished data). A study of a small number of stream crossings in Vermont found that those that built to bank full width survived Tropical Storm Irene, while undersized crossings in similar areas did not (Gillespie et al. 2014). Unfortunately, building appropriately designed structures is typically more expensive than installing undersized pipe culverts, although the difference in cost can vary widely from project to project (N. Wark, VTrans, unpublished data).

Maine, like Vermont, has width requirements for stream crossings. Since 2010, all priority 1 roads have been required to have crossings at least 1.2 times bank full width, and smaller roads require permits for any crossings not built to bank full width (J. Gates, MaineDOT, unpublished data). Although the requirements were initially instituted for the benefit of salmon and other fish, they have the dual benefit of creating a more resilient system from a transportation perspective.

Although adaptation is not a part of Maine's primary transportation planning documents—none of the terms "adaptation," "resilience," or "climate change" appear in the most recent STIPs or work plans—the state is beginning to undertake adaptation-related initiatives. The political climate in Maine has likely contributed to the state's relatively slow movement on adaptation. Governor Paul LePage, sworn in during 2011, was widely criticized for his disbelief in climate change and, in 2013, drew more criticism for publicly stating that climate change could have major benefits for the state (Moretto 2013). Recognizing the dangers posed by sea level rise in particular, MaineDOT has begun to pursue adaptation. With the help of FHWA grant funding, the agency recently embarked on a vulnerability study to assess the risk posed to transportation infrastructure.

3.2 Institutionalizing resilience through project prioritization procedures

States and MPOs in intergovernmental networks have different methods for selecting which projects to include in the STIP or Transportation Improvement Program (TIP) (Zia and Koliba 2013). Analysis of their procedures for prioritization reveal which criteria are deemed most pressing and which are given less weight (or are not considered whatsoever). At the state DOT level, both Vermont and Maine fail to include adaptation-specific criteria.

While VTrans recognizes the need for adaptation, progress is impeded by other demands made on the system. The Environmental Policy Manager for VTrans noted that information, ideas, and best practices for improving resilience are becoming increasingly available. VTrans is collaborating more closely with the Agency of Natural Resources, striving to establish partnerships that strengthen the system overall (G. Campoli, VTrans, unpublished data). While these are beneficial steps, they do not actually impact project prioritization. The current project prioritization scheme, which assigns points quantitatively based on a project's ability to meet certain criteria, is based on asset classes, and none of these criteria directly include "adaptation" or "resilience" in the scoring list. Although VTrans does indeed direct funding explicitly toward bridges and list criteria, such as scour, that can be associated with resilience, such indirect effects are not summed up in their own category as adaptation or resilience. Some criteria may also overlap with adaptation/resilience: "regional priority," for example, may be one area in which adaptation-related concerns could be factored into the evaluation scheme. Table 2, below, displays the current project prioritization processes in place at VTrans. The point system was determined based on input from a series of meetings between VTrans and the Directors of the Vermont Association of Planning and Development Agencies. A multi-criteria analysis tool also aided decision-makers in creating procedures that considered stakeholder concerns (Novak et al. 2015).

Table 2 VTrans project prioritization procedures

Asset class	Factors	Points
Paving	Pavement condition index	20
	Benefit/cost (60 points)	60
	Regional priority	20
Roadway	Highway system	40
	Cost per vehicle mile	20
	Regional priority	20
	Project momentum	20
	Designated downtown project (bonus class)	10
Bridge	Bridge condition	30
	Remaining life	10
	Functionality	5
	Load capacity and use	15
	Waterway adequacy and scour susceptibility	10
	Project momentum	5
	Regional priority	15
	Asset-benefit cost factor	10
Traffic operation	Intersection Capacity	40
	Accident rate	20
	Cost per intersection volume	20
	Regional priority	20
	Project momentum	10
Bicycle/pedestrian	Land use density	20
	Connectivity to larger network	10
	Multi-modal access	5
	Designated downtown	5
	Project cost	20
	Regional priority	20
	Project momentum	20
Park and ride	Total highway and location	40
	Cost per parking space	20
	Regional priority	20
	Project momentum	20

Data from Chittenden Country Regional Planning Commission 2011

By contrast, MaineDOT employs a prioritization scheme that is less quantitative. First, it divides roadways into five Highway Corridor Priority (HCP) classes, with priority 1 roads carrying the highest volume of traffic. The agency then also identifies three different customer service levels (CSLs): safety, condition, and service. Projects are given report card style grades, A–F, based on their priority and CSL performance.

After the initial quantitative weighing of projects, a group of experts convenes to make the final choices (B. Condon, MaineDOT, unpublished data). Although the final round of decision-making uses input from the grading and from different departments within MaineDOT, it is ultimately a qualitative process. There is not a quantitative method for determining the value of a grade “C” versus a grade “D,” for example. While such a process allows for some flexibility and the inclusion of factors that are difficult to quantify, it also allows for the interference of politics, personal ideals, and public preferences. One transportation planner noted that factors such as public complaints and roadway access to business networks are commonly part of project considerations (B. Condon, MaineDOT, unpublished data).

Much like the prioritization procedures used by VTrans, those used by MaineDOT do not explicitly incorporate any adaptation components. Certain factors, such as scour and bridge condition, can be construed to incorporate adaptation, but they are not required to do so under the current system. Neither climate change nor sustainability resiliency or adaptation measures are awarded any points. While Maine’s four MPOs each have their own prioritization systems, some of which consider environment, none currently includes adaptation as a specific factor (T. Reinauer, Kittery Area Comprehensive Transportation System; C. Eppich, Portland Area Comprehensive Transportation System; D. Rice, Bangor Area Comprehensive Transportation System; unpublished data).

3.3 Funding allocations

Below, Fig. 1a, b provides a snapshot of bridge and culvert funding allocations in Vermont and Maine from 2000 to 2015, derived from the new database. It is important to note that the funding information presented here represents planned—not actual—spending. The Vermont Capital Program for year 2011, for example, was written in May of 2010. The spike in 2011 funding, therefore, is not at all related to Tropical Storm Irene nor is the 2012 funding, which was allocated in early 2011. The 2011 spike is largely attributable to the reconstruction of the Crown Point Bridge, which was allocated over $27.5 million for the year 2011 alone. A single large, expensive bridge can skew the funding patterns, particularly in small states like Vermont. Additionally, it should be noted that the figures here have not been adjusted for inflation over the 15-year period.

Mean funding per project is not consistent from year to year in either state, ranging broadly from a minimum of $0.32 million to a maximum of $2.2 million (both in Maine). In Vermont, the mean funding per project over the 16-year period is $0.76 million (standard deviation of $0.29 million), and for Maine, it is $0.82 million (standard deviation $0.5 million). In general, the funding trend in Vermont is more consistent than in Maine, indicative of a general increase in bridge investments in the former. Absolute allocations in terms of total yearly funding have seen a steady increase in Vermont since 2010. For the period from 2000 to 2009, the mean funding allocation was $51.9 million per year (standard deviation $7.9 million); funding has increased to a mean of $125.9 million per year (standard deviation $18 million) for 2010–2015 period. As Tropical Storm Irene damage continues to be incorporated into the database, that figure will continue to rise. In contrast, the increase in Maine has been much less dramatic:

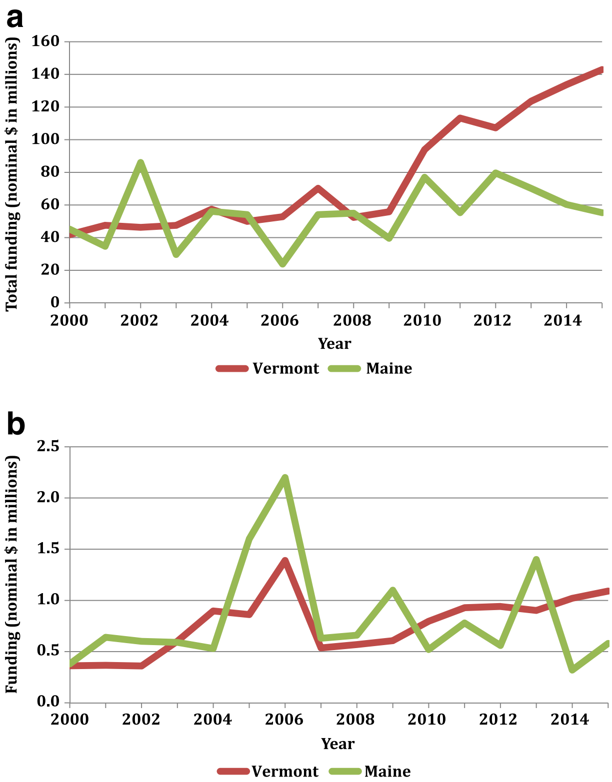

Fig. 1 **a** Planned bridge spending in Vermont and Maine, 2000–2015 (standard deviation is 35.5 for Vermont, 17.6 for Maine). **b** Mean funding per bridge/culvert project in Vermont and Maine, 2000–2015 (standard deviation is 0.29 for Vermont, 0.50 for Maine)

mean yearly funding was $47.8 million (standard deviation $17.7 million) for the 2000–2009 period and $66.3 million (standard deviation $10.8 million) for the 2010–2015 period. The database assembled for this paper is currently being used to build an agent-based model to simulate the changes in the expected funding projections with and without adaptation to climate change scenarios, similar to a roadways model that was recently developed (Zia and Koliba 2013). The funding shortages in the coming decades are expected to be substantial; further research will aim to quantify the expected damages under alternate climate change and land use change scenarios.

3.4 Geospatial analysis

The geospatial analysis revealed broad discrepancies across the state of Vermont. The mean number of bridges in a town—among those towns that have any bridges listed—is just under 20 (with a standard deviation of 7.1), while the mean funding over the 15-year period examined is $5,787,080 per town (standard deviation $664,314). The mean federal funding, which was not used as a variable in this mapping project, is $4,430,248, obviously constituting a large portion of the funding for state-level bridges. The mean average annual precipitation for any given town is 46 in. and the mean terrain slope is 8.1°.

Figure 2 shows a basic map of precipitation levels. This map was isolated to avoid the lack of clarity caused by including too many variables on a single map layout. Not surprisingly, precipitation is typically highest along the spine of the Green Mountains, where elevation is also highest.

Figure 3 shows cumulative 15-year bridge funding according to town, as well as a total bridge count by town. Several towns with at least a dozen state-level bridges have received no bridge funding since the year 2000, while many more have received $2.5 million or less. To offer perspective, a single small-to-medium length bridge on a state route, built to adaptation standards, can easily cost $2.5 million. Although more research would be necessary to offer

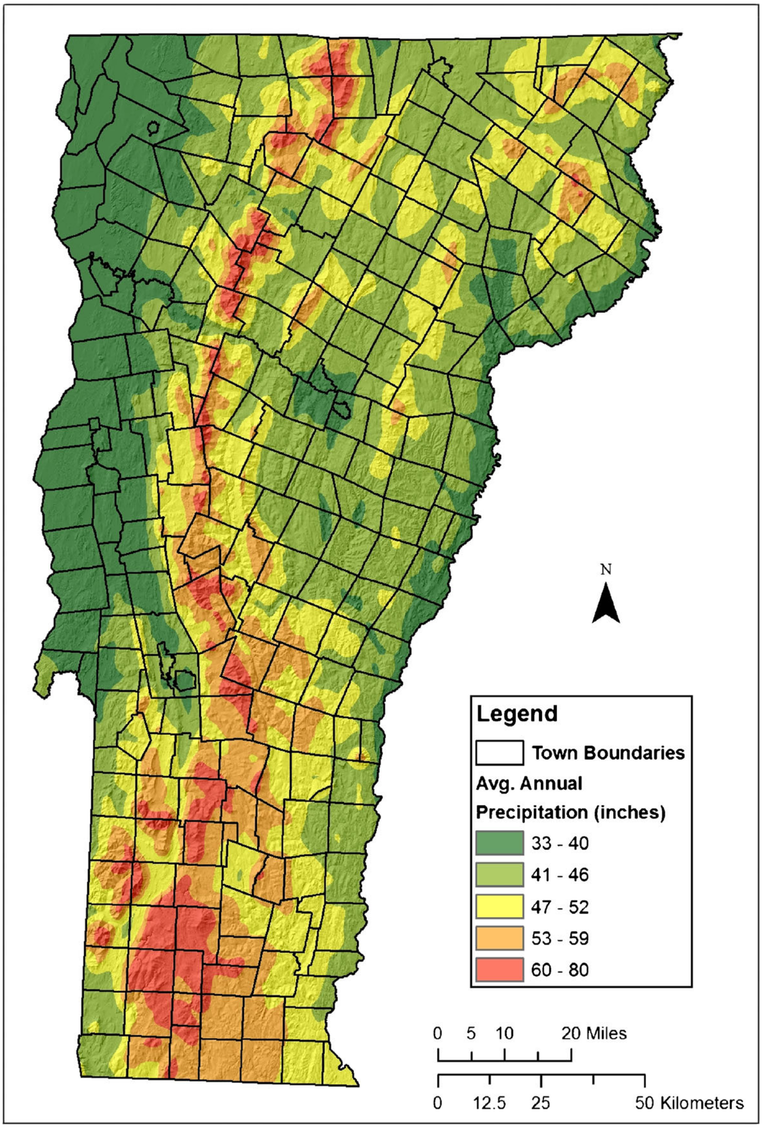

Fig. 2 Average annual precipitation levels overlaid with Vermont town boundaries

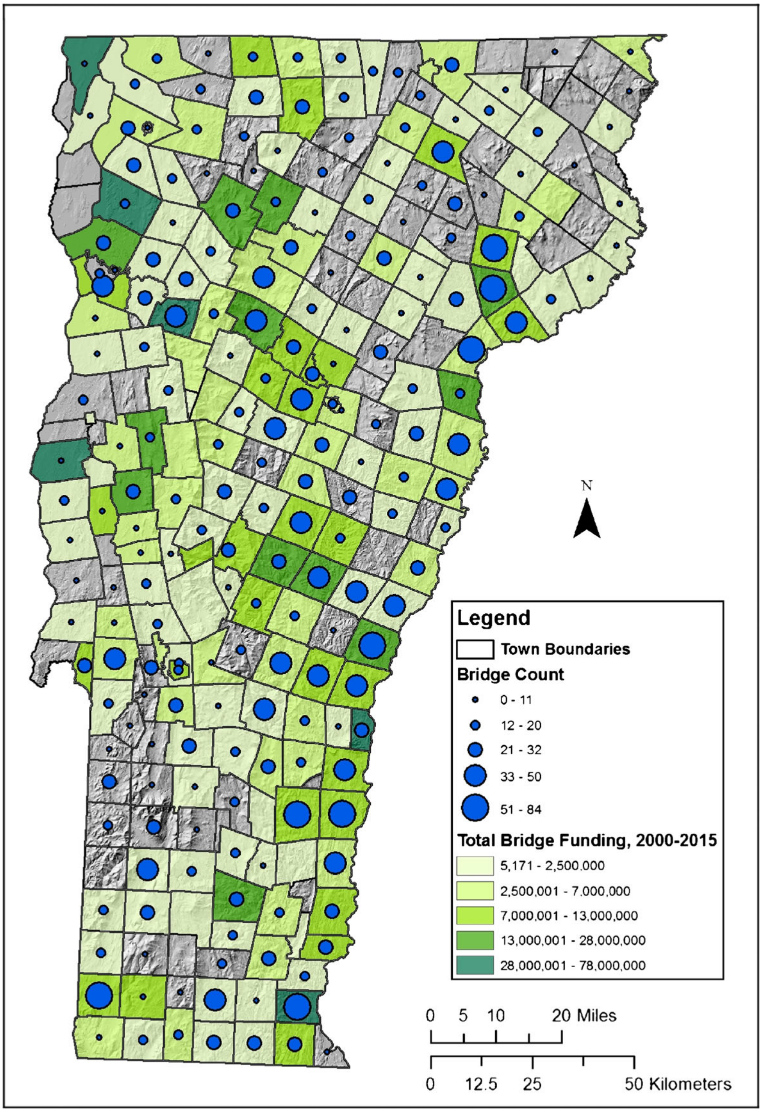

Fig. 3 Bridge funding, 2000–2015, and bridge count by town in Vermont

proof, towns with a high number of bridges and very low amounts of funding may have more vulnerable structures than those towns with few bridges and plenty of funding to maintain them.

Figure 4 identifies nine towns that are deemed to be most vulnerable according to the basic evaluation undertaken in this project: Granville, Bridgewater, Plymouth, Wallingford, Ludlow, Manchester, Sunderland, Newfane, and Halifax. As mentioned above, these towns had high bridge counts, slope, and precipitation but low funding. When evaluated for income, they also all had below-average incomes (the mean average annual wages for the state was $28,617). Their populations, however, were also below average, meaning that bridge failures in those towns might not disrupt transportation for very many people.

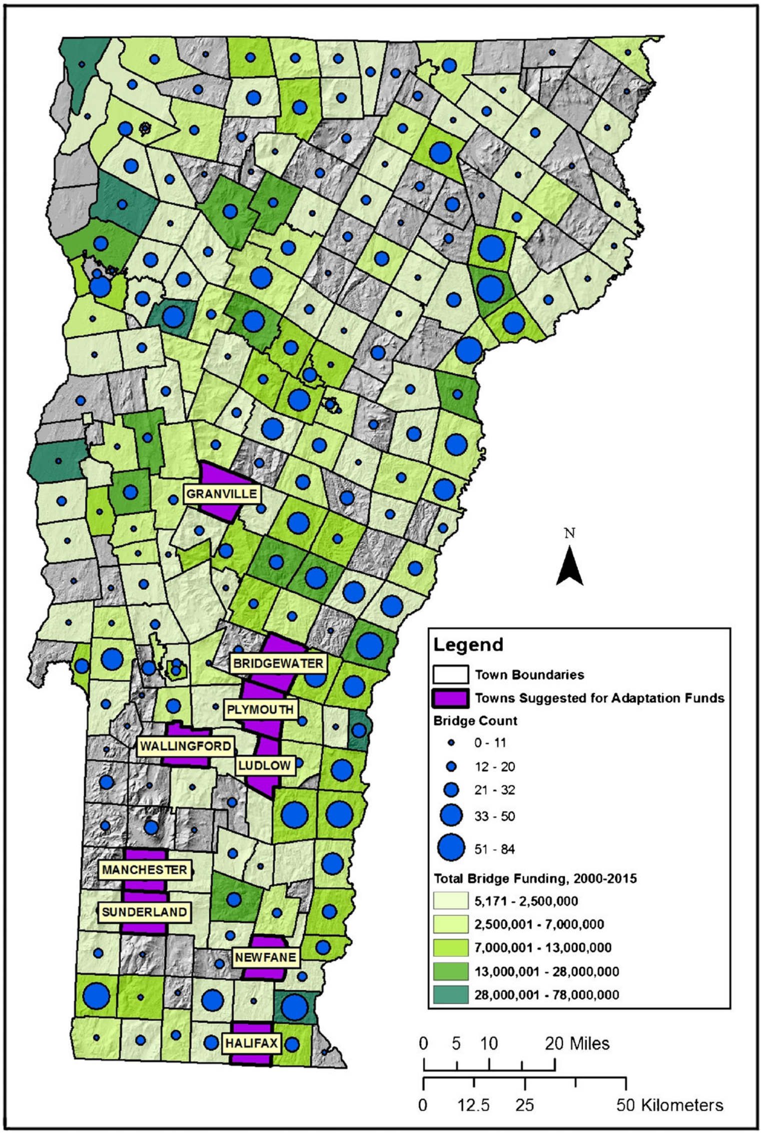

Fig. 4 Towns recommended for bridge adaptation funding

There are many more important factors that were disregarded in this analysis due to the exploratory nature of the research. Major traffic corridors, for example, are important considerations, as is bridge size and year built. River flow patterns are likely very influential. The term "bridge" is itself a complicated one when discussing climate adaptation: some bridges span highways and are at very minimal risk for flooding. Thousands of local bridges were excluded from the count, as were tens of thousands of culverts, and some (though not many) of these structures may have received funding. In short, this project is a very basic investigation into bridge funding practices and their implications for adaptation. More granular/high resolution research is needed to direct future adaptation funding, but the towns selected here may likely be appropriate recipients of funds. Process-based flood risk models that account for soil structure and other parameters could potentially improve the risk assessment procedure for prioritizing adaptation funding. Here, we have just presented a demonstrative example to show the potential for using such spatial models to quantify the flood risk in the face of climate change and ultimately incorporate the quantified risk in the intergovernmental planning practices. High resolution and process model-based spatial risk assessments could be prioritized at international scale by the adaptation funding agencies in the transportation sector. Quantified risk from such risk assessments could be integrated in multi-criteria (Vermont-like) or qualitative (Maine-like) intergovernmental planning processes.

4 Discussion: gaps in adaptation planning

Adaptation planning varies widely among states and regions, but certain challenges are shared. Critical gaps in resources and knowledge render adaptation planning difficult for many organizations.

4.1 Resources

The most notable gap in resources is the limited availability of funding, which influences the availability of almost all other resources. Funding for infrastructure is typically devoted to the most severely failing structures, and, additionally, funding is limited for personnel as well. VTrans, for example, has a hydraulics staff of four people, yet Vermont has more than 2700 bridges *not* including those under 20 ft in length (N. Wark, VTrans, unpublished data). Without funding to hire additional staff, the hydraulics team is forced to attend to the most urgent problems and does not have the capacity to work proactively.

In additional to financial resources, state DOTs and MPOs alike are hindered by their limited access to other types of tools. Several organizations are striving to equip transportation planners with better tools for integrating resilience: for example, the National Cooperative Highway Research Program (NCHRP) recently released a guide aimed at developing transportation professionals' understanding of how the changing climate will impact the transportation system and, consequently, how to adapt for the sake of resilience (NCHRP 2014). Risk management frameworks have been cited as a critical part of a city or region's ability to develop resilience (Oswald and McNeil 2013). Developing such frameworks is not without cost, however: communities must identify both their exposure to certain hazards and the vulnerabilities in their transportation system, then they must also define and measure their system's current resilience (Schmidt and Meyer 2009).

Tailoring sensitivity matrices to individual regions could help transportation planners screen for especially sensitive assets and services (Rowan et al. 2013). Similarly, decision-support tools could help agencies target the most vulnerable places and structures, diverting funding to those projects that are most critical for resilience (Croope and McNeil 2011). The expansion of asset management systems could help agencies track the status of more vulnerable infrastructure under changing conditions (Meyer et al. 2010). GIS programs could be used to map assets relative to climate-based risks (Wu et al. 2013). Many existing tools could prove exceptionally useful; the challenge lies in financing both the acquisition of certain tools and of staff trained in their use.

4.2 Knowledge

To date, most climate data are generalized over relatively broad regions. Within those regions, impacts can vary. More locally specific climate data would be useful to planners who are trying to weigh investment versus risk. Many agencies rely on flood recurrence data that are outdated and, additionally, build structures with a design life that does not consider the anticipated changes in environmental conditions for the end of the design life (N. Wark, VTrans, unpublished data). Yet, another knowledge gap relates to semantic differences in the terms and methods of analysis used by climate scientists versus those employed by civil engineers. While climate scientists are typically focused on trends in magnitudes of precipitation and flooding, engineers may be more concerned with changes in the number of exceedances (Bonnin et al. 2001).

Because building more resilient infrastructure is typically more expensive, transportation agencies are faced with a choice: either they invest now, anticipating that improved infrastructure can withstand the onslaught of climate change, or risk paying to repair damaged infrastructure in the future. Agencies would benefit immensely from cost–benefit analyses that consider different adaptation scenarios and evaluate the tradeoffs. The spatial analysis employed here is rudimentary, but the methodology can be refined and extended. Using existing funding data to aid in quantifying risk can be integrated into the channelization of adaptation funding in intergovernmental planning contexts. The use of GIS is promising as a tool to aid decision-making: improved access to geospatial analysis may advance agencies' capacity to appropriately guide the allocation of funding toward the most vulnerable locations.

5 Challenges and opportunities for institutionalizing resilience in intergovernmental networks

The intergovernmental transportation network in the US context operates at three to five distinct levels at which policy and planning can address transportation adaptation to climate change in a rather complex inter-twined system: federal, state, regional (the level of MPOs and RPCs), counties, and local towns/villages. Each level has distinct challenges to and opportunities for incorporating adaptation into transportation planning. Transportation policies are infamously complex, necessitating the use of multi-faceted analysis that appropriately considers the major process variables at work (Zia and Koliba 2013; Novak et al. 2015). While a full analysis is a major undertaking, here we hope to offer insight into some of the considerations that should be made when examining adaptation planning alternatives. At any level, political feasibility, budget availability, and efficiency are important factors in weighing a policy's relevance. As of now, however, climate adaptation policies for transportation are so anemic that a variety of alternatives could represent an improvement. Rather than being prompted into action by dramatic focusing events such as natural disasters, policy-makers can take steps toward institutionalizing resilience by introducing appropriate legislation in advance. There are, however, cross-scale complexities for quantifying the risk and allocating the resources through the intergovernmental planning processes.

5.1 Federal (national) level

The primary policy alternative at the federal level is legislation that either allocates funding for adaptation efforts, mandates states, provinces, or regions to incorporate adaptation or does both. The costs of such a policy could be vast and, since there is little precedent for this type of policy, it is difficult to predict whether the benefits would be substantial (Cambridge Systematics 2009). Given the US Congress' failure to pass a new transportation funding authorization bill, federal funding in the USA remains unpredictable. Despite initial funding requirements, the long-term benefits of some adaptation measures may outweigh the risks and costs associated with the failure to adapt. Because the federal government, through FEMA and FHWA, is responsible for providing aid to states struggling with natural disasters, this is a relevant concern: without adaptation, rebuild costs may be higher.

One major issue with a national policy relates to the different needs among states. South Dakota, for example, has vastly different adaptation needs than New York. Differences in geography, climate, population distribution, and existing infrastructure render adaptation a much greater priority for some states than others. Furthermore, uniform national policies and resource allocation programs that approach infrastructure with "one-size-fits-all" standards are the least flexible options, making it difficult to reassess and adapt in the face of dramatic events like extreme storms. Given the sheer number of competing interests and extreme political polarization present in national political arena, political feasibility is yet another challenge. Small allowances in federal policy, however, can provide states, provinces, and regions with the power to undertake actions of their own. In the case of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), measures to protect the environment were not explicitly required but were rather made more easily eligible for funding (Downing and Noland 1998).

5.2 State, provincial, and local levels

In the USA, states and MPOs have considerable control over the transportation activities undertaken within their boundaries. It is the state DOTs and MPOs, not the federal agencies, that develop the STIPs and Capital Plans and thereby create the transportation work lists. Prioritization procedures and funding allocations are dictated by policies at the state and local level. Furthermore, state and local agencies are more familiar with their infrastructure, climate, and stakeholders. In New England, the focus region of this paper, states are geographically small enough that state-level policy can be appropriately targeted. Restructuring of prioritization procedures for STIPs and TIPs would be a relatively straightforward, inexpensive way to begin to incorporate adaptation. Allocating a small number of points to projects that incorporate adaptation could modify the slate of projects undertaken in any given year and begin to shift the emphasis from maintenance to forward-thinking design and building. Similar planning practices can be adopted by intergovernmental networks in developing countries where transportation infrastructure is vulnerable to climate change-induced extreme events.

In the US context, if funding does not increase and emphasis begins to shift away from maintenance and constant rebuilding of damaged infrastructure, states and localities may need to engage in conversations and planning processes to address strategic disinvestment. Boston MPO, with its present inclusion of adaptation criteria in its STIP, may provide an interesting case study for other MPOs trying to restructure project prioritization. Politics and local priorities may exert strong influence over how and whether states and MPOs incorporate adaptation criteria. In the case of Boston, collaborations with other agencies and local policy objectives both played major roles in changing prioritization criteria (S. Pfalzer, Boston MPO, unpublished data). In Vermont, local or state transportation officials would have to determine which present criteria would need to be deemphasized to shift points toward adaptation.

It is at the state and local levels that GIS and spatial risk analysis are most promising as well. Performing geospatial analysis over too broad a region poses the risk of losing granularity and, consequently, may result in overly generic results that are of reduced practical use to decision-makers. As illustrated here, geospatial analysis conducted at the state, provincial, metropolitan levels has the power to employ specific variables to isolate individual localities likely to be in greatest need of funding. Combining funding analysis with spatial components offers a unique way to assess vulnerability. “Hot spots” defined by particular geographic and climatological variances can be mapped with climate- and geography-specific variables, such as precipitation and slope, with the addition of information pertaining to biogeochemical properties of the landscape.

The methodology presented here, however, suffers from certain weaknesses and assumptions that could be addressed in future research. First, rather than examining means, certain variables could be assessed for limits or tipping points that have been shown to demonstrate increased risk in actuality. Second, funding data would ideally display actual expenditures, and emergency funding data would be incorporated into funding databases to identify which towns may have new (and likely sturdier) bridge infrastructure. Third, the methodology could be further tailored and strengthened by incorporating additional attributes depending on the availability of data. Soil type, land cover, and bridge age are all examples of potentially contributing variables.

6 Conclusions

While climate change-induced extreme events could have devastating consequences for transportation infrastructure such as roads and bridges, institutionalization of adaptation and resilience in the planning processes are rather complex and compete with other goals. Despite the clear trend toward increasing climate change impacts, in this study, we find that transportation agencies in Vermont and Maine are not undertaking significant planning changes to engage in adaptation actions that will improve system resilience. Due to limited federal funding and competing political interests, top-down change appears unlikely to happen from the national level. Adaptation to climate change is by nature very local, which requires bottom-up, innovative solutions to the risks posed by climate change across different landscapes. In the USA, state agencies and MPOs, with their important role in planning, have the ability to take steps toward improving planning processes in intergovernmental networks. By modifying project prioritization structures to explicitly incorporate adaptation and resilience measures, state agencies and MPOs can begin changing planning processes to adequately prepare for the risks and costs that climate change will place on our transportation system. Further, in the face of funding shortfalls, spatial risk analysis approaches can be used to target limited funds to the local towns that are vulnerable to climate change-induced hydrometeorological hazards such as floods, flash floods, and landslides.

Adapting infrastructure to climate change, both in the planning and implementation phases, is a concern for transportation agencies across the globe. Although these intergovernmental networks will likely vary across countries, the approaches to study and address the challenges to building robust governance networks designed to ensure transportation infrastructure adaptation and resilience introduced in this article may be applied to a diverse array of settings. Project design and prioritization are key components of building resilience within the transportation sector. In the face of challenges related to knowledge, financial resources, and political processes, approaches are needed that are both novel and replicable. The alteration of project prioritization procedures, coupled with the use of spatial risk analysis, may provide a new strategy for allocating scarce resources to adaptation initiatives.

Acknowledgments We gratefully acknowledge funding from the United States Department of Transportation via the University of Vermont Transportation Research Center and National Science Foundation EPS-1101317.

Compliance with ethical standards The authors bear complete responsibility for all the data and information provided in this manuscript. The authors also verify that there are no conflicts of interest; that this manuscript has not been simultaneously submitted in full or in part to another journal; that no part of this manuscript has already been published; that no animal subjects were used in research; that human subjects were used only as non-personal interview sources; and that those individuals provided informed consented for the use of their statements in our research findings.

References

Bierbaum R, Smith JB, Lee A et al (2013) A comprehensive review of climate adaptation in the United States: more than before, but less than needed. Mitig Adapt Strat Glob Chang 18:361–406

Bonnin GM, Maitaria K, Yetka M (2001) Trends in rainfall exceedances in the observed record in selected areas of the United States. J Am Water Resour Assoc 46(2):344–353

Boston Region MPO (2013) FFYs 2014–17 TIP evaluation scoring. www.ctps.org/Drupal/data/pdf/plans/TIP/TIP_Evaluation_Scoring.pdf. Cited 6 March 2015

Cambridge Systematics, Bipartisan Policy Center (2009) Transportation adaptation to global climate change. http://bipartisanpolicy.org/library/research/transportation-adaptation-global-climate-change. Cited 6 March 2015

Chittenden County Regional Planning Commission (2011) Prioritization of transportation projects. www.ccrpcvt.org/library/CIRC/docs/VTrans_CCRPC_Prioritization_Methdology_20110805.pdf. Cited 6 March 2015

Croope SV, McNeil S (2011) Improving resilience of critical infrastructure systems postdisaster: recovery and mitigation. Transp Res Rec 2234:3–13

Downing D, Noland RB (1998) Environmental consequences of reducing the federal role in transportation: legal framework. Transp Res Rec 1626:3–10

Eisenack K, Stecker R, Reckien D, Hoffman E (2012) Adaptation to climate change in the transport sector: a review of actions and actors. Mitig Adapt Strateg Glob Chang 17:451–469

Federal Highway Administration (2011) Geographic information systems applications for climate change decision-making: peer exchange summary report. https://www.gis.fhwa.dot.gov/documents/GIS_for_Climate_Change_Proceedings.pdf

Federal Highway Administration (2012) Climate change and extreme weather vulnerability assessment framework. http://www.fhwa.dot.gov/environment/climate_change/adaptation/publications_and_tools/vulnerability_assessment_framework/fhwahep13005.pdf

Gallivan F, Ang-Olsen J, Turchetta D (2009) Integrating climate change into state and regional transportation plans. Transp Res Rec 2119:1–9

Gillespie N, Unthank A, Campell L, Anderson P, Gubernick R, Weinhold M, Cenderelli D, Austin B, McKinley D, Wells S, Rown J, Orvis C, Hudy M, Bowden A, Singler A, Fretz E, Levine J, Kirn R (2014) Flood effects on road-stream crossing infrastructure: economic and ecological benefits of stream simulation designs. Fisheries 39(2):67–76

Horton R, Yohe G, Easterling W et al. (2014) Chapter 16: Climate change impacts in the United States: the third National Climate Assessment. In: Melillo JM et al. (eds) Climate change impacts in the United States: the third national climate assessment. Available via US Global Change Research Program. http://nca2014.globalchange.gov/report/regions/northeast. Cited 12 June 2014

Hunt A, Watkiss P (2011) Climate change impacts and adaptation in cities: a review of the literature. Clim Chang 104(1):13–49

IPCC (2013) Climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. www.climatechange2013.org. Cited 2 May 2014

Jaroszweski D, Chapman L, Petts J (2010) Assessing the potential impact of climate change on transportation: the need for an interdisciplinary approach. J Transp Geogr 18(2):331–335

Johnson I (2012) Adapting Vermont's transportation infrastructure to the future impacts of climate change: VTrans climate adaptation white paper. http://vtransplanning.vermont.gov/sites/aot_policy/files/documents/planning/Climate%20Change%20Adaptation%20White%20Paper.pdf. Cited 15 May 2014

Kehew RB, Kolisa M, Rollo C et al (2013) Formulating and implementing climate change laws and policies in the Philippines, Mexico (Chiapas), and South Africa: a local government perspective. Local Environ 18(6): 723–737

Koliba C, Meek J, Zia A (2010) Governance networks in public administration and public policy. CRC Press/ Taylor & Francis, Boca Raton

Lowe A, Foster J, Winkelman S (2009) Ask the climate question: adapting to climate change impacts in urban regions. Center for Clean Air Policy (CCAP), Washington, DC

Lysák M, Bugge-Henricksen C (2014) Current status of climate change adaptation plans across the United States. Mitig Adapt Strateg Glob Chang. doi:10.1007/s11027-014-9601-4

Maine Department of Transportation (2000–2014) Statewide transportation improvement programs. http://www.maine.gov/mdot/stip/. Cited 15 July 2014

Masozeraa M, Bailey M, Kerchnerc C (2007) Distribution of impacts of natural disasters across income groups: a case study of New Orleans. Ecol Econ 63:299–306

McBeath J (2003) Institutional responses to climate change: the case of the Alaska transportation system. Mitig Adapt Strateg Glob Chang 8(3):3–28

Meyer M, Amedkudzi A, O'Har JP (2010) Transportation asset management systems and climate change: adaptive systems management approach. Transp Res Rec 2160:12–20

Moretto M (2013) LePage sees upside for global warming in Maine with opening of northeast passage. Bangor Daily News. 5 December 2013. http://bangordailynews.com/2013/12/05/politics/lepage-sees-upside-for-global-warming-in-maine-with-opening-of-northeast-passage/. Cited 30 June 2014

National Cooperative Highway Research Program (2014) Strategic issues facing transportation: climate change, extreme weather events, and the highway system: practitioner's guide and research report. Report 750(2). http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_750v2.pdf. Cited 30 June 2014

Novak D, Koliba C, Zia A, Tucker D (2015) Evaluating the outcomes associated with an innovative change in a state-level transportation project prioritization process: a case study of Vermont. Transport Policy

Oswald MR, McNeil S (2013) Methodology for integrating adaptation to climate change into the transportation planning process. Public Works Manag Policy 18(2):145–166

Plumeau P, Lawe S (2009) Meeting the challenge of institutional fragmentation in addressing climate change in transportation planning and investment. Transp Res Rec 2139:81–87

Regmi M, Hanaoka S (2011) A survey on impacts of climate change on road transport infrastructure and adaptation strategies in Asia. Environ Econ Policy Stud 12(1):21–41

Revi A, Satterthwaite DE, Aragón-Durand F et al. (2014) Urban areas. In: Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the fifth assessment report of the Intergovernmental Panel on Climate Change [Field CB, Barros VR, Dokken DJ et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 535–612

Roberts D, O'Donoghue S (2013) Urban environmental challenges and climate change action in Durban, South Africa. Environ Urban 25(2):299–319

Rowan E, Evans C, Riley-Gilbert M, Hyman R, Kafalenos R, Beucler B, Rodehorst B, Choate A, Schultz P (2013) Assessing the sensitivity of transportation assets to extreme weather events and climate change. Transp Res Rec 2326:16–23

Russell E, Cousins C, Curtis A, Lynds J (2011) Thousands without power, bridges closed as state cleans up after Irene. Bangor Daily News. 29 August 2011. http://bangordailynews.com/2011/08/29/news/state/the-cleanup-from-irene-begins-nearly-200000-mainers-without-power/. Cited 2 July 2014

Savonis MJ, Burkett VR, Potter JR (eds) (2008) Impacts of climate change and variability on transportation systems and infrastructure: Gulf Coast study, phase I. US Department of Transportation; Washington, DC

Schmidt N, Meyer MD (2009) Incorporating climate change considerations into transportation planning. Transp Res Rec 2119:66–73

Springston G, Underwood K (2012) Impacts of tropical storm Irene on streams in Vermont. http://www.anr.state.vt.us/dec/geo/pdfdocs/IreneGeomorphRevised02142012small.pdf

US Government Accountability Office. (2014) Emergency transportation relief: agencies could improve collaboration begun during Hurricane Sandy response. GAO-14-512. http://www.gao.gov/products/GAO-14-512. Cited 2 July 2014

Venner M, Zamurs J (2012) Increased maintenance costs of extreme weather events: preparing for climate change adaptation. Transp Res Rec 2292:20–28

Vermont Agency of Natural Resources (2014) Stream alteration general permit. http://www.watershedmanagement.vt.gov/rivers/docs/2014_04_10_Stream_Alteration_GP.pdf. Cited 30 June 2014

Vermont Agency of Transportation (2000–2014) Capital Programs. http://vtrans.vermont.gov/about-us/capital-programs. Cited 30 May 2014

Walker L, Figliozzi MA, Haire AR, MacArthur J (2011) Climate action plans and long-range transportation plans in the Pacific Northwest and Alaska. Transp Res Rec 2252:118–126

Walsh J, Wuebbles D, Haykoe K et al. (2014) Chapter 2: Our changing climate. In: Melillo JM et al. (eds) Climate change impacts in the United States: the third national climate assessment. Available via US Global Change Research Program. http://nca2014.globalchange.gov/report/sectors/transportation. Cited 5 July 2015
Wu Y, Hayat T, Clarens A, Smith BL (2013) Climate change effects on transportation infrastructure: scenario-based risk analysis using geographic information systems. Transp Res Rec 2375:71–81
Zia A, Koliba C (2013) The emergence of attractors under multi-level institutional designs: agent-based modeling of intergovernmental decision-making for funding transportation projects. AI & Society: Knowledge, Culture, and Communication. http://link.springer.com/article/10.1007/s00146-013-0527-2/fulltext.html. Cited 5 May 2014