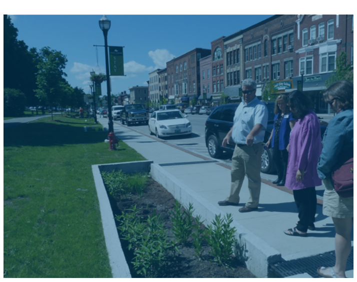
Chapter 2

Statewide Assessment of Risk, Economic Activity and Associated Infrastructure



Chapter 2

Overview

Understanding the type, frequency and level of risk faced by a business, community or state is needed in order to plan, prepare, and respond to those risks. Therefore, one of the first tasks for the Vermont Economic Resiliency Initiative (VERI) project team was to understand the natural and man-made risks faced by Vermont and determine what hazards this project would evaluate on a statewide basis. Knowing and understanding risk is the first step in avoiding economic disruption and loss after a disaster.

The team looked at the State's Hazard Mitigation Plan (SHMP), which is required by the Federal Emergency Management Agency (FEMA) in order for states to receive federal funding for response and recovery (2013 Vermont SHMP: http://vem.vermont.gov/sites/vem/files/VT_SHMP2013%20FINAL%20APPROVED%20ADOPTED%202013%20VT%20SHMP_scrubbed_cleaned MCB.pdf). The SHMP includes an analysis of statewide risk from common man-made and natural disasters such as tornadoes, hurricanes, earthquakes, flooding, winter storms, landslides, wildfires, dam failures, and terrorism. Other less common categories in the plan include: wind, structural fires, transporting hazardous materials, power outages, infectious disease outbreaks, and invasive species. Table 2.1 illustrates the hazards considered from the SHMP which were ranked qualitatively by the State Hazard Mitigation Committee.

Table 2.1: Hazards Considered from the State Hazard Mitigation Plan

Hazard	Frequency of Occurrence	Warning Time	Geographic Extent	Potential Impact
Flooding and Fluvial Erosion	Highly Likely	None - Minimal	Region-wide	Major
Tornadoes	Occasionally	None- Minimal	Community-wide	Major
Severe Thunderstorms	Highly Likely	6-12 hours	Region-wide	Moderate
Landslides/ Rockslides	Likely	None - Minimal	Community-wide	Moderate
Wildfires	Occasionally	6-12 hours	Statewide	Moderate
Dam Failure	Unlikely	3-6 hours	Community-wide	Major
Severe Winter Storms	Highly Likely	More than 12 hours	Region-wide	Minor
Hail	Likely	6-12 hours	Region-wide	Minor
Ice Jams	Highly Likely	More than 12 hours	Community-wide	Minor
Rockcuts	Occasionally	None - Minimal	Community-wide	Minor
Extreme Temperatures	Likely	More than 12 hours	Region-Wide	Negligible

When assembling a team to assess risk in a state or region, it is important to include representatives from emergency management as they have information on repetitive damage, hazard types – key ingredients when developing a risk assessment.

Each hazard poses a different and unique threat to business activity. Depending upon location and context, some are more important than others. For this project, secondary risks were omitted entirely from the VERI analysis, as the likelihood and predictability of these events disrupting economic activity in Vermont is low. This analysis would be different for other states. In California, for example, earthquakes, invasive species or wildfires are a real and present danger to business and/or agriculture.

The project team reviewed each type of risk and considered the probability of occurrence, response and recovery costs, and if the location of occurrence could be predicted. After that analysis, the team decided that this project would focus on the risk from flooding, both inundation and fluvial (river-related) erosion. This is in line with the SHMP and the 1999 Act 137 Report to the Vermont General Assembly, which both identified flooding and fluvial erosion as the number one risk to the state and its economic centers (the report can be found here: http://watershedmanagement.vt.gov/rivers/docs/rv_act137.pdf). Other "highly likely" hazards for Vermont include ice jams, severe thunderstorms, and winter storms, each of which can cause flooding.

High winds, snow storms and ice are all high risk factors in Vermont, but predicting and mitigating their effects is difficult. Nonetheless, several of the tools in Chapter 6, such as local emergency and hazard mitigation plans and continuity of operations plans (COOP) are relevant preparation tools for any disaster.

The Cost of Flooding to Vermont's Economy

In 2011, thousands of Vermont's small businesses were affected by the flooding associated with both the spring flooding around Lake Champlain and Tropical Strom Irene, and suffered prolonged disruptions to operations. This in turn caused a delay in getting employees back to work and prolonged the recovery of the whole community. Damage to or loss of businesses following a disaster brings multiple hardships to a community including lost job, lost tax revenues for local government, and lost work and sales for local businesses. According to FEMA's Lessons Learned and Information Sharing network, "the private sector employs most of the nation's workforce, owns 85% of critical infrastructure, and produces goods and services necessary for the day-to-day functioning of society." The recovery of a community is therefore directly related to the recovery of its businesses and workforce.

Damage from a disaster has ripple effects in the lives of individuals, business operations, and community budgets. In April 2012, FEMA issued an Economic Impact Assessment examining the quantitative and qualitative consequences of Tropical Storm Irene (US EDA, 2012) (see resource section). The results of this analysis make it clear that the storm's overall effect was significant:

- By late March 2012, the Small Business Administration had made loans totaling more than $33 million to businesses and individuals;

- The FEMA Individuals and Household Program recorded Real Property Verified Losses as a result of Tropical Storm Irene of almost $25.5 million, representing just over 1,000 homes and businesses;

- By November 2011, the US Department of Agriculture (USDA) had received reports of damage to 463 agricultural producers and it is estimated that 9,348 acres of land damage occurred as a result. Damage ranged from lost crops and infrastructure, land washed away by overflowing rivers and creeks, to wind damage to maple sugar woods; and

- Vermont experienced a sharp spike in initial weekly unemployment claims immediately following Tropical Storm Irene, with an increase in claims of 149% for the week ending September 3rd and the culmination of initial claims from September 3-10th representing a 376% increase.

While flooding and other natural disasters are not uncommon in Vermont, the scale and impact of the events of 2011 (both the spring flooding around Lake Champlain and Tropical Storm Irene) served as a wake-up call and raised awareness of the need for improved strategies to protect areas of key economic importance.

Evaluating Economic Activity

In the past, when river corridors and their associated watershed have been assessed, recommended management strategies were focused on achieving river stability and floodplain function. The goals were to mitigate hazards, protect public safety, improve water quality, and maintain habitat. However, these strategies did not consider the potential to reduce business closings and loss of income. One key goal of this project was to bring the economic impacts into the prioritization of implementation strategies.

Before conducting a detailed analysis on how best to ensure businesses remain open and economic impacts to communities are reduced at the local level, the VERI project team developed a methodology to assess economic activity across the state. This economic activity data was then ranked along with information on at-risk infrastructure, and commercial buildings within the river corridor to assist in prioritizing five study areas. This chapter outlines the methodology we developed and Chapter 3 summarizes the ranking and prioritization process.

Vermont Economy: An Overview

Vermont is a place of apparent contrasts. It is a small rural state with more than 7,000 farms and the largest private sector employer is IBM (now GlobalFoundries), the iconic electronics manufacturer. The state is known for cheeses, craft beers and skiing, yet, increasingly, its cutting-edge technology companies (such as Dealer.com, BioTek, Logic Supply and NRG Systems) make INC. magazine's list of fastest-growing companies. Vermont has more than 100 general stores and, at the same time, is home to MyWebGrocer, an Internet-based grocery marketing company with over 300 employees.

In the wake of 2011's Tropical Storm Irene, Vermont set out to not only repair its infrastructure, but to create a stronger and more prosperous state; resilient to both natural and economic impacts. With guidance and support from the US Economic Development Administration (US EDA), the state gathered input from stakeholders to develop a Comprehensive Economic Development Strategy (CEDS). The CEDS lays out goals to strengthen the Vermont economy, and like VERI, focuses on key sectors that could be weakened by climate change – skiing, agriculture, maple and forest products, and tourism, as shown in Table 2.2 (VT ACCD, 2014).

Table 2.2: Major Industry Sectors that Contribute to State of Vermont Economy

Sector Name	2012 GDP ($ million)	Employees	Number of Businesses	Location Quotient
Agriculture, Forestry, Fishing and Hunting	325		417	1.275
Mining, Quarrying, and Oil and Gas Extraction	52	800	65	.10
Utilities	774	1,800	48	1.451
Construction	1035	14,200	2848	1.056
Manufacturing	3150	31,800	1075	.962
Wholesale Trade	1263	9200	1451	.802
Retail Trade	2195	37,700	3253	1.319
Transportation and Warehousing	542	6,800	555	.659
Information	655	4,700	488	.541
Finance and Insurance	1480	9,000	972	.679
Real Estate and Rental and Leasing	3683	3,100	708	1.09
Professional, Scientific, and Technical Services	1775	14,000	2995	.849
Management of Companies and Enterprises and Administrative and Support and Waste Management and Remediation Services	793	10,100	100	.727
Educational Services (not including preK-12, public schools)	616	12,600	405	1.953
Health Care and Social Assistance	2827	48,100	1878	1.384
Arts, Entertainment, and Recreation	245	4,000	400	.912
Accommodation and Food Services	1335	29,500	1755	1.614
Other Services (except Government)	697	10,100	1982	1.055
Government (includes preK-12 public schools)	3803	55,000	n/a	1.1136

(Source VT ACCD, 2014)

Economic Activity: The Methodology

The project team began with a review of data sets that provided town-level information and were available consistently statewide. Information related to employment, taxes, revenues and profits, and commercial buildings or 'units' were evaluated. The methodology developed takes into account the value of goods produced and services provided, and the labor force that produced them, for each town in which they were produced.

'Economic activity' is a measure of the economic transactions that take place within any community. Those transactions are the result of value-added goods and services production that arise through the combination of labor and the utilization of natural and built capital. Total economic activity is a combination of changes in the value of built capital, changes in the value of natural capital, and income to workers and business owners.

The project team incorporated expert opinions by consulting the staff in the State Auditor's Office and the State's Economist, regarding the methodology for measuring and screening economic activity by town.

Measuring total economic activity can begin with the total dollar value of the transactions that take place in a community. Every sale of goods or services is a reflection of the value of the goods and services produced. For this study, the team reviewed several sets of data that provide a piece of the story with respect to the sales going on in the community. Some are direct measures of the transaction such as sales tax, meals and rooms tax or property transfer tax. However, these are only a subset of value added transactions taking place. Manufactured items are typically sold at a wholesale level and not subject to sales tax. Food and clothing are two large categories of goods not subject to sales tax. Very few services, including the professional services of health care and legal services are subject to sales tax.

The income received by workers is another approach to understanding the value of economic activity in a community and allows a more complete understanding of the range of transactions. However, just as with measuring individual transaction volume, the income for workers is an incomplete measure of total economic activity. One large reason is that the location of a worker's paycheck may not be the same as the location where the value added activity takes place. For example, utility workers are paid from a central office, but their work tends to be distributed over a wide area.

The increasing mobility of labor and knowledge based industries makes it almost impossible to use a limited set of measures to gauge the economic activity in different communities. For this study, the project team used the basic measures and reviewed the results with individuals and organizations with local knowledge about the different character of economic activity in each community.

To assess economic activity at a municipal level, the project team sought data to answer the following questions:

- What is the value of goods and services produced in each municipality?
- What is the value of the labor force that produces goods and services in each municipality?

The Data Sets

The team reviewed various data sets, identified the key information provided and assessed any limitations. Table 2.3 summarizes the team's data set review. Data limitations are noted. The final primary data sets chosen are discussed in the text that follows.

Table 2.3: Summary of Economic Data Set Review

Data Set	Information Provided	Limitation
Average annual number of business establishments by town	An establishment is an 'economic unit' (a farm, factory or store) that produces goods or provides services at a single physical worksite and that is engaged, predominantly, in one type of economic activity	The count of business is not a measure of business size, profitability and workforce.
Average annual employment by town	The number of jobs in each town. The annual average of the monthly employment figures in each town, as reported by covered employers.	These data exclude self-employed people, most farms, some non-profits, churches, rail workers, elected officials, student workers, and officers and family members of sole proprietorships or partnerships.
Annual Total wages, by town	The total of all wages paid by reporting establishments in each town. Includes wage data from businesses that report to the quarterly census. Businesses that report to the QCEW include private, for-profit businesses with one or more employees, government agencies, non-profit organizations with four or more employees, and farms employing ten or more workers.	Self-employed people are not covered, nor are the majority of farms, non-profits such as churches, railroad workers (covered separately), elected officials, sole proprietorships or partnerships, and student workers. This is not total payroll data by town of employment.

Data Set	Information Provided	Limitation
Income Tax withholding data, by town	Income tax withholding is an indirect measure of wages for a business.	Individuals can change the amount of withholding depending on their personal tax situation. For example, workers with a larger household will have lower withholding than a worker in a single-person household.
Sales Taxes Received, by town		Sales taxes are based on a subset of sales. Most transactions are not subject to sales taxation including food, residential energy use, and most services.
Meals Receipts, by town	Prepared foods in restaurants is subject to the meals tax	A combined measure of tourist activity and local resident's use of restaurants. Small towns with few tax collecting restaurants do not have their results reported by VT DOT.
Rooms Receipts, by town	Overnight accommodations are subject to the rooms tax	Another measure of local tourism activity. This does not include second home ownership and as with the meals tax, small towns may not have enough tax paying businesses to have their receipts reported by VT DOT.
Property Valuation	Each town has a Grand List that includes the value of all properties. The total of property value is both a reflection of the potential for development and the value of improvements that have taken place.	
Per Capita Income		Does not incorporate the location in which the income was generated.
Vermont Small Business Development Center Client Network		A limited subset of the small businesses in the state.
Internet Fiber/Broadband Mapping		There is limited data on the extent of coverage by town that is publicly available.
American Community Survey (2007-2010)	Provides 5-Year Estimates of Employment	Not as current as other obtainable state data.
National Flood Insurance Program Data	The Community Information System (CIS) provides the number of policies for both residential & non-residential properties	While this can easily be done for state & county levels, it would be an onerous task to do this for towns because it would need to be analyzed one town at a time.

Data Set	Information Provided	Limitation
Utility Data [Green Mountain Power (GMP)]	GMP had location data on commercial accounts by town in their service area.	There are many towns not served by GMP and the data from the other utilities is variable in its format and coverage. Reaching out to the other small municipal and private utilities to piece together statewide data set would have been time consuming and the information may not have been consistent.
Insurance Companies	The following information was requested: • What percentage of Vermont companies that are insured for floods? • What percentage of Vermont companies are covered for other disaster-related property losses? • How many business claims are filed and for businesses in which towns? • How do insurers target the risk pool?	Proprietary information that is not publicly available

The project team was assisted by the Vermont Department of Labor (VT DOL) and reviewed information it uses from the Quarterly Census of Employment and Wages (QCEW, from the US Bureau of Labor Statistics). The team also reviewed various data sets provided by the Vermont Department of Taxes (VT DOT) and considered using several other datasets, reported in Table 2.3 along with the VT DOL and DOT information. Ultimately, the additional data sets were not used due to the limitations outlined in the table or because they provided duplicative information. It should be noted that a limitation of the VT DOL information is that big corporations headquartered outside of Vermont will only file under one return for the whole corporation, even if they have operations/buildings in Vermont.

Other states wishing to replicate the VERI model, will find varying degrees of accuracy and relevance for each data set. The availability of municipal level data, the subset of businesses represented, and the comparability of state data and federal data will inform decisions about the usefulness of the data.

After reviewing all the data sets, evaluating the type of information they provide, and their geographic distribution, the project team used the following primary and secondary data sets to rank statewide economic activity in each community.

Selected Primary Data Sets

The following data sets were used in the evaluation of statewide economic activity:

- ***Annual Number of Establishments***, 2012 (VT DOL data).
- ***Annual Average Employment,*** 2012 (VT DOL data).
- ***Total Wages,*** 2012, (VT DOL data).
- ***Rooms Sales*,** 2012, (VT DOT data). These data were used as a proxy for the tourism sector of the economy.

Selected Secondary Data Sets
The following information was also used in evaluation and ranking of towns:

- ***Top Five Employers within each Region:*** Critical employers within each town and region were identified. The project team reached out to Vermont's Regional Development Corporations (RDCs) and asked them to provide this economic information.

- ***Towns and Regions Dependent on One Employer:*** The RDCs provided the names and locations of Vermont's top employers in each region, with an indication of which were critical to the health of the local economy, and which were firms on which the local or regional economy was dependent. This information helped to minimize the limitation around big corporations headquartered outside of Vermont only filing one tax return for the whole corporation, even if they have operations/buildings in Vermont.

- ***Agriculture:*** Number of dairy, vegetable and fruit farms per town which was provided by the Vermont Agency of Agriculture, Food and Markets (VT AAFM).

While researching, analyzing, and finalizing the data sets to develop a town-by-town snapshot of economic activity, the VERI project team developed a methodology to evaluate flood risk and understand where it intersects with economic activity and any associated infrastructure.

Understanding Vermont's Flood Risk

As noted above, flooding due to inundation and fluvial erosion has caused and will cause widespread damage, property loss, and socio-economic disruption in Vermont. In order to understand the statewide risk of inundation and fluvial erosion, the Vermont Agency of Natural Resources (VT ANR) developed a statewide flood hazard map layer and then applied a river sensitivity assessment to determine where the risk of flooding would likely be greatest. The information below provides an overview of the 'how-to' steps taken in Vermont to perform this statewide assessment, an important step in understanding where this risk intersects with areas of economic activity and associated infrastructure.

There are eleven **Regional Development Corporations** (RDCs) throughout Vermont. They provide local technical assistance to the businesses and employers within the communities they serve. This entails, but is not limited to, real estate and site selection assistance, project finance coordination, workforce development programming, and general business advocacy.

Mapping Flood Hazard Areas

Inundation

Inundation, or overbank flooding, occurs when a stream channel or waterbody receives a significant amount of rain or snow melt, or when the stream channel is blocked by debris or an ice jam. The excess water spills out onto or 'inundates' the floodplain. Inundation is easiest to visualize if one thinks of a bath tub filling up with water and spilling out over the top.

Inundation risk can be assessed on the most current FEMA-published Flood Insurance Rate Maps (FIRM) on which the National Flood Insurance Program (NFIP) is based. These maps are based on the area of floodplain that would flood during the '100-year flood' or the area with a 1% probability of flooding in any given year (see resource section for more information about FEMA FIRM maps).

1% annual chance of flood = 100-year flood = base flood

Fluvial Erosion

In Vermont, fluvial erosion results in the greatest flood-related losses. Fluvial erosion is the wearing-away of river channel beds and banks by the action of water. It results when stormwater picks up speed as it moves downhill in river and stream channels, picking up sediment and debris in one reach and depositing it in a slower moving reach of river or piling up behind bridges and culverts. The magnitude or rate of fluvial erosion is highly variable, ranging from a gradual and continual process to an episodic or catastrophic event.

Fluvial Erosion refers to the wearing-away of materials off the stream bed and banks by the action of water during a high flow event.

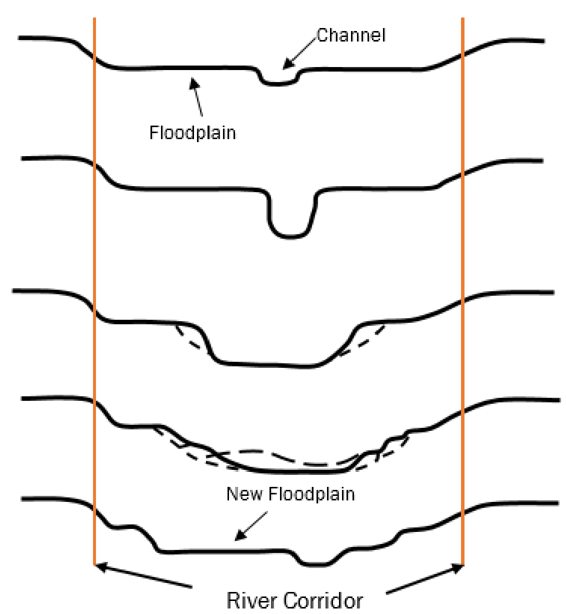
Currently available FEMA FIRM maps only cover 20% of Vermont's rivers and streams and depict inundation flooding. However, due to Vermont's topography of hills and valleys, the areas of greatest risk are fluvial erosion hazard (FEH) zones. FIRM maps are also of limited use in Vermont because they are a static depiction of the floodplain. They map only a small percentage of water bodies, and map updates are infrequent. Thus, as part of this project, VT ANR developed river corridor maps for all perennial streams to indicate the area of greatest risk from fluvial erosion and current or future inundation.

The river corridor maps developed take into account different types of risk and the dynamic nature of flood hazards, and have a broader reach. They can be used strategically to plan growth and development along rivers, and to better protect property and businesses. The river corridor also represents, on average, the minimum amount of floodplain necessary to accomplish vertical stability (Ward et al., 2002, Ward, 2007). It is important to remember that when rivers are vertically stable with enough room to meander and inundate floodplains, they are in their least erosive form.

VT ANR developed a mapping protocol for river corridors to encompass an area around and adjacent to the river channel where the following are most likely to occur:

- ***Fluvial erosion***: the area where flowing water can cause vertical and lateral movement of stream banks and beds (see Figures 2.1 and 2.2);

Figure 2.1: River Corridors Designed to Encompass Channel Evolution

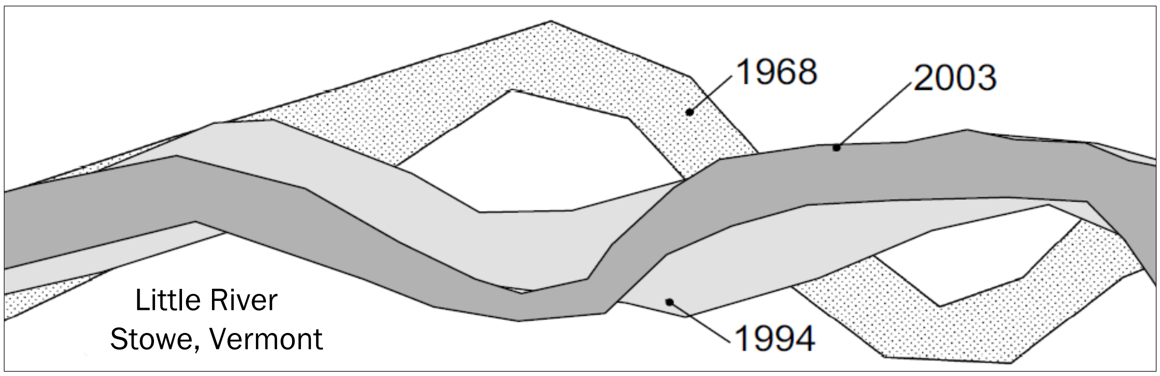


Five stages of channel evolution, starting with a shallow depth to floodplain, followed by channel deepening, widening, filling, and finally, at Stage V, a new floodplain formed at a lower elevation. Approximately 75% of VT stream channels are at Stages II – IV.

The red lines on either side of the channel indicate how the river corridor would be delineated in cross-section to capture all stages of the channel evolution process.

- ➲ ***Channel evolution***: stream channels continually evolve toward the development of floodplains (i.e., overall channel depth) that more evenly distribute the flows and energy of differing flood events over time. River corridors accommodate these floodplains and where this evolution is most likely to occur (see Figure 2.2);

Figure 2.2: Stream Channel Meander Pattern Adjustment over Time



- ➲ ***Down-valley meander migration***: streams naturally deposit on the inside of channel bends and erode on the outside of bends, all the while maintaining the vertical stability brought about by the channel evolution process described above.

A **stream geomorphic assessment** (SGA) is a physical study of a river's geology, size, shape, movements, and existing conditions which affect river flow patterns and stability.

VT ANR developed its river corridor mapping methodology over the past decade. During this time several peer reviews and studies were conducted to verify the reasoning and methodology for stream geomorphic assessment and river corridor mapping in Vermont. VT ANR worked with the Lake Champlain Basin Program and the US Environmental Protection Agency (US EPA) to conduct an academic peer review. FEMA and the USDA also completed independent quality assurance reviews. Prior to the development of the statewide river corridor layer, staff conducted a study of over a hundred unconstrained river reaches and compared the new Vermont calculated meander belt widths with those produced by the published formulas and found that its adopted methodology was sound and supported by locally-derived data.

Mapping river corridors in this way covers both inundation and erosion hazard areas and shows an area that, if protected, will serve over time to restore floodplains, which are important for storing flood water and minimizing the risks associated with inundation and erosion.

River Corridor Mapping Procedures: The Details

This section provides the details of the river corridor mapping procedure developed in Vermont. It is designed for the technical staff (river engineers, biologist and Geographic Information System (GIS) professionals) in other communities or states who wish to replicate this work.

River corridor widths were calculated to represent the narrowest band of valley bottom land necessary to accommodate the least erosive river floodplain that would exist naturally within a given valley setting.

VT ANR mapping procedures also recognize that certain rivers are highly managed or constrained by human structures and delineates the river corridor to reflect the existence of certain man-made constraints. (The ANR river corridor mapping procedures are formally adopted in the Vermont Department of Environmental Conservation (VT DEC) Flood Hazard Area and River Corridor Protection Procedures (12-05-2014) http://www.watershedmanagement.vt.gov/rivers/docs/FHARCP_12.5.14.pdf.)

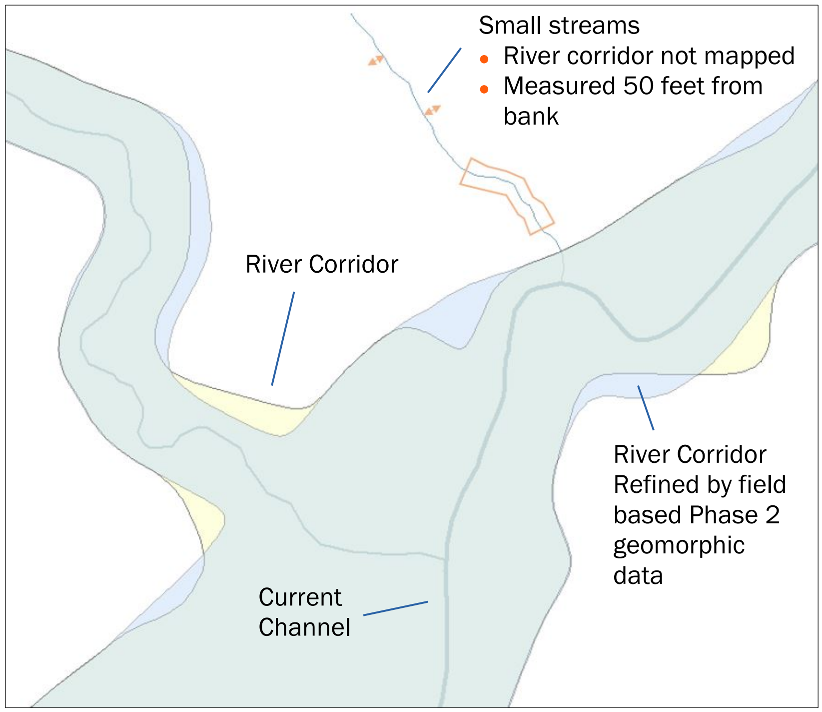
The final product, a Statewide River Corridor Map Layer, was developed to indicate the following map categories:

- ***Drainage Areas of Less than or Equal to Two Square Miles:*** simple top-of-bank 50 foot setbacks for streams draining less than or equal to two square miles;

- ***Drainage Areas Larger than Two Square Miles:*** river corridors were drawn using hydrographic (i.e. river flow) and topographic data and modifying for natural and man-made confining features. Details for how this was developed are below; and

- *Phase II Assessments:* river corridors drawn as updates or administrative revisions to the base layer based on new data, detailed field studies, or municipal planning at the reach-scale or the watershed-scale. Currently, over 2,057 miles of Vermont streams have undergone detailed, field-based study through completed stream geomorphic assessments (SGA).

Figure 2.3: Sample Phase II River Corridor Map

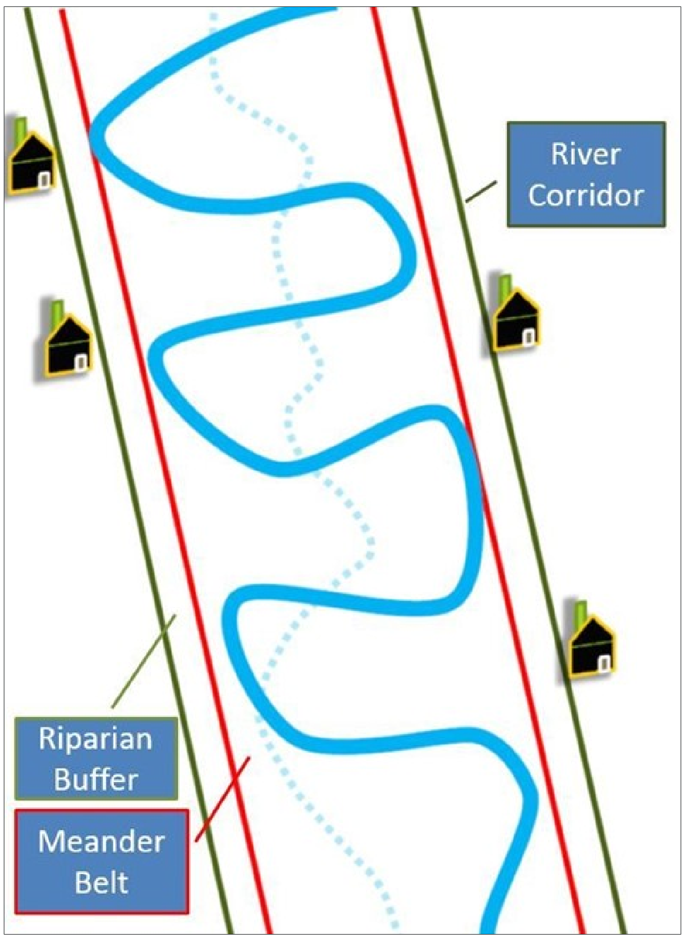


Base Layer Development

The river corridor base layer is derived from an analysis of digital elevation data to calculate valley geometry (slope and width) and an analysis of drainage data to calculate channel and meander belt widths. Existing structures like state roads and railroads were established as artificial valley walls and used to delineate the location of the meander belt on the base layer. Rivers and streams do not follow the same course, but instead snake, or meander over time. As water flows through a stream channel, it erodes the outer banks, widens its valley, and deposits silt and debris on the flatter areas that have less energy. It is a natural process. The risk occurs when homes, businesses and infrastructure are within the area where a river naturally moves. The area that the river snakes is known as the meander belt and this area provided the foundation of the base layer for the river corridor maps developed by VT ANR.

For streams in unconfined, low slope alluvial settings (e.g., a flat meadow), the average meander belt width is approximately six channel widths wide (Williams, 1986; Kline and Cahoon, 2010). The meander belt extends laterally across the river valley from outside meander bend to outside meander bend, thereby encompassing the natural variability of the stream channel (Figure 2.4).

Figure 2.4: Depiction of Meander Centerline and Belt Width



Protecting this area from development maintains the channel slope and minimizes vertical channel instability over time along the extent of the stream reach (Riley, 1998). Ideally, the meander belt can be achieved by three channel widths either side of a meander centerline.

Vegetative buffers are a least cost, self-maintaining practice to provide natural boundary conditions and stream bank resistance against erosion and moderate lateral channel migration. Providing space for these functions is consistent with the goal of achieving and maintaining least erosive conditions, thereby minimizing the risk of harm to life, property and infrastructure from flooding.

Valley topography or other constraints (e.g., bedrock and exposed ledge) may prohibit channel movement, such that the full six channel widths can only be achieved by providing more width on one side of the stream than the other. (Note: For more discussion of the delineation of the meander centerline and the belt width, refer to Appendix E of the *VT Stream Geomorphic Assessment Handbooks* and other VT *DEC technical guidance* http://www. watershedmanagement.vt.gov/rivers/docs/assessmenthandbooks/rv_apxecorridordef.pdf*)*. Also, note that many of Vermont's streams have been straightened, channelized, or have become incised (deepened), losing access to their historic floodplains. In many cases, these streams are undergoing channel evolution or the processes of erosion and deposition to adjust and re-establish a stable channel slope (Refer to the State Rivers Program's website to examine fluvial geomorphic data stored on the Data Management System or via Map Viewer: http://www.watershedmanagement.vt.gov/rivers.htm)

Planform is the meandering shape of the river from a birds eye view.

The table in Appendix 2.1 describes how the meander belt width and other factors were used to develop river corridors in Vermont. Variables include the inherent stability of the stream channel; its sensitivity to erosion hazards; the presence of natural or significant human-created confining features; the evidence or likelihood of valley side slope failure; and the presence of hydrologically-connected features within the river valley.

VT ANR added an additional 50 foot setback on either side of the meander belt on all rivers except for small streams, to allow space for the establishment and maintenance of a vegetated buffer when the stable slope and planform are achieved. This riparian buffer aids in bank stability and slowing flood water velocity. It also serves as a margin of safety ensuring that if new structures placed immediately adjacent to a river corridor there would still be space between a stabilized streambank at the edge of the meander belt and the edge of the structure. For small streams (those draining less than or equal to two square miles), the 50 foot setback from each bank is used to serve both meander and riparian buffer functions.

Risk Assessment

Statewide river corridor mapping was the first step in conducting a risk assessment. Next, the team used river sensitivity and a vulnerability assessment to determine risk.

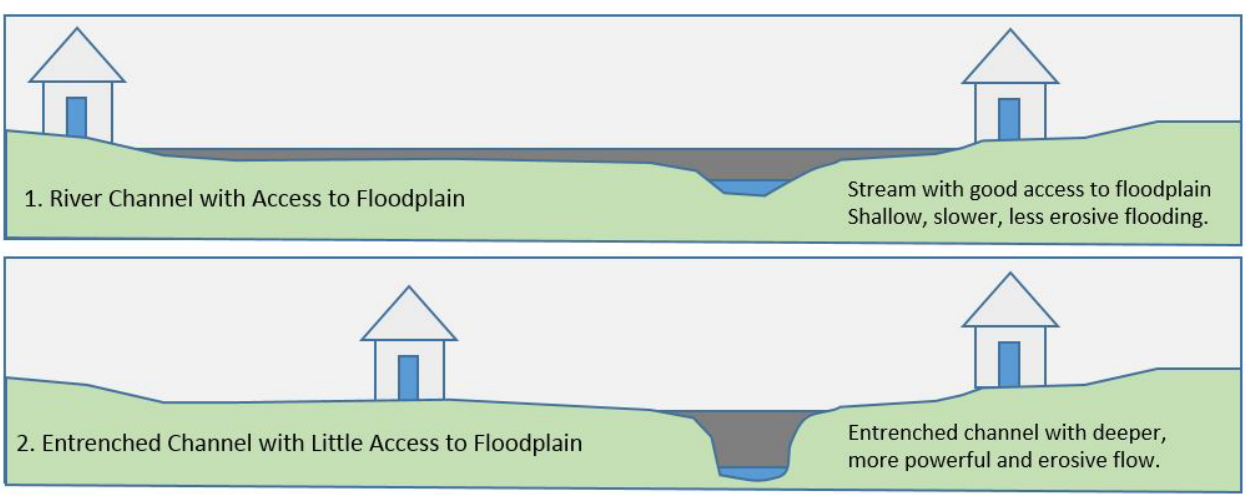
River Sensitivity:
A sensitivity assessment shows a river's tendencies to carry and/or deposit sediments or debris throughout the watershed. The river sensitivity data used in the VERI project to assess flood risks statewide included:

- Using the methodology described above, the ***land area in the river corridor*** based on the meander belt widths derived from watershed size, channel slope, and valley confinement. The mapped river corridor indicates an area where risk is higher.

- ***Erosion and deposition risk ratings*** for each segment of river corridor based on changes in stream power and confinement, stream confluence areas, and the number of road crossings.

Functioning floodplains, particularly adjacent to low gradient, unconfined streams are critical to the moderation of stream power and fluvial erosion. Steeper-deeper flows are more erosive due to their higher stream power. Increasing floodwater, upon spilling to an adjacent floodplain, becomes only incrementally more powerful because depth has not grown proportionately with flows. In confined systems, where floodplain is limited, either naturally or by human encroachment, flood water becomes very powerful and erosive because depths are increasing more proportional with volume of flow (see Figure 2.5).

Figure 2.5: Impact of Floodplain Access on the River Channel



A River Corridor Flood Sensitivity Coarse Screen was developed to enhance statewide risk assessments with respect to fluvial erosion hazards. In conjunction with developing the Statewide River Corridor Map Layer, VT ANR provided technical support to the Vermont Land Trust (VLT) in the development of the River Corridor Flood Sensitivity Coarse Screen. VLT, using private foundation funding, developed the coarse screen data for each VT ANR delineated river corridor segment. With permission from VLT, staff applied the VLT data to the statewide layer to support the vulnerability assessment of the VERI project.

The Coarse Screen rates both direct and indirect erosion risks. Indirect erosion risk may be defined as the risk of erosion damage resulting from channel avulsions that occur when flood-deposited sediments and debris block a stream channel. When a stream segment becomes "plugged" by deposited sediments and debris, high velocity flows completely leave the channel (i.e., avulse) causing over-land erosion and severe downcutting erosion as the stream cuts a new channel away from the old one (see Figure 2.6 below).

Figure 2.6: 1927 Flood in Randolph, Vermont

Aerial picture of the Third Branch of the White River in Randolph, Vermont after the 1927 flood. Evidently, the river flowed along a more sinuous path, through large meanders, prior to the flood.

During the flood these meander bends became plugged with sediment and debris causing the river to rise up and leave the channel, then flow straight down-valley, cutting new channels along the way.

The Course Screens were developed using the following data:

Erosion Risk Coarse Screen

- ***Specific stream power*****:** which is a function of the channel slope and depth. The deeper and steeper the flow, the more power it has to erode materials on the channel bed and banks.
- ***Natural channel confinement by the valley:*** confinement is calculated by dividing the valley width by the channel width. The higher the ratio, the lower the confinement of the channel by the natural valley walls. Floods tightly confined within a narrow valley are more erosive than unconfined flood flows which spill onto a floodplain.

- ***Percent increase in confinement by existing permanent infrastructure*****:** natural valleys that are bisected by infrastructure may be more prone to erosion. Naturally unconfined stream, with functioning floodplains, are characterized by finer-grained (more erodible) bed and banks. When the confinement is significantly increased in this type of stream, the beds and banks are much more easily eroded during floods.

Deposition Risk Coarse Screen

- ***Specific stream power*****:** which is a function of the channel slope and depth. Flows that are shallow in depth and of lower gradient have less power it transport sediment and woody debris. During a flood when loads (or inputs) of sediment and debris increase beyond the capacity (or power) to transport them, they deposit within the channel and begin forming a "plug" or blockage to flows.

- ***Reaches with significant decreases in slope*****:** Stream reaches that exit a steep, confined valley into a low gradient (or low slope), unconfined setting will switch dramatically from being erosional (i.e., with high sediment transport capacity) to being depositional. Over time these reaches become characterized by alluvial fans, which are domes of sediment that have built up due to this switch from transport to depositional flows.

- ***Confluences with larger tributaries*:** Stream confluences are high deposition zones. Typically, a tributary flood will rise faster than that of the main stem stream to which it flows. The main stem will act as a dam to the sediment-laden floodwaters of the tributary stream. The damming effectively flattens the slope of the tributary flood and it loses transport power depositing sediment and debris in the confluence area.

- ***Number of road crossings:*** Bridges, culverts, and their road approaches often impound floodwater behind them (flattening the slope of the flows). Islands form above stream crossings from sediment deposition, especially where the crossing is significantly undersized to the stream.

Each parameter in the erosion and deposition screens were characterized as low, moderate, or high based on a range of values in published studies and VT ANR's stream geomorphic assessment protocols. Each river corridor segment in the Statewide River Corridor Map Layer was rated as presenting a high, medium or low risk of erosion or deposition process by compiling the scores of the three erosion parameters for sensitivity to erosion and the four deposition parameters for sensitivity to deposition.

The Course Screen is a valuable tool because, using remote sensing data, VT ANR can generate a consistent, statewide sensitivity rating for every river corridor segment. However, the Course Screen has limitations in evaluating risks at the site-specific level. For project development, erosion and deposition processes are evaluated based on field data from stream geomorphic assessments.

For a step-by-step process and timeline for the design and development of the Vermont River Corridor Geodatabase, see table in Appendix 2.2.

Utilizing the Information

The VERI project team used these maps and river sensitivity analysis along with a vulnerability assessment and information on economic activity to help analyze risk in Vermont municipalities and determine the five communities for further analysis (see Chapter 3). There are many other uses for river corridor maps.

River corridor maps serve as a planning and assessment tool for reducing damages to existing structures and property, avoiding new damages, protecting public safety, and avoiding the high cost to install and maintain bank stabilization structures. Minimizing investments within the river corridor will reduce the need for channel maintenance, which, in turn, will avoid the unintended consequences of transferring bank erosion and other damaging effects from upstream (Brookes, 1988; Huggett, 2003; Brierley and Fryirs, 2005).

Infrastructure, Commercial Buildings and River Corridors: A Vulnerability Assessment

Economic activity – the movement of goods and services, ability of employees to get to work and customers to receive services – depends on infrastructure, especially transportation infrastructure. For example, the Route 9 Bridge over the Whetstone Brook in Brattleboro, Vermont connects more than 16,000 people daily to their jobs and local businesses. If damaged and closed, the impact to the economy is great.

Working with the Agency of Transportation (VTrans) and VT ANR, the VERI team developed a vulnerability assessment for the state's roads, bridges, and non-residential buildings.

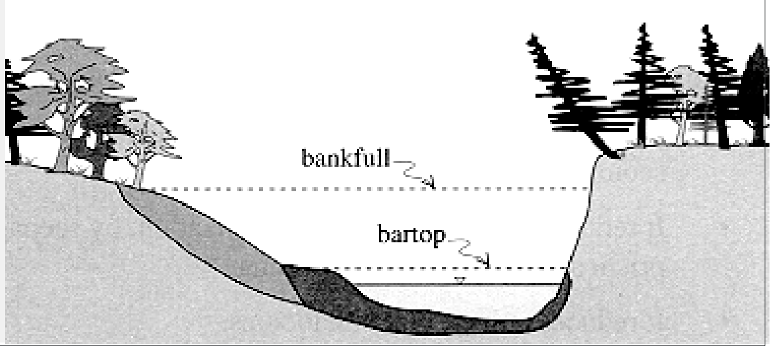
Vulnerability describes the characteristics of a community that make it susceptible to the damaging effects of a hazard. From a physical vulnerability standpoint, the VERI project team looked at the size and location of transportation infrastructure and non-residential buildings to begin assessing vulnerability to economic activity. Common types of transportation infrastructure damage after a flood are washouts, undercuts or sink holes. The damage can occur by the sheer force of water overtopping a road, or by other erosive forces of a river.

VTrans conducted a GIS-level vulnerability assessment of state and town bridges, federal aid highways, and non-residential buildings in river corridors statewide in every municipality. This assessment was aggregated by town and combined with other indicators to develop a short list of municipalities that were considered as candidates for the more detailed VERI case studies.

- ***Bridges having spans of less than bankfull channel width:*** Defined as bridges too narrow in span to pass the annual flood or semi-annual flood event. Such undersized bridges lead to upstream deposition and downstream scour (i.e., erosion) and are more likely to fail from either being undermined from scour or plugging and being out-flanked during a flood event (see Figure 2.7). Information about bridge span was obtained from the VTrans bridge inventory system and compared to the bank-full width of the river it crosses from the Statewide River Corridor GIS data. Only bridges that VTrans inspects were included in the analysis, which are those with spans greater than 20 feet on both the state and town highway system, and those between six and 20 feet on the state system. Because of inconsistent data availability, the assessment did not include bridges with spans less than 20 feet on town highways or any culverts on the state or town highways.

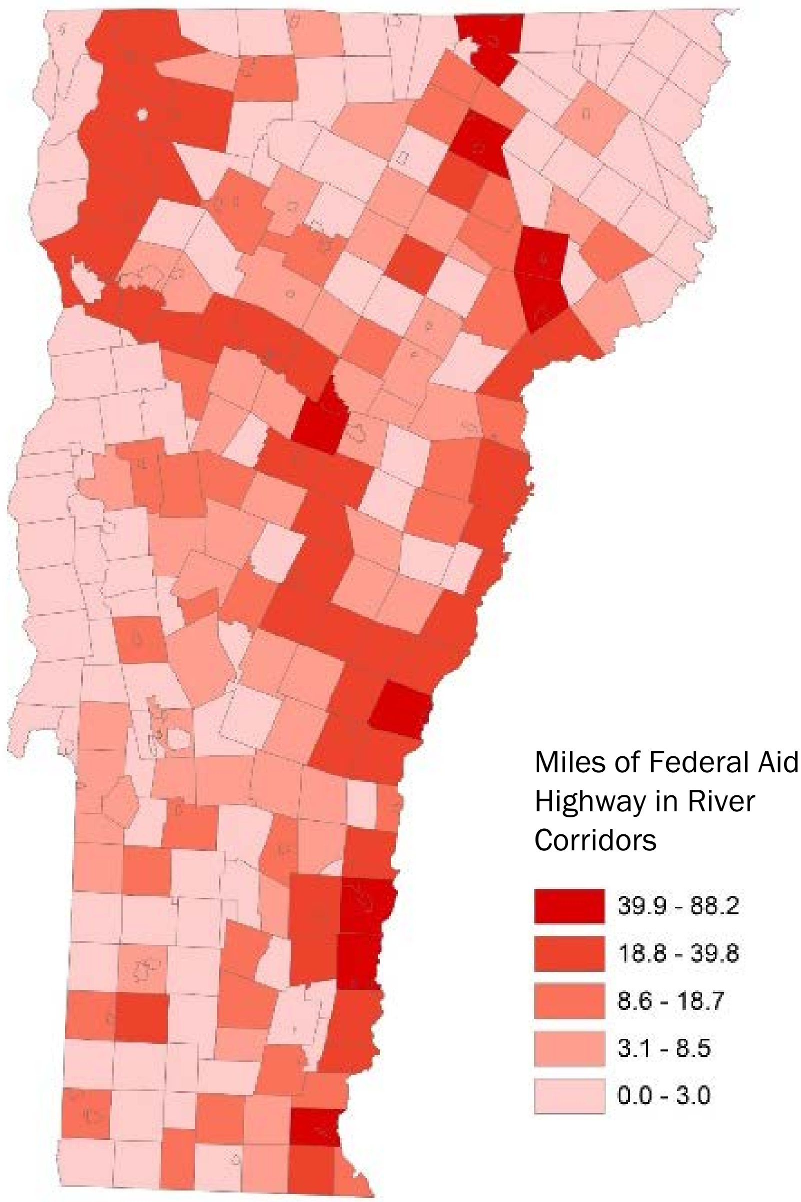
Figure 2.7: Bankfull Width

A bridge that provides adequate bankfull width can accommodate water volume and movement of sediment which helps to maintain a river's stability near the structure under normal circumstances and reduces the potential for damage during heavy precipitation events.



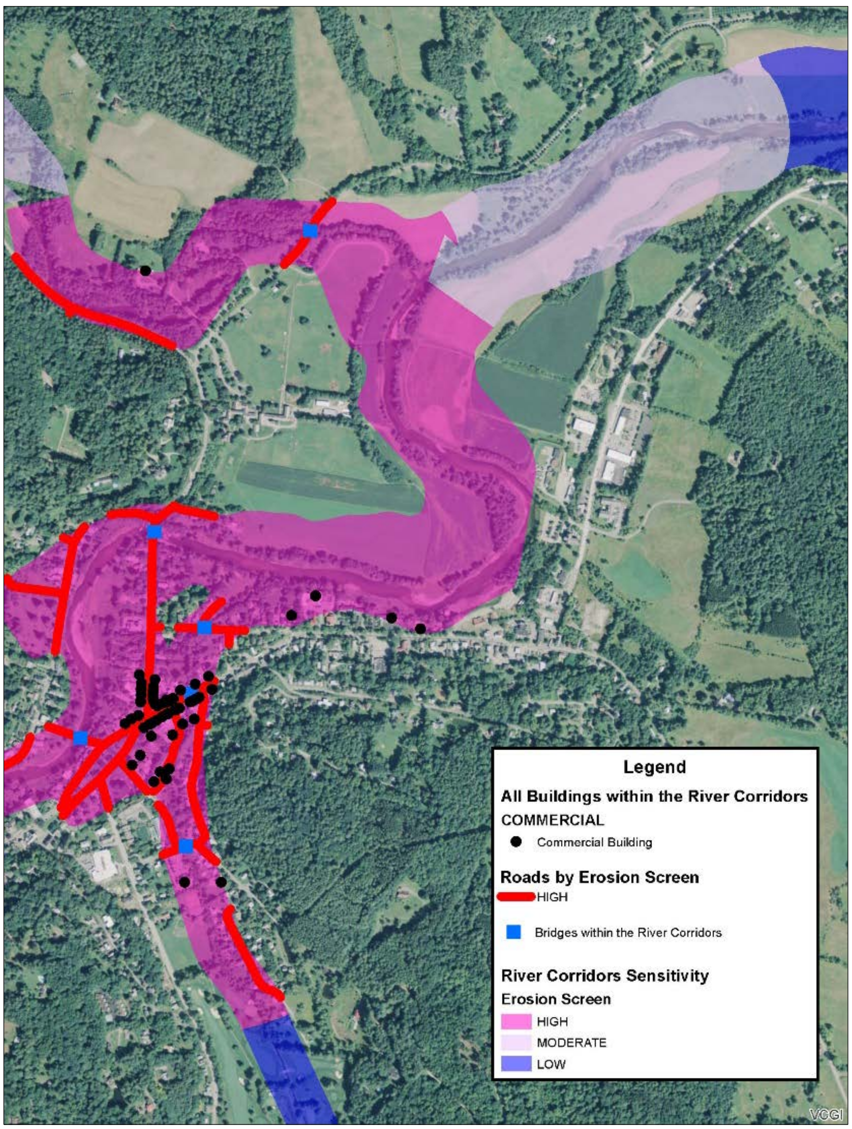
- ***Number of Federal Aid Miles within a Town in River Corridors:*** In general, federal aid roads include the Interstate, major roads that have a US or VT route number, and local roads that connect more than one town. Federal aid roads provide the backbone of the network and are most critical for access to jobs and moving freight. When these roads are within or abutting a river corridor they are vulnerable to loss or damage from fluvial erosion during a flood event (see Figure 2.8).

Figure 2.8: Map of Federal Aid Highway Miles in River Corridors



➲ ***Percent of Federal Aid Road Miles within a Town in High Erosion Risk Portion of River Corridors:*** This is a subset of the federal aid roads that are in or abutting reaches of a river corridor that and deemed to be at high risk to erosion damage. The coarse screen identifies those road miles, in high gradient settings, that have greatly increased the confinement of the stream within the valley (see Figure 2.9).

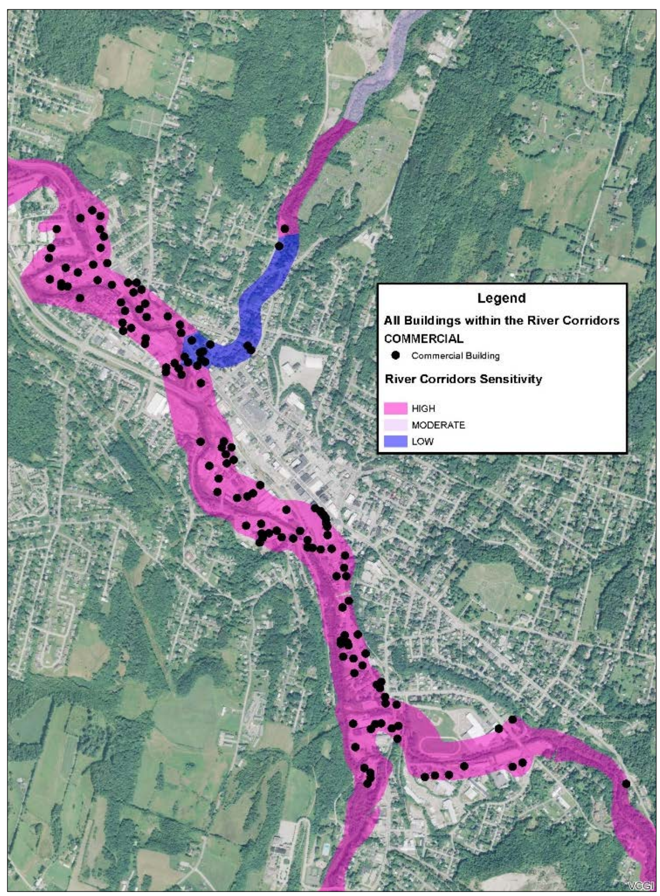
Figure 2.9: VTrans Vulnerability Assessment in Woodstock



- *Percent of Federal Aid Road Miles within a Town in High Deposition Risk Portion of River Corridors:* This is a subset of the federal aid roads that are in or abutting reaches of a river corridor that are deemed to be at high risk to damage or disruption due to deposition caused by a flood-related event. The coarse screen identifies those road miles, in lower gradient settings, either directly downstream of a higher gradient stream segment or near stream confluences and/or road crossings (see Figure 2.9).

- ***Number of Non-residential Buildings in River Corridors Based on E-911 site data*:** Non-residential buildings are most likely some type of business, commercial or industrial use. Where these buildings are within or abutting a river corridor they are vulnerable to loss or damage from flood or fluvial erosion (see Figure 2.10).

Figure 2.10: VTrans Vulnerability Assessment in Barre City



VTrans staff also considered using the Network Robustness Index but decided to limit roadway vulnerability assessment to roadways that are part of the federal aid system as this includes major collectors (often town highways that connect two or more towns) through interstates. The team made this decision because these are the roads that have the greatest impact on access to jobs and goods and services movement.

This GIS-level screening provides a reasonable means to compare the relative vulnerability of the roads and bridges to damage from floods in over 250 municipalities in Vermont. However, the probability that specific road segments or bridges identified in the screening will actually fail during a flood cannot be determined without more detailed analysis. For additional information on the analysis, see Appendix 2.3.

The project did not review structures such as wastewater treatment plants, water or electrical utilities, high hazard dams, or culverts in the state vulnerability assessment as this information was not easily accessible for towns across the state. Where available, the team did evaluate the impact of these systems malfunctioning on business recovery in the five target communities. Transportation infrastructure that has been repeatedly damaged, or for which there are no alternative routes, were also considered in the priority areas, as part of the infrastructure hazards analysis.

Next Steps: Prioritizing Five Communities

The data sets discussed in this chapter were used in the ranking process outlined in the following chapter. The information allowed us to develop a prioritization process so that the VERI team could choose five regions to develop in-depth projects that would reduce, avoid, and mitigate risk in areas of high economic activity.

Resources

- Agency of Commerce and Community Development (2014). Vermont 2020: Comprehensive Economic Development Strategy.

- Brierley, G.J., and K.A. Fryirs (2005.) Geomorphology and River Management: Applications of the River Styles Framework. Blackwell Publishing.

- Brookes, A. (1988). Channelized Rivers: Perspectives for Environmental Management. John Wiley & Sons, Chichester.
- Huggett, R.J. (2003). Fundamentals of Geomorphology. Routledge Fundamentals Physical Geography.
- Kline, M and B. Cahoon (2010). Protecting River Corridors in Vermont. Journal of the American Water Resources Association (JAWRA) 1-10. DOI: 10.1111/j.1752-1688.2010.00417.x
- Riley, Ann L. (1998). Restoring Streams in Cities: A Guide for Planners, Policymakers and Citizens. Washington DC: Island Press.
- US Department of Commerce, Economic Development Administration (2012). Economic Impact Assessment: Economic Recovery Support Function – Vermont DR-4022.
- Ward, A.D. (2007). Technical Supplement 14S: Sizing Stream Setbacks to Help Maintain Stream Stability. In *USDA-NRCS National Engineering Handbook Part 654 Stream Restoration Design.*
- Ward, A. et al. (2002). Sizing Stream Setbacks to Help Maintain Stream Stability. The Society of Engineering in Agricultural, Food, and Biological Systems. 2002 ASAE International Mtg, Chicago, IL.
- Williams, G.P. (1986). River Meanders and Channel Size. Journal of Hydrology 88.

For more information on FEMA FIRM

FEMA has published extensive information regarding the mapping of flood hazard areas. The FEMA Map Service Center (http://msc.fema.gov) is the primary online repository of flood hazard area data and provides educational information and technical assistance.

A recent flood insurance study titled, *Guidelines and Standards for Flood Risk Analysis and Mapping* provides technical information detailing the engineering, scientific, and mapping specifications (found at: http: //www.fema.gov/guidelines-and-standards-flood-risk-analysis-and-mapping).

Flood insurance studies and flood hazard area maps are on file in the municipal offices of communities participating in the NFIP.

In addition, in VT DEC maintains digital copies of the maps and studies and publishes the maps on VT ANR's Natural Resources Atlas (found at: http://anrmaps.vermont.gov/websites/anra/).

Appendix 2.1

Table 2.4: Factors Used to Make River Corridor Delineations in Vermont

Type of Stream	How the River Corridor was Determined
Streams with a Drainage of Less than or Equal to Two Square Miles	Small streams shall be assigned a simple setback of at least 50 feet on either side of the stream, measured horizontally and perpendicularly from the top of each streambank. A corridor may be delimited for a small stream during a map update, if field data verifies a moderate to high sensitivity
Very Low and Low Sensitivity Streams	The meander belt width shall be equal to the existing channel width, if the stream is a bedrock or boulder substrate reference stream type (very low to low sensitivity). For mapping purposes, the meander belt shall be delimited at the top of the stream bank of the existing channel or a minimum of a half channel width on either side of the meander centerline, whichever provides the greater lateral extension on either side of the meander belt
Moderately Sensitive Streams (with a drainage > 2 square miles)	The meander belt width shall be equal to a minimum of four channel widths, if the stream (i.e., at the reach scale) is a steep to moderate gradient (greater than 2 percent gradient) reference stream type, and the existing stream type does not represent a stream type departure. The meander belt is delineated with a minimum of two channel widths on either side of the meander centerline
Highly and Extremely Sensitive Streams (with a drainage > 2 square miles)	The meander belt width shall be equal to a minimum of six channel widths, if the stream is a gentle gradient or braided reference stream type or if the stream is in a moderate gradient valley setting, but the existing stream type represents a stream type departure.[1] For stream types that are in either very low gradient settings or very high deposition areas, the meander belt width multiplier may be increased up to eight times the channel width. The meander belt is delineated with a minimum of three to four channel widths on either side of the meander centerline. Within zones of extremely high and active deposition (e.g., active alluvial fans), the river corridor shall be delineated to include all recent channels and the entire zone of active depositional process;
Natural or Human-Imposed Confining Features	Where the meander belt extends a certain distance beyond the toe of the valley wall (including bedrock outcrops or ledge that limit river movement), the corridor is truncated at the valley toe, and that truncated distance is used to extend the meander belt laterally on the opposite side, to provide a total belt width as described above. This extension may, in some cases, be limited by the valley wall on the opposite side of the stream as well; in which case the meander belt extends from the toe of one valley wall to the toe of the other and will be narrower than the multiple of channel widths prescribed above. If the initial meander belt delineation extends beyond an engineered levee, railroad, or federal aid highway, the full river corridor shall be measured from the embankment toe of that infrastructure and extend laterally on the opposite side. This shift of the river corridor acknowledges the alignment of the road has been structurally maintained over time in those locations. The river corridor is shifted to optimize attainment of naturally stable conditions and the reduction of flood velocities and erosion potential within the stream reach. Adjustment of the river corridor for road infrastructure does not imply that adjacent road infrastructure is outside of an area subject to fluvial erosion hazards; on the contrary, infrastructure or other improvements directly abutting the boundaries of a river meander belt may be as, or more, vulnerable to fluvial erosion as infrastructure within the corridor.

Type of Stream	How the River Corridor was Determined
Streams Subject to Bank or Slope Failure	Erosion hazards outside the meander belt may also exist. If field evidence indicates bank erosion and/or large, mass wasting failures along the valley wall exist or would exist concurrent with the edge of the calculated meander belt, an additional setback to the top of the immediately adjacent erodible side-slope or slope stability allowance, as determined by a geo-technical analysis, shall be added to the meander belt to accommodate stable bank slopes
Natural or Manmade Depressions Adjacent to Streams	If field evidence indicates features such as natural or human-created depressions and old channels adjacent to the stream are deeper than the stage of the annual flood, the meander belt may extend laterally to encompass those features in recognition of their potential to be captured by the river or contribute to a channel avulsion (relocation) during a flood;

Appendix 2.2

Table 2.5: Vermont River Corridor Geodatabase Design and Development

		Details	Timeline	% of Timeline
Step One	Develop lines that identify the toes of Valley Walls (VWs)	Spatial Analyst and ArcGIS software and VT 10-meter Digital Elevation Model, slope, and VT hydrology Dataset (VHD) were used to create a cost-distance raster for streams draining greater than 2 square miles. Raster converted to polygons. River Scientists QC'd valley walls against aerial photos, topographic maps, contour lines, and field visits.	6/2013 - 11/2013	15%
Step Two	Split Vermont Hydrography Dataset (VHD) into Reach segments	River Scientists digitized reach break points along VHD, based on VT's Stream Geomorphic Assessment Tool (SGAT) procedures. ArcGIS used to split VHD into "SGAT reaches."	6/2013 - 9/2013	5%
Step Three	Delineate subbasin catchments for each reach break	ArcHydro Tools and Spatial Analyst software were used to divide watershed basins into stream-reach sized catchments. Cumulative drainage area was assigned from catchments to each VHD reach.	8/2013 - 9/2013	10%
Step Four	Create Meander Centerlines (MCLs) as per the River Corridor Protection Guide (2009)	Digitized for all streams draining greater than 2 square miles by River Scientists and temporary employee.	8/2013 - 9/2013	10%
Step Five	Attribute MCLs with drainage area and slope values	ArcGIS and 3D Analyst software used to assign MCLs with slope, drainage area, and buffer multipliers.	11/2013 - 12/2013	2%
Step Six	Create MCL buffer polygons	Buffers calculated from channel multiplier, slope, bankfull width, and Vermont hydraulic geometry curve.	11/2013 - 3/2014	2%
Step Seven	Bump and clip MCL buffers by VWs	Draft 1 "natural" River Corridor Protection Area produced.	2/2014 - 3/2014	5%
Step Eight	Bump and clip buffers by roads, railroads to create River Corridor Protection Area (RCPA)	Draft 1 River Corridor Protection Area (RCPA) produced.	2/2014 - 3/2014	5%
	QA/QC Draft 1 RCPA	River Scientists examined three test basins.	4/2014 - 5/2014	5%
	Assign Sensitivity attributes to Draft 1 RCPA	Map-based stream sensitivity developed by Milone & MacBroom, Inc. for Vermont Land Trust and used by ANR by MOA to support Agency of Commerce and Community Development with the Vermont Economic Resiliency Initiative (**VERI**). ArcGIS used to assign attributes to RCPA.	12/2013 - 1/2014	5%
	Draft 2 RCPA process refinement and production	Refine Valley Walls, MCLs, channel multipliers, and basin catchments; re-run processes.	4/2014 - 5/2014	5%

		Details	Timeline	% of Timeline
	Draft 3 RCPA process refinement and production	Add VHD single channel buffers to RCPA.	6/2014 - 7/2014	5%
Step Nine	Create River Corridors (RC) from RCPA	Add 50 foot buffer to Step Six buffers-- re-run all bump and clip processes to get RC.	6/2014 - 7/2014	10%
	Draft 4 RCPA and RC process refinement and production	More refinements to bump and clip process to smooth corridors through stream crossings	7/2014 - 9/2014	5%
	Manual refinement of Draft 4 RC	Add/Remove Edit software tool created by IT contractor for River Scientists to use in manually modifying RC. Results in RC_EDITS versions 1, 2, and 3.	9/2014 - 11/2014	8%
	Final River Corridors geodatabase	Final River Corridors converted to geodatabase; Federal Geographic Data Consortium compliant metadata developed in ArcGIS.	12/2014	1%
	Vermont River Corridors (VRC) geodatabase uploaded to Agency of Natural Resources online Atlas	Website upload handled by ANR GIS.	1/2/2015	1%
	VRC attributed with VLT stream sensitivity attributes for VERI project	Shapefile copy VERI deliverable to Agency of Commerce and Community Development (ACCD).	1/2015	1%
				100%

Appendix 2.3

Transportation Vulnerability Assessment

To assist the Vermont Agency of Commerce and Community Development (VT ACCD) with screening municipalities in Vermont relative to economic importance and risk from damage and disruption due to flooding, VTrans conducted a GIS-level vulnerability assessment of all state and town highways. The vulnerability assessment also includes all bridges and other structures on state and town highway within the VTrans bridge inventory. The vulnerability assessment of highways and bridges was aggregated by town and combined with other indicators to develop a short list of municipalities that were considered as candidates for the more detailed VERI case studies.

Additional detail on the highway and bridge vulnerability screening is provided below.

Highways

- Road centerline data, which is available in a GIS data layer and includes all state, local and private roadways in Vermont, was intersected with the River Corridor Sensitivity data layer. Through this overlay, river corridor sensitivity attributes were applied to the road centerline arcs. The intersect process was run on the full road centerline data layer, so both State Highways and Town Highways could be evaluated and summarized.

- Road segments that were within the bounds of high sensitivity river corridor reaches were identified as high risk road segments.

- Highway mileage summaries were generated by the High, Moderate and Low sensitivity categories for Erosion and Deposition for all State Highways and Class 1, 2, 3 Town Highways. Through this process, identification of risk status for both state and local roads was possible for the high sensitive river corridor reaches.

Bridges

- In conformance with the National Bridge Inventory (NBI), Vermont maintains an historical record of all bridges subject to the National Bridge Inspection Standards (NBIS). These standards establish requirements for inspection procedures, frequency of inspections, qualifications of personnel, inspection reports, and both the preparation and maintenance of a state bridge inventory. The NBIS apply to all structures that are longer than 20 feet in length and located on public roads, which include state and town highways. These bridges are commonly referred to as long structures. The NBI also includes long structures that are within federal lands such as national forests and national parks. The vulnerability of these bridges to flood damage will be important to consider in areas of the country where national parks, forests and other federal lands drive the local and regional economies. The NBI is available everywhere in the country because all state departments of transportation are required to maintain an inventory of long structures in their state in order to receive federal transportation funding (The most recent NBI data are available: http://www.fhwa.dot.gov/bridge/nbi/ascii.cfm). The attribute within the bridge inspection data that was used to conduct the preliminary screening of bridges vulnerable to flood damage (i.e., its span is less than the bankfull width of the channel) was the length of maximum span (Item #48 in the NBI data).

- VTrans also has an inventory of state owned "short structures" with spans between 6 and 20 feet that were also included in the VERI analysis. The inventory of short structures is not currently required in order to receive federal transportation funding and therefore may not be available in every state. The analysis does not include town structures with spans less than 6 feet or culverts on the state or town highways.

- In order to compare long and short structure spans to a river channel's bankfull width, the structures must be in a GIS data layer. VTrans works collaboratively with the Vermont Center for GIS to maintain and annually update a GIS data layer that contains all the long structures from Vermont's NBI and all of the short structures not in the NBI. If a GIS data layer for bridges is not available, the NBI also includes latitude and longitude data (NBI items 16 and 17) for each structure which can be used to generate a GIS layer of bridges.

- Using typical GIS spatial analysis tools, the structure data was extracted from the VTrans NBI and short structure inventory and intersected with the River Corridor Sensitivity data layer, which applied the river sensitivity attributes to each structure. A key attribute for assessment is the bank-full width field that exists within the River Corridor Sensitivity data layer.

- Each structure was evaluated to assess the structure's span and the width of the corresponding river. The maximum span of each structure was compared to the bank-full width of the adjacent river reach and those with spans that were less than bank-full width were then identified as vulnerable.