THE HYDROLOGIC IMPACT OF THE VERMONT INTERSTATE HIGHWAY SYSTEM

A Thesis Proposal Presented

by

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to

The Faculty of the Geology Department

of

The University of Vermont

April 2012

Accepted by the faculty of the University of Vermont, in partial fulfillment of the requirements for the degree of Masters of Science specializing in Geology.

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ABSTRACT

Development and impervious surface in Vermont has increased during the past half-century. This increase can be attributed to the construction of the Interstate Highway system, which introduced over 11.8 million square meters of pavement to the State and resulted in the displacement of massive amounts of sediment and rock, effectively changing the connectivity of the landscape, rivers, and ecosystems. While the interstate is 4.5% of the paved roads in Vermont, it is 10% of the area. Interstate construction is still affecting Vermont today in the form of interstate catalyzed build-out, which is apparent in heavily developed interstate exit towns like Williston and St. Albans. My goal is to quantify the hydrologic effects of interstate-related development within Vermont. Using the Landscape Change Program database as a starting point, I will rephotograph, field map, and determine the suitability of 12 preliminary study areas for hydraulic modeling. I will select four of these towns and model their changing hydrology over time based on air photo evidence; this will allow me to quantify the effect of the Interstate on surface water hydrology.

I. INTRODUCTION

The construction of the interstate highway system was America's largest and most expensive public works project to date (Kaszynski, 2000) moving over 32 billion cubic meters of material (Missouri Department of Transportation, 2012), paving over 1.7 billion square meters of land (Appendix I)[1], and costing an estimated $215.5 billion in today's dollars (Obenberger and DeSimone, 2011). Interstate construction poses well-known environmental impacts like the loss of wetlands and threats to endangered species (Brian J. Smith, 1989; U.S. Department of Transportation, 2006). As a result of these impacts, the Department of Transportation Act of 1966 and the National Environmental Policy Act of 1969 were enacted to ensure an environmental assessment is done prior to interstate construction (Weingroff, 1993).

1 All uncited road measurements and calculations can be found in Appendix I

The Vermont Interstate Highway System, constructed between 1958 and 1983 (Smith, 2006; Vermont Department of Highways, 1965) is 516 km long an has 53 exits (Vermont Agency of Transportation, 2012) (Figure 1). Vermont's interstate system is particularly interesting in that the interstate, state roads, the railroad, rivers, and towns often share the same confined valley bottom.

The construction of the interstate has had many effects on Vermont's profoundly rural landscape, the first being the addition of 11.8 million square meters of impervious road. This represents nearly 12 square km of area. The second and still ongoing effect is build-out – also called sprawl – near interstate exit towns like Williston, VT (Jay, 1996). This build-out further increases the area of impervious surface, which can affect river morphology, runoff, and the general health of streams (Frankl et al., 2011). For my thesis, I am focusing on how the construction of the interstate and build-out catalyzed by the interstate affects surface hydrology. I will test whether construction of the interstate and the associated build-out increased the amount of impermeable surface sufficient to change peak flow and run off volume, and if so whether I can relate this to changes in stream planform, incision depth, and bed material.

The Landscape Change Program database (http://www.uvm.edu/landscape/) – an archive of 50,000 images of Vermont spanning over 300 years and supported by the National Science Foundation (NSF) and the National Endowment for the Humanities (NEH) – has over 13,000 images of the Vermont Interstate Highway system before, during, and after construction. I will use the image database, rephotography, and a series of aerial photographs to identify build-out patterns and then quantify changes in impervious surfaces and surface hydrology associated with those build out patterns. I will also be using the Hydraulic Engineering Center's Hydraulic

Modeling System (HEC-HMS) to simulate and analyze changes in runoff, urban drainage, etc, from before interstate construction to today.

II. STUDY SITES

With help from my NEH advisory committee, I chose 12 study sites from the towns that are adjacent to Vermont's interstate exits (Figure 2). The towns represent a spectrum of development type, socioeconomic status, and build out trajectories over time. During summer fieldwork, I will determine the suitability of each town as a site for hydrologic modeling. Of the 12 towns, I will select four to study intensively. These four towns will reflect a continuum of development intensity, including end members such as Springfield and Williston, Vermont.

III. BACKGROUND

The Federal Interstate Highway System

While legislation as far back as 1938 funded research into the feasibility of an interstate-like system, it was not until the Federal-Aid Highway and Highway Revenue Acts of 1956 were passed that an adequate level of funding needed for construction was secured (Pfeiffer, 2006). The construction of the Vermont interstate system began in 1958 and finished in 1983 with 516 km of interstate being built (Smith, 2006; Vermont Department of Highways, 1965). Interstate roads, paved and much wider than their predecessors, resulted in a sudden 11.8 million square meter increase in impervious surface in Vermont, and 1.7 billion square meters nationwide. As the interstate increased the connectivity of the country, it changed the connectivity of the landscape, rivers, and ecosystems.

The Federal-Aid Highway Act of 1956 called for uniform highway design and construction based on factors such as population density and topography (Arnold and Gibbons, 1996). This includes a minimum of: two lanes of travel each direction (each lane being 3.6 m wide), and right and left shoulders of 3 m and 1.2 m respectively (U.S. Department of Transportation. Federal Highway Administration, 2011). In comparison, other roads in Vermont must have at minimum: one lane of travel each direction (each lane being at least 3 m wide), and a right shoulder of 1.8 m (Vermont Agency of Transportation, 1997). The footprint of an interstate is therefore about 22,800 square meters per km of road, whereas it is only about 9,600 square meters per km of roads in the rest of Vermont. While the interstate only makes up 4.5% of the paved roads in Vermont, it accounts for 10% of the area.

Over a half-century after construction commenced, the interstate system is reaching the end of its useable lifetime, and in the near future large amounts of money will be needed for freeway rehabilitation if it is to continue to be utilized (Napolitan and Zegras, 2008). The American Society of Civil Engineers 2009 report estimates that the cost of repairing the nation's infrastructure over the next five years to be $2.2 trillion dollars (Hansen, 2009). These factors along with a shift in the values and priorities of the American public, has led to the removal of several urban interstates (Napolitan and Zegras, 2008). In the next 50 years, politicians will need to decide to either fund the interstate and its upkeep or divert money and resources into other modes of transportation, and studies like this will help to inform and enable them to make educated decisions.

Rephotography

Rephotography, the repeated capture of a particular image over time, is a useful tool in the analysis of landscape change and thus hydrologic change. For this project I will be using two types of images for rephotographic comparison: ground-based photographs and aerial photographs. The ground based rephotographs document small-scale changes that cannot be seen in arial photographs (Figure 3), while the aerial photographs will be used to track large-scale changes like the addition of buildings, roads, and parking lots (Figure 4).

Ground Based Rephotography

Rephotography has been used in academic literature to track many changes, of greatest interest to me are uses that observe and quantify changes in river channel morphology, vegetation density, and riparian vegetation (Frankl et al., 2011; Munroe, 2003; Zaimes and Crimmins, 2010). For this project, the photos were commissioned by the State of Vermont in order to catalogue the area around the interstate highway before, during, and after construction in Vermont. The photographs capture scenes of altered hillsides, rerouted rivers, and interstate paving (Figure 5).

Aerial Rephotography

Aerial rephotography has been used to track changes in land use, river morphology, vegetation, and urban centers over time (Galster et al., 2008; Heller et al., 1967). Vermont's aerial photography record extends back to the early 1900s with photos of towns, mills, and natural disasters (University of Vermont, 2012). More extensive collections of Vermont aerial images start in the 1930s and 1940s and come from the Soil Conservation Services. Starting in the 1950s, the United States Department of Agriculture (USDA) began taking and storing aerial images, and in 1974, a program to take aerial images of the entire state of Vermont for tax purposes (Vermont Center for Geographic Information, 2012). The images available from the Bailey Howe Map Room are summarized in Table 1. Limited free aerial photographs (1987 – present), Digital Orthophoto Quadrangles (DOQs) (1987 – present), single frame records (1937 – present), and high resolution orthoimagery (2000 – present) are also available through the United

States Geological Survey (USGS) Earth Explorer web site (Earth Resources Observation and Science Center, 2011).

Impervious Surfaces

Increases in impervious surfaces – and their spatial distribution – can affect the environment in several ways, including changes in flow paths, increases in runoff, higher peak flows, changes in stream morphology and water quality, decreased ground water discharge, and the degradation of stream health(Alberti et al., 2007; Arnold and Gibbons, 1996; Atasoy et al., 2006; Carlson, 2004; Chadwick et al., 2006; Harbor, 1994; T.R. Schueler and Holland, 1994). The Environmental Protection Agency (EPA) has noted that in the United States, polluted precipitation runoff is the leading threat to water quality (U.S. Environmental Protection Agency, 1994). A relatively small percentage of impervious surfaces, only 10%, can trigger many of the effects listed above (Booth et al., 2002; T.R. Schueler and Holland, 1994).

Hydraulic Modeling

Hydraulic models that take into account percent imperviousness can simulate flood hydrology and runoff. In the past, efforts have been made to separate imperviousness into effective and noneffective impervious areas. Effective areas drain into stormwater systems while noneffective drain onto pervious areas like lawns (Alley and Veenhuis, 1983). However, most modern models use total imperviousness as an input (Alley and Veenhuis, 1983; In et al., 2003).

While there are several models that can be used to simulate the effects of increased imperviousness, the one I have chosen to use is the HEC-HMS model, which is designed to simulate runoff with a wide range of watershed conditions (US Army Corps of Engineers, 2012a). This model was been developed by U.S. Army Corps of Engineers and is free to download and use. I chose HEC-HMS because it can simulate many processes including precipitation/runoff and urban drainage conditions (US Army Corps of Engineers, 2012a).

IV. METHODS

Work Completed

Over the course of the last 6 months, I laid the foundations this project forward. I started by driving, photographing, and observing the current condition of Vermont's 53 interstate exits. This led to the preliminary classification of exits into three categories based on their level and type of development: undeveloped/basic services, developed-residential, and developed-commercial (Figure 6). The undeveloped/basic services exits typically consist of an interstate exit transitioning into a state road before entering a town. In this type of exit, the change in impervious surface over time has been minimal (1-2 additional gas stations, a single hotel/motel, 1-2 restaurants) (Figure 7). The rest of the area generally remains forested or used for agriculture. Developed-residential areas transition immediately from the off ramp into residential streets lined with houses (Figure 8). While these areas have high amounts of impervious surface, further research is needed to distinguish how much is directly related to interstate construction. Developed-commercial exits are typically lined with gas stations, restaurants, and large chain stores (Figure 9). These buildings and their associated parking lots have greatly increased the impervious area surrounding the exit, thus likely contribute to increases in runoff into local streams and rivers and changed flow paths.

To narrow down the number of study sites from 20 preliminarily selected towns to 12 study sites, I created a matrix (Table 2) which evaluated the current level of development at the site, the development trajectory over time, and the socioeconomic status of each town. Using this matrix, I was able to evaluate the towns and choose those that represent a diverse set of conditions (Figure 2).

I familiarized myself with the images of the Landscape Change Program database which currently contains 50,000 photos, 20% of which I processed for public viewing over the past 6 months. Over 25% of the database is currently composed of images related to interstate construction, and of those over 1600 are oblique aerial images, which act as a lens into the past and can be used for comparison to those same areas today.

In March of 2012, I presented my preliminary findings about the geomorphic impacts of the Vermont interstate – using the Landscape Change Program database as my primary resource – at the Northeast Geological Society of America conference. The abstract for this submission can be found in Appendix II, and the poster can be seen as a plate in Delehanty 101.

Current and Future Work

The goal of this project is to understand how the interstate and associated development associated has affected Vermont's hydrology. The potential hydrologic impacts include changes in flow paths, base and peak flow of streams, and runoff, all of which can in turn affect sediment transport and erosion. During summer and fall fieldwork I will perform four tasks: aerial photo analysis, ground based rephotography, field mapping of stream impacts (incision, aggradation, avulsion), and hydraulic modeling.

Aerial Photo Analysis

Aerial photo analysis of the towns will allow me to quantify changes in imperviousness over time. With differences in seasons, heights, and angles, the images must be altered to lay correctly over one another (Umakawa et al., 2008). Nearly all of the aerial images will require rectification – the process of projecting a 3D image of Earth onto a 2D plane and removing any geometric distortions. After rectification, I will evaluate the best method to extract data on the quantity of impervious surfaces present. This may include looking at the ratio of light to dark pixels, generating and compiling random points and their classification as impervious or not, or running programs that separate regions after a supervised classification based on training sites. These processes will be done using the programs ERDAS Imagine and eCognition. I will also use aerial rephotographs to monitor changes in river channel width and lateral movement over time (Ambers and Wemple, 2008).

Ground Based Rephotography

During the summer of 2012, I will rephotograph ground-based images of the interstate and the surrounding development at the 12 study sites. We will take printed images of the old photos into the field to determine appopriate distances and angles from which to rephotograph. This method of rephotography is cost effective and of sufficient quality for the level of analysis needed. The photos will be loaded into the image database and described and linked with their historical counterparts allowing for landscape change analysis over the past 50 years. Data and observations that can be derived from the rephotographs are changes in run off generation and flow paths, build-out patterns, riparian zone extent and condition, and general stream channel morphology.

Hydraulic Modeling

I will use models simulating past and future responses to the interstate and interstate related development once rectification and rephotography are complete for the final four study sites. The area of interest in the models will be the watershed in which the study site resides. This model also allows for analysis of subbasins and reaches. Within the model is a tool with which imperviousness of the subbasin can be changed (US Army Corps of Engineers, 2012b). The change in imperviousness information will be derived from historic and recent aerial photographs. I intend to run the model for four different sets of conditions: 1962, 1974, 1980, and 2009. The 1962 photographs may be replaced by earlier series for those areas in which the interstate was already constructed. HEC- River Analysis System (RAS) will also likely be utilized to gauge the impact interstate development has had on flow and sediment transport (US Army Corps of Engineers, 2012c). The majority of the modeling work will be done from the end of summer through winter of 2012.

Fieldwork

During the summer of 2012, I will attempt to identify and document evidence that may be due to increases in imperviousness. This will include rivers with scouring, aggradation, avulsion, or channel migration. In addition I will examine bridges piers, water intake pipes, and discharge pipes to see if there is either aggradation around or undercutting of the structures.

Another feature we will look for is slope instability, particularly near roads. Indicators may be trees with pistol butt bottoms, shrubs/pioneer species surrounded by more mature trees, pavement cracking, and displacement of previously existing features like fences. Gullying will also be noted. We will use the field data gathered to check the accuracy of the models that will be run in the fall.

V. TIMELINE

Timing	Task
Spring 2012	-Process images -Present poster at NEGSA -Draft Proposal -Contact local historical societies, town clerks, and listers -Receive Vermont Folk Life center training -Determine method for quantifying imperviousness in historical photos
Summer 2012	-Photograph and enter ground-based rephotography -Determine suitability of areas for modeling by observing rivers, streams, and slopes for hydrologic impacts related to change in impervious surfaces -Choose 4 final study sites -Learn to use HEC-HMS and HEC-RAS models
Fall 2012	-Run HEC-HMS and HEC-RAS models for final study sites -Rectify and analyze aerial photographs -Rectify and analyze rephotographs -Prepare and present progress report
Spring 2012	-Finish running models -Compare model results to field data -Write and defend thesis

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APPENDIX I: ROAD MEASUREMENTS AND CALCULATIONS

Length of VT Paved Roads*	11394 km
Length of VT Unpaved Roads*	14065 km
Area of VT Paved Roads	115.8 km^2
Length of VT Interstate	516 km
Length of US Interstate**	75440 km

	Lanes Each Direction	Lane Width (m)	Right Shoulder (m)	Left Shoulder (m)	Total Width (m)
Interstate	2	3.6	3	1.2	22.8
Normal Road	1	3	1.8	-	9.6

	Width (m)	Area/km (m^2)	Length in VT (km)	Area in VT (km^2)	Area in US (km^2)
Interstate Highway	22.8	22800	516	11.8	1720
Normal Paved Road	9.6	9600	10878	104	-
Difference	13.2	13200	10362	92.2	-

* Data from the Vermont Agency of Transportation, Mapping Unit – General Stats, 2011

** Data from the US Department of Transportation and Federal Highway Administration, Interstate FAQ

APPENDIX II: NEGSA Poster Abstract

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A RIVER RUNS THROUGH IT – THE GEOMORPHIC IMPACTS OF THE VERMONT INTERSTATE HIGHWAY SYSTEM

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The Vermont interstate highway system, constructed between 1958 and 1983, is 510 kilometers (317 miles) long and has altered the sediment distribution pattern and riparian vegetation in many of the state's rivers and the development pattern in towns near interstate exits. Vermont's interstate system is unique in that the interstate, state roads, the railroad, rivers, and towns often share the same confined valley bottom.

Using the Landscape Change Program database (http://www.uvm.edu/landscape/) – an archive of nearly 42,000 images of Vermont spanning over 300 years and supported by the National Science Foundation and the National Endowment for the Humanities – we viewed nearly 5000 images of the interstate before, during, and after construction. These images are part of a larger collection of 36,000 images taken from 1958 to 1979, during interstate construction in Vermont.

The photographs taken during construction show the clear cutting of forests, building of cofferdams, and rerouting of rivers necessary to construct the interstate. They also show the construction of bridge piers and the placement of riprap on riverbanks to maintain and protect the structural integrity of the highway. During and immediately after construction, rivers were inundated with sediment and hill slopes were at the mercy of accelerated erosion due to the clear cutting of forests and construction of cofferdams. Rephotography of these areas shows evidence of sediment accumulation immediately adjacent to and downstream of bridge piers, revegetation of riverbanks and surrounding hillslopes, and a routing of runoff from increased amounts of impervious surface. It is apparent that even after 45 years, both the direct and the indirect effects of the interstate system are still being felt.

FIGURES

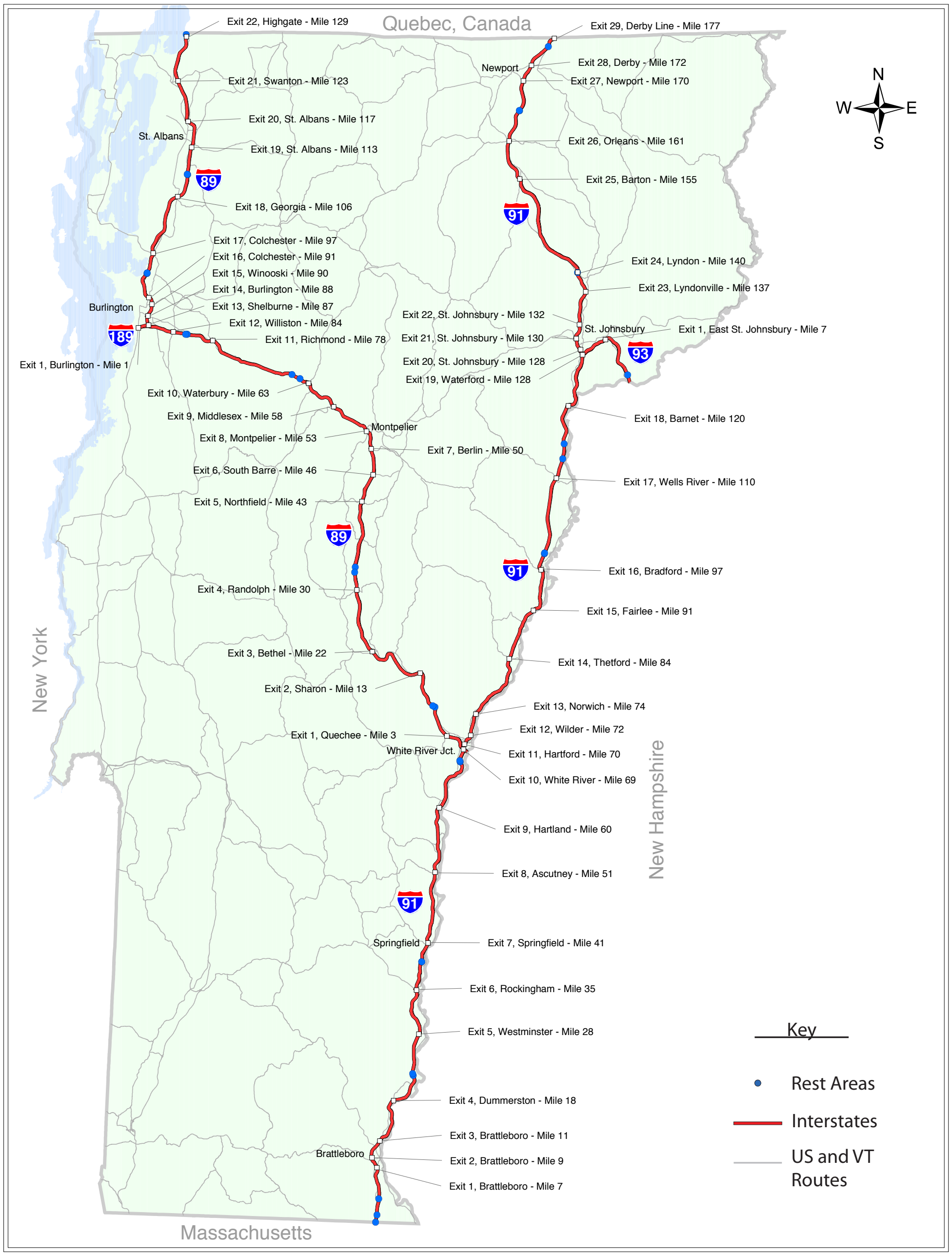

Figure 1. Vermont Interstate Highway System map including exits and rest areas. The Vermont Interstate Highway System, constructed between 1958 and 1983 (Smith, 2006; Vermont Department of Highways, 1965) is 516 km long an has 53 exits (Smith, 2006; Vermont Agency of Transportation, 2012). Modified from the Vermont Agency of Transportation, 2012.

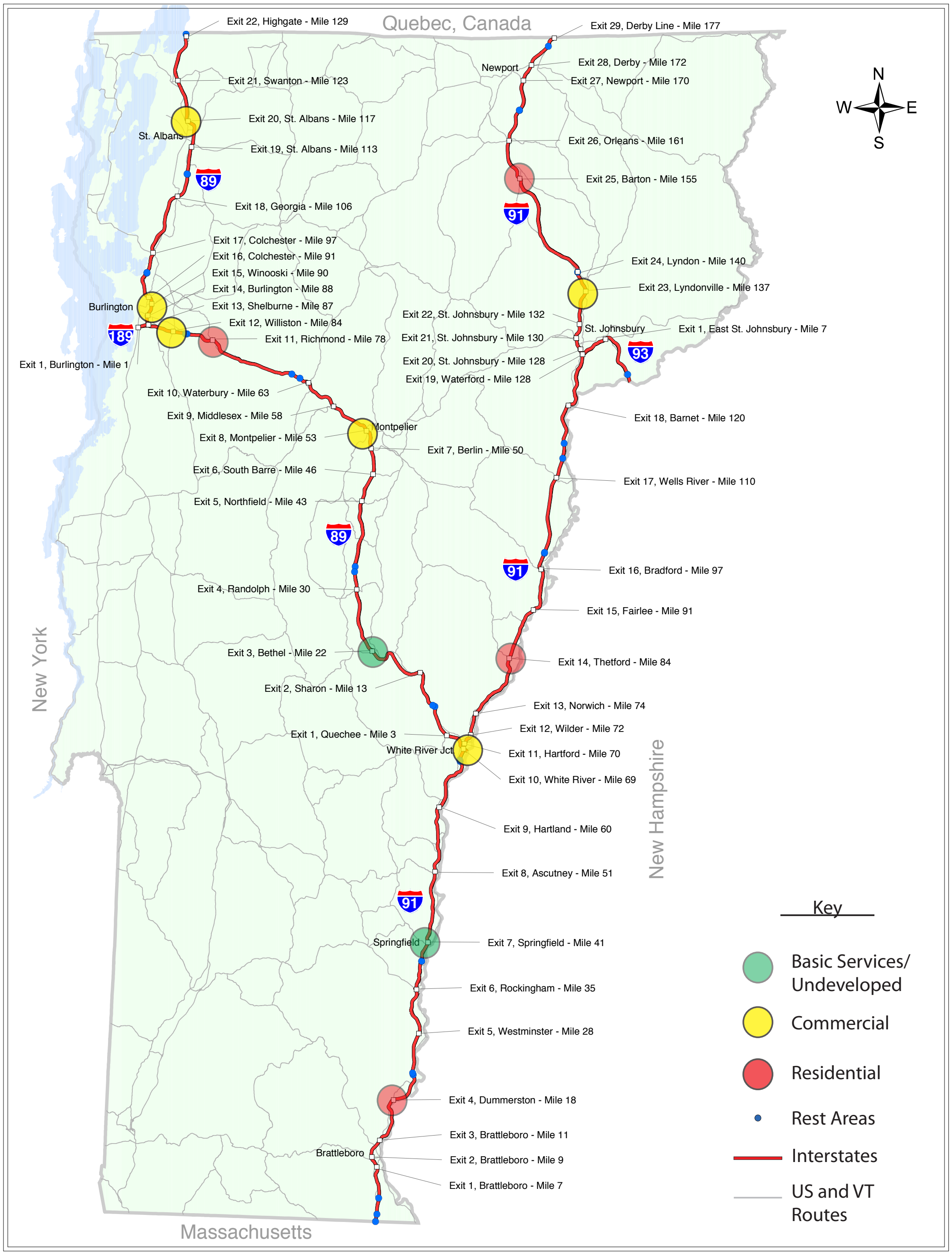

Figure 2. Location of summer 2012 study sites. Green circles indicate Basic Services/Undeveloped exits, yellow circles indicate Commercial exits, red circles indicate Residential exits. Modified from the Vermont Agency of Transportation, 2012.

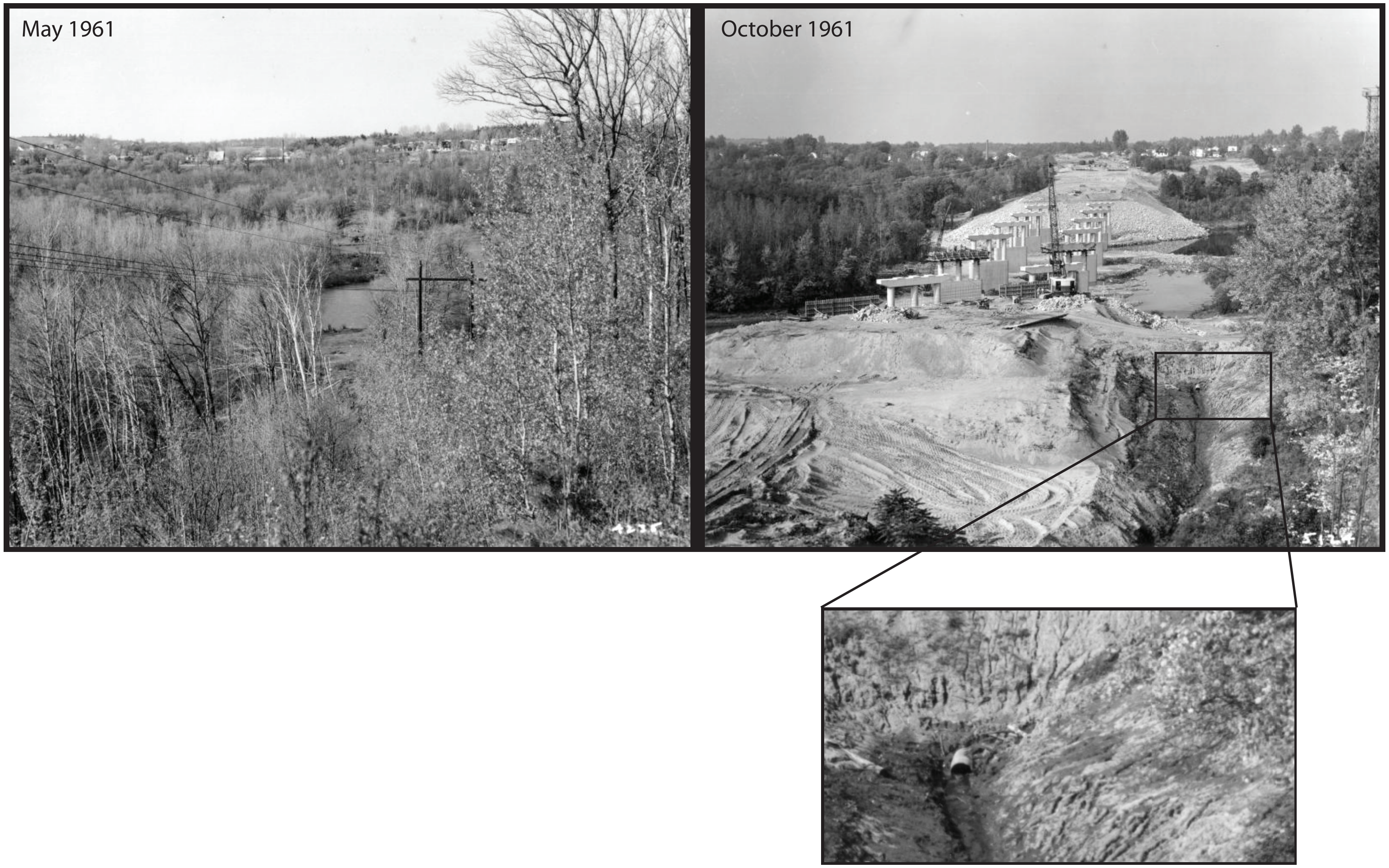

Figure 3. The above photographs are an example of ground-based rephotography (University of Vermont, 2012). The image to the left is from May 1961, and shows the Winooski River from the top of a heavily wooded hill in South Burlington. The image to the right is an October 1961 rephotograph of the previous image. It depicts the clear cutting of forest in order to accommodate interstate construction. The foreground of the image is dominated by loose soil. Bridge piers run up the center of the image followed by more cleared land that extends into the background. Gullying can be seen in the zoomed in image, as well as a pipe that is draining runoff into the Winooski River below. These images were sourced from the Landscape Change Program database. These images were sourced from the Landscape Change Program database (LS00376_001/LS00376_000).

Figure 4. The above photographs are an example of oblique aerial rephotography (University of Vermont, 2012). The image to the left is a 1927 photo of Middlesex, VT. The image to the right was taken 77 years later. In the more recent image, it is apparent that the interstate and state two lane highway have been constructed adjacent the already present railroad, greatly increased the necessary right of way. These images were sourced from the Landscape Change Program database (LS01472_000/ LS01472_001).

Figure 5. Interstate excavation and preparation for paving. The image to the left was taken in 1959, and is of excavation and interstate construction near Montpelier, Vermont. The image to the right was take in 1963, and shows men using machinery to flatten the road for future pavement near Westminster, Vermont. These images were sourced from the Landscape Change Program database (LS37392_000/LS41753_000).

Bailey Howe Map Library			
Year	**Coverage**	**Type**	**Source Scale**
1937	Most of Chittenden County	Panchromatic	1:20,000
1939-1942	Fragmentary Coverage of Vermont	Panchromatic	-
1962	Statewide	Panchromatic	1:18,000
1962	Select Town Centers	Panchromatic	1:6,000
1968	Central and Southern Vermont	Panchromatic	1:24,000
1974	Northern Half of the State	Panchromatic	1:20,000
	Southern Half of the State	Panchromatic	1:62,500
1977	Statewide	CIR	1:80,000
1980	Statewide	Panchromatic	1:40,000
1988	Most of Chittenden County	Panchromatic	1:7,800

VCGI - Select Datasets			
Year	**Coverage**	**Type**	**Source Scale**
2003	Statewide	Truecolor	1:40,000
2004	Most of Chittenden County	Truecolor	1:1,250
2004	Most of Chittenden County	Color IR	1:1,250
2004	Chittenden County	Panchromatic	1:1,250
2008	Statewide	Truecolor and Infared	1:40,000
2009	Statewide	Truecolor	1:40,000
2006-2010	Statewide	Panchromatic	1:5,000

Table 1. The above table is a list of the available aerial photography in both the Bailey Howe Map Room and through the Vermont Center for Geographic Information (VCGI). Included are the year of the photo, the area covered, the type of image, and the source scale.

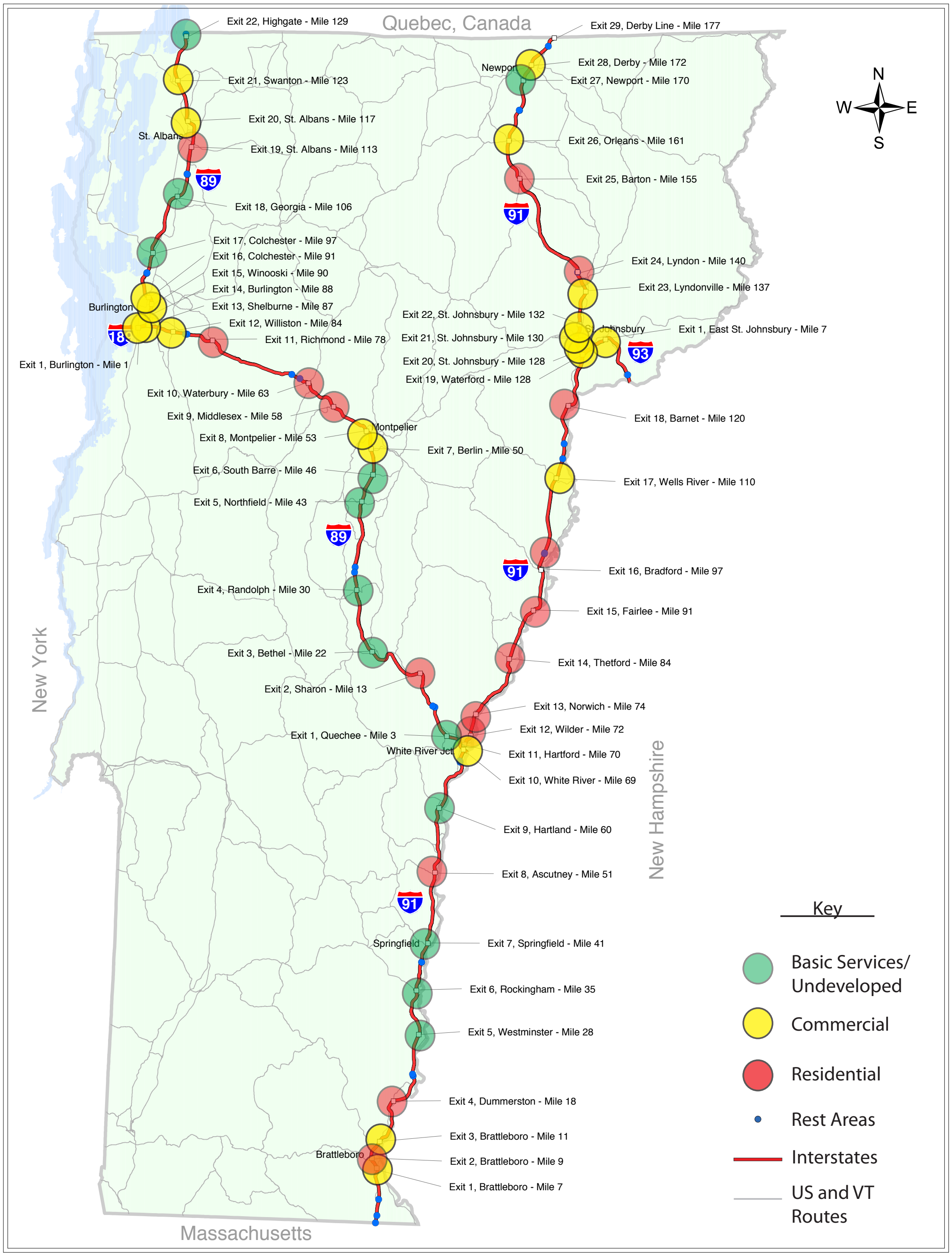

Figure 6. Classification of Interstate exits. The exits have been separated into three categories based on their level and type of development: Undeveloped/Basic services (green), Developed-Residential (red), and Developed-Commercial (yellow). Modified from the Vermont Agency of Transportation, 2012.

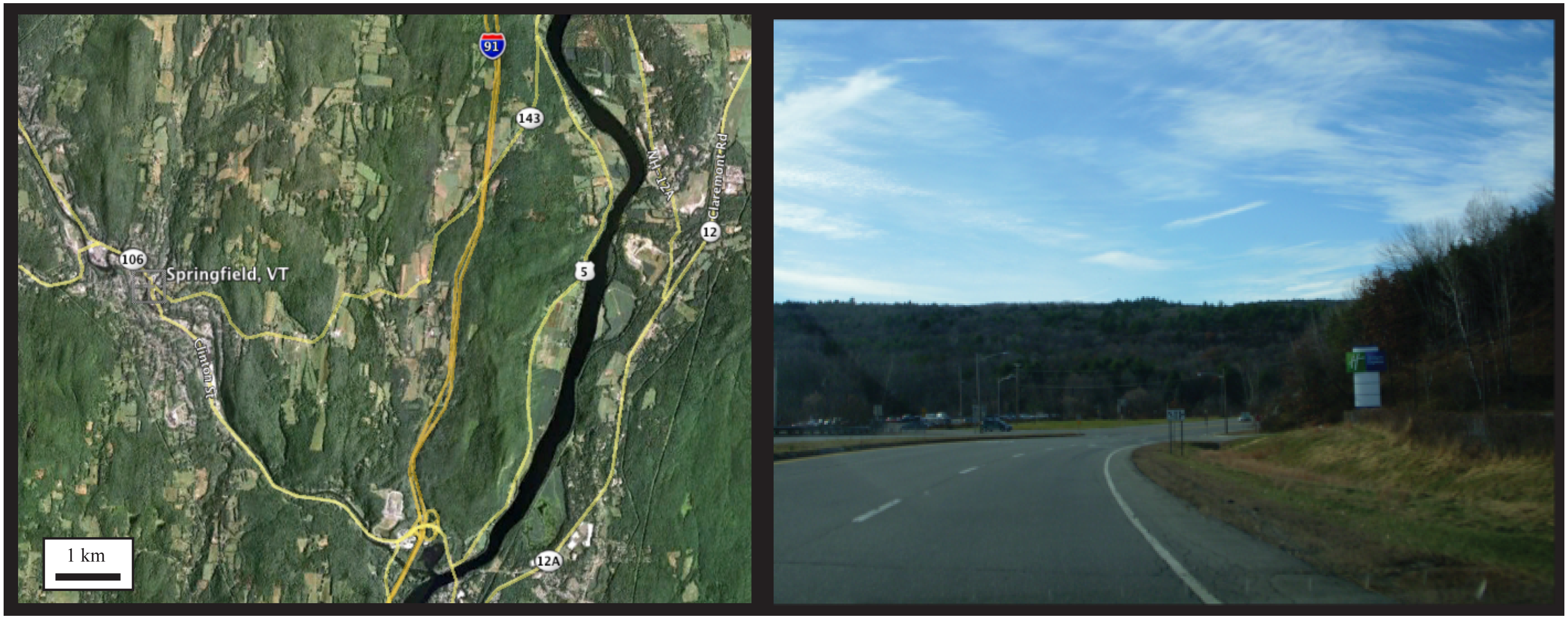

Figure 7. Exit 7 (Springfield) on Interstate 91, is an example of an Undeveloped/Basic Services exit. As seen in both the Google Earth image to the left and the photograph to the right, there is very little development adjacent to the exit.

Figure 8. Exit 14 (Thetford) on Interstate 91, is an example of a Residential exit. Although it is difficult to tell in the Google Earth image to the left, it is apparent from the photograph to the right, that the area near the interstate exit is primarily residential.

Figure 9. Exit 12 (Williston) on Interstate 89, is an example of a Commerical exit. It is apparent from both the Google Earth image to the left, and the photograph to the right, that the area has been heavily commercially developed.

Town	Current Development	Mean Income	Change in Development
Barton*	Residential	43711	Little change
Bethel*	Undeveloped/Basic	54092	Little change
Brattleboro	Commercial (Exit 1)	53184	Little change
Brattleboro	Residential (Exit 2)	53184	Little change
Brattleboro	Commercial (Exit 3)	53184	Drastic change
Burlington	Commercial	56707	Drastic change
Dummerston*	Residential	79071	Little change
Lyndonville*	Commercial	37397	Little change
Montpelier*	Commercial	63892	Little change
Orleans	Commercial	36889	Little change
Richmond*	Residential	83703	Some change
Sharon	Residential	64034	Little change
Springfield*	Undeveloped/Basic	53392	Little change
St. Albans	Residential (Exit 19)	52557	Some change
St. Albans*	Commercial (Exit 20)	52557	Drastic change
Thetford*	Residential	81975	Some change
Waterbury	Residential	75150	Little change
Westminster	Undeveloped/Basic	63222	Little change
White River Junction	Commercial	48297	N/A
Williston*	Commercial	109121	Drastic change
Winooski*	Commercial	54001	Drastic change
Georgia	Undeveloped/Basic	80398	Some change
Hartford*	Commercial	64520	Some change
Vermont	-	78467	-

*Indicates chosen field site

Table 2. Preliminary study site matrix. This table is a matrix of 20 towns adjacent to interstate exits. Listed for comparison are the current type of development, five year estimates for mean household income from the 2010 Census, and change in development over time based on a comparison between the 1962 panchromatic aerial images from the Bailey Howe Map room and the most recent Google Earth imagery. Towns with an * are the 12 chosen study sites.