THE HYDROLOGIC IMPACT OF THE VERMONT INTERSTATE HIGHWAY SYSTEM

A Thesis Progress Report

by

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to

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Introduction and Goals

The construction of the interstate has had many effects on Vermont's profoundly rural landscape, one being the addition of at least 11.8 million square meters of impervious roadway. The second and still ongoing effect is build-out 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 the landscape, specifically surface water hydrology. The goal of this project is to determine whether construction of the interstate and the associated build-out increased the amount of impervious surface to a sufficient degree such that there is a detectable change in peak flow and run off volume of the local hydrologic systems. If this hypothesis proves true, I also plan to determine if it can be related to changes in stream planform and incision depth.

Study Towns - Completed Work and Progress on NEH Project

I began this project by categorizing Vermont's 53 interstate exits into three categories based on their type of development: undeveloped/basic services, developed-residential, and developed- commercial. With this classification scheme, a development trajectory, and socioeconomic data, I narrowed down my preliminary NEH study sites to 12.

In these towns, we used newly processed historic photographs (we processed over 18,000 by the beginning of summer 2012) to take over 500 new repeat photographs that documented landscape change since the construction of the interstate. While in these towns, we completed another phase of grant related work by distributing interstate attitude surveys, giving interstate related talks to the public, and interviewing Vermont residents who helped to build the interstate, were affected by the interstate, or have an opinion about the interstate. These oral histories are being archived by the Vermont Folklife Center.

The last phase of grant related work includes a public outreach and education component, where 20 portable vertical banner displays will tour libraries, rest areas, and fairs during the summer of 2013. The goal of the banners is to inform the public of how Vermont has changed, both physically and culturally, since the construction of the interstate. I have created rough drafts of the banners, which have been reviewed by our 9-person advisory committee, and I will continue to revise them before sending them to print in February, 2013 (Figure 1).

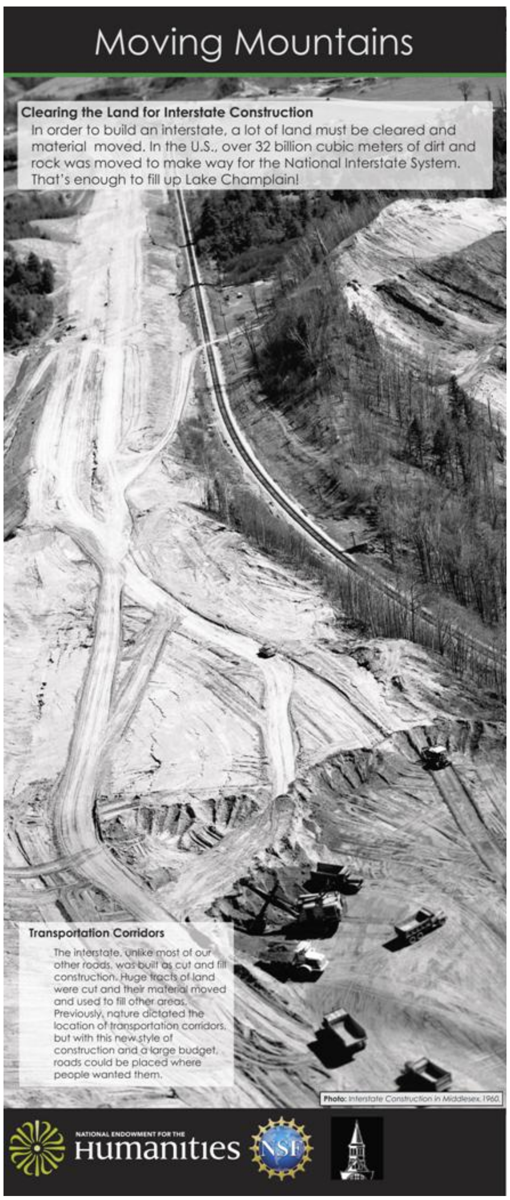

Figure 1. This banner is one of 20 draft banners that will eventually be printed as a part of the outreach portion of the NEH grant. It highlights the scale of physical change done by the interstate.

Hydrology Progress

Test Watershed –I chose Muddy Brook, a subwatershed of the Winooski River watershed, as my first study area because it lies within an region that has been significantly affected by interstate related growth (Figure 2). Muddy Brook, because it lies primarily within the highly populated Chittenden County, also has more aerial photo availability than many other regions of Vermont (1937, 1962, 1968, 1977, 1980, 1988, 2003, 2004, 2006-2011). In addition, it contains both urban features (housing tracts, malls, airports) as well as rural features (rivers, forests, and agricultural fields), which allows me to test how the rectification and detection of impervious surfaces in historical aerial photos functions when both sets of characteristics are present.

Acquiring Aerial Photographs – The aerial photography record extends back much further in time (1930s) than satellite imagery (1960s) and digital scans of aerial photography can be made or acquired for little to no cost (Campbell, 2008).

Many of the images of the Muddy Brook watershed were already scanned and available as digital copies at the Bailey Howe Map Library. Where digital copies were not available, I used the Map Library's Epson Expression 10,000 XL scanner. Scans were done to the standards of the Map Library (8-bit black and white scan, 600 dots per inch, and saved as a tiff) and were added to their digital archive. All the image years acquired along with select metadata can be seen in Table 1. The steps to prepare this data for analysis and for analysis itself can be found both in the text below and in Figure 3.

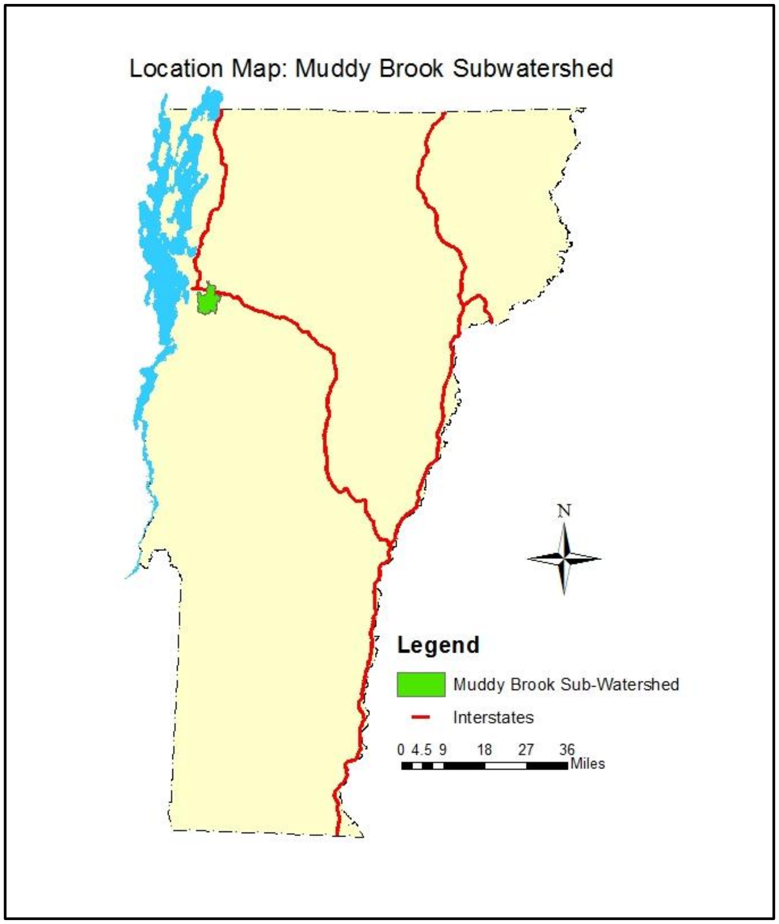

Figure 2. Location map of the Muddy Brook Subwatershed. The study area is highlighted in green while interstates are shown in red.

Aerial Photo Metadata

Date	Coordinate System	Scale	Flight Height	Scanned DPI
May 1962	n/a	1:18,000	9000 ft	600
April/May 1988	n/a	1:20,000	10,000 ft	600
April 1999	Vermont State Plane	1:5,000	-	n/a
April/May 2011	Vermont State Plane	1:5,000	-	n/a

Table 1. This table displays the aerial photograph years that were acquired for this study and will be used in a watershed model once image rectification and impervious detection is complete.

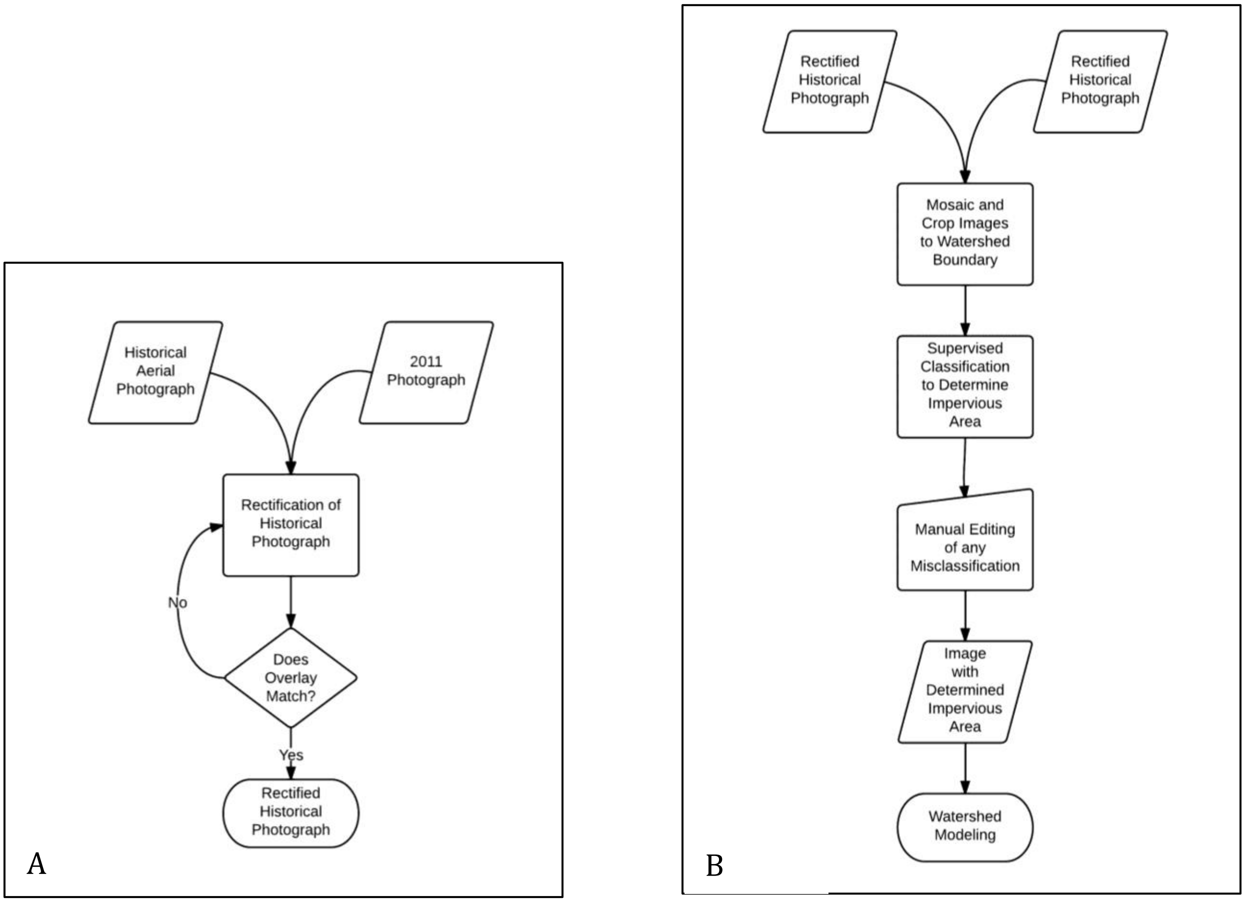

Figure 3. Figure 3A shows the general steps for rectifying historical aerial images. Figure 3B details how to use the rectified historical photograph to determine impervious area which will later be used as a boundary condition in the watershed model.

Preparing Aerial Photographs for Analysis – Geometric distortion in aerial photography is caused by the angle of the photo, curvature of the earth, and variations in altitude. Much of this distortion can be reduced by rectifying the photos, after which further analysis can be performed (Umakawa, Zhu, & Tachibana, 2008).

I rectified aerial photos of the Muddy Brook Watershed from 1962 and 1988 using the remote sensing application ERDAS IMAGINE. The 1999 and 2011 aerial images are available online in a rectified and georeferenced format. To rectify the photos, I mosaiced together the 2011 aerial images of Muddy Brook. Using the set as a reference, I rectified the historical images using the Multipoint Geometric Correction tool, which allows for ground control points (GCPs) to be placed. A GCP is an object with a known location on both maps (figure 4). There are two types of GCPs: hard GCPs which are unlikely to have moved (buildings and intersections), and soft GCPs which are more likely to have moved (trees and agricultural field divisions) (Hughes, McDowell, & Marcus, 2006). The number and type of GCPs used were dependent on the image itself. The 1962 photographs had fewer potential hard GCPs so a mixture of hard and soft GCPs were used, whereas only hard GCPs were needed to rectify the 1988 photographs.

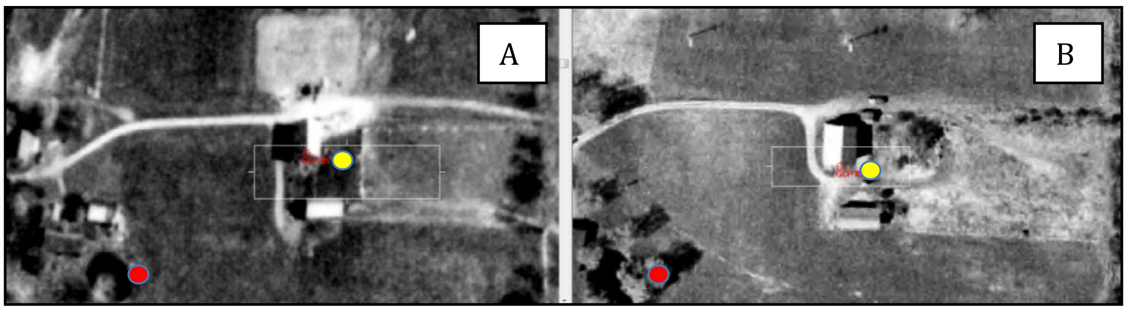

Figure 4. The image on the left (A) is from 1962, while the image of the right (B) is from 2012. The yellow dot indicates a hard GCP – the corner of a house, while the red dot indicates a soft GCP – a tree that may or may not be in the same location in both images.

The geometric model used to rectify the image was a 2nd degree polynomial model. Hughes et al. (2006), found that a second-degree polynomial yielded the lowest range of error as compared to first and third degree polynomials. The images were resampled using a Cubic Convolution algorithm, where the nearest 16 cells are used to calculate the new cell value (ERDAS, 2010).

Once resampled, I draped the historical image atop the 2011 reference. This allowed me to observe the effectiveness of the rectification. If portions of the rectified image did not correctly overlay the 2011 reference, I added GCPs to that area when possible and resampled the image again (Figure 5).

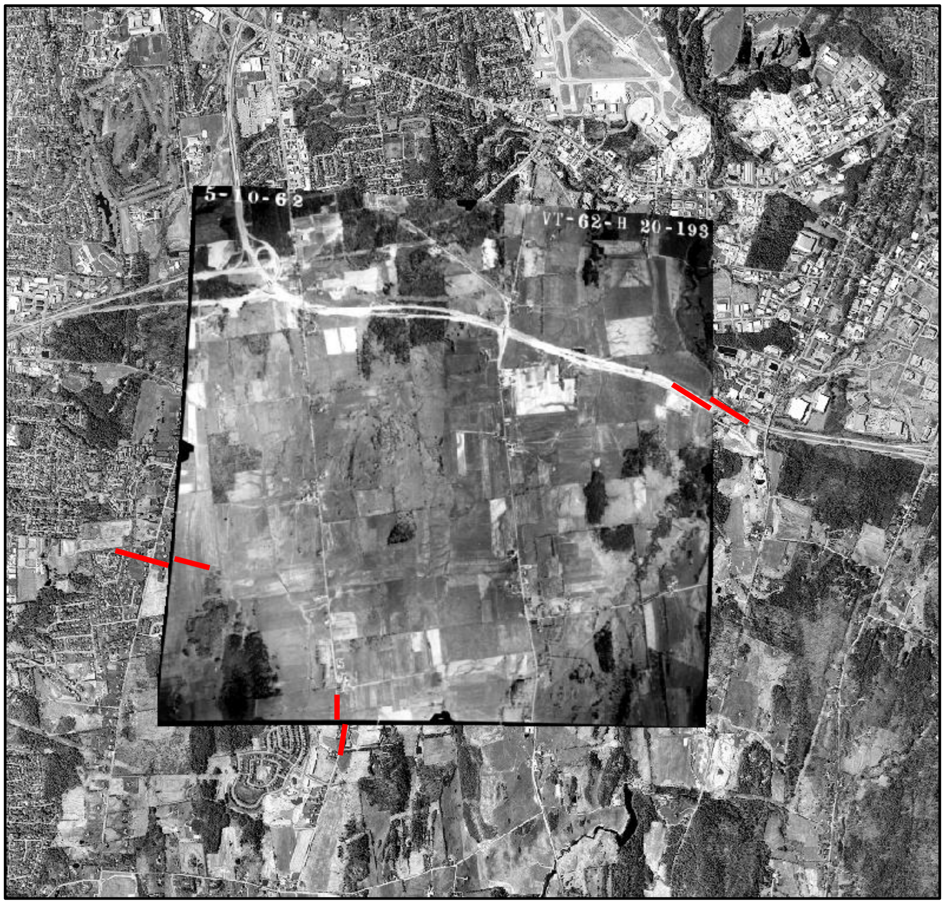

Figure 5. This image shows a rectified 1962 aerial photo atop a 2011 aerial photo. The 1962 image has been stretched to the dimensions of the 2011. The red lines on the photos show where roads should match but do not. GCPs need to be added in those areas to achieve a more accurate rectification.

Error – After 6 GCPs have been placed, the Multipoint Geometric Correction tool begins to predict the location of corresponding GCPs (I place the first point and the program places the corresponding GCP in the other image which can be moved if necessary), and calculating the root-mean-square error (RMSE) for each GCP. This helps the user to determine where more GCPs are needed, and to evaluate the overall accuracy of the rectification. I typically place between 15 and 30 GCPs in an image (dependent on size and potential GCPs), and the total RMSE never exceeds 0.50.

Impervious Detection in Aerial Data - To detect the percent of impervious area in the Muddy Brook watershed, I used the object oriented software eCognition. This software first breaks the photo into image objects based on shape, compactness, and scale parameter. A high shape value places more emphasis on the color of the object (color = 1 – shape) and a high compactness value allows there to be compact objects in an otherwise non-compact area. For scale parameter, a high value allows for large image objects, and a low value allows for smaller image objects (Definiens, 2010).

Once the image has been segmented, a list of use defined classes are created (agriculture, forest, impervious surface, etc.), and representative image objects are chosen. eCognition then uses the image objects' attributes as well as the training site information to determine the class of the remaining unclassified image objects. Any misclassified objects can be manually edited to represent the correct class (Figure 6).

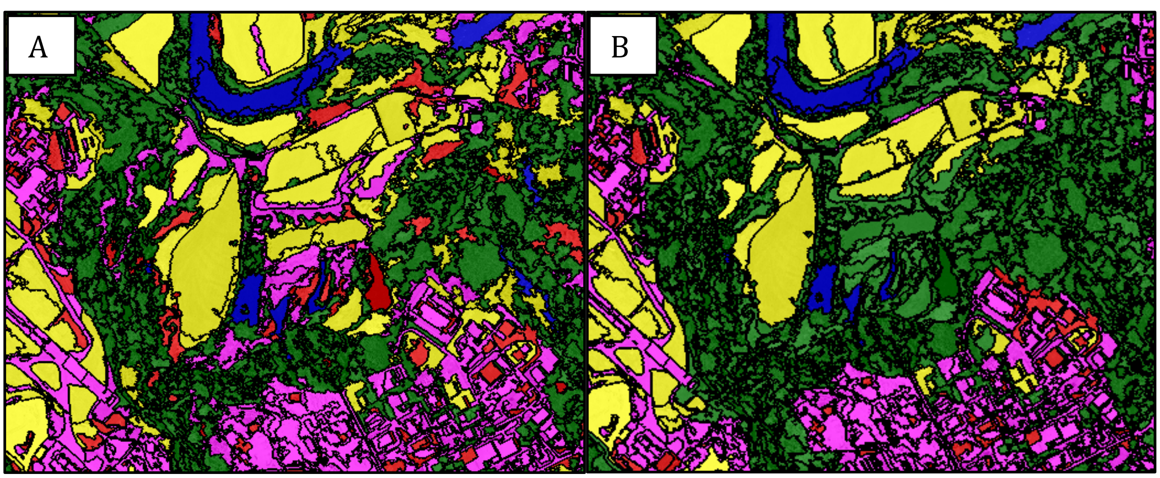

Figure 6. Image A shows the results of a supervised classification. Many forested areas (green) were misclassified as light and dark colored impervious areas (pink and red). I image B shows the supervised classification after manual editing to correct misclassified image objects.

Error - This means of classification is a relatively fast way to determine the percent of impervious surface in an area. However there are drawbacks to this method of classification. One of the primary issues is that the image objects work well for larger features like roads and commercial complexes, but less so for smaller features like residential areas.

In order to gauge the accuracy of the object oriented impervious detection method, I used a single aerial image that included many land use categories as a test area. For this image, I compared the eCognition program, the results of the 2001 and 2006 National Land Cover Data (NLCD) program, and manual digitization.

Manual digitization of the image yielded 30.1% impervious area. Error was not calculated for manual digitization. NLCD for 2001 and 2006, where 50% or more of a pixel was impervious, yielded 33.3% and 34.3% impervious area, respectively. Unfortunately the error assessment for 2001 and 2006 NLCD has not been published, but the standard error of the 1992 NLCD is 0.06 (Multi-Resolution Land Characteristics, 2007). The eCognition program yielded a value of 33.1% impervious area. eCognition performs an accuracy assessment based on the input samples, and in this case found an overall accuracy of 97.9%. All three methods of impervious detection (manual digitization, NLCD, and eCognition) were within 4.2% of one another. The graphical representation of these methods can be seen in Figure 7.

Preliminary Results

The amount of impervious surface in the Muddy Brook Subwatershed has increased over the past 50 years. After rectifying and detecting impervious surfaces, I found that the impervious area in 1962 made up 2.9% of the subwatershed, in 1988 it was 4.6%, in 1999 it increased to 6.6%, and the impervious area in 2011 was 7.1% (table 2). A comparison between the impervious areas of 1962 versus 2011 can be seen in Figure 8.

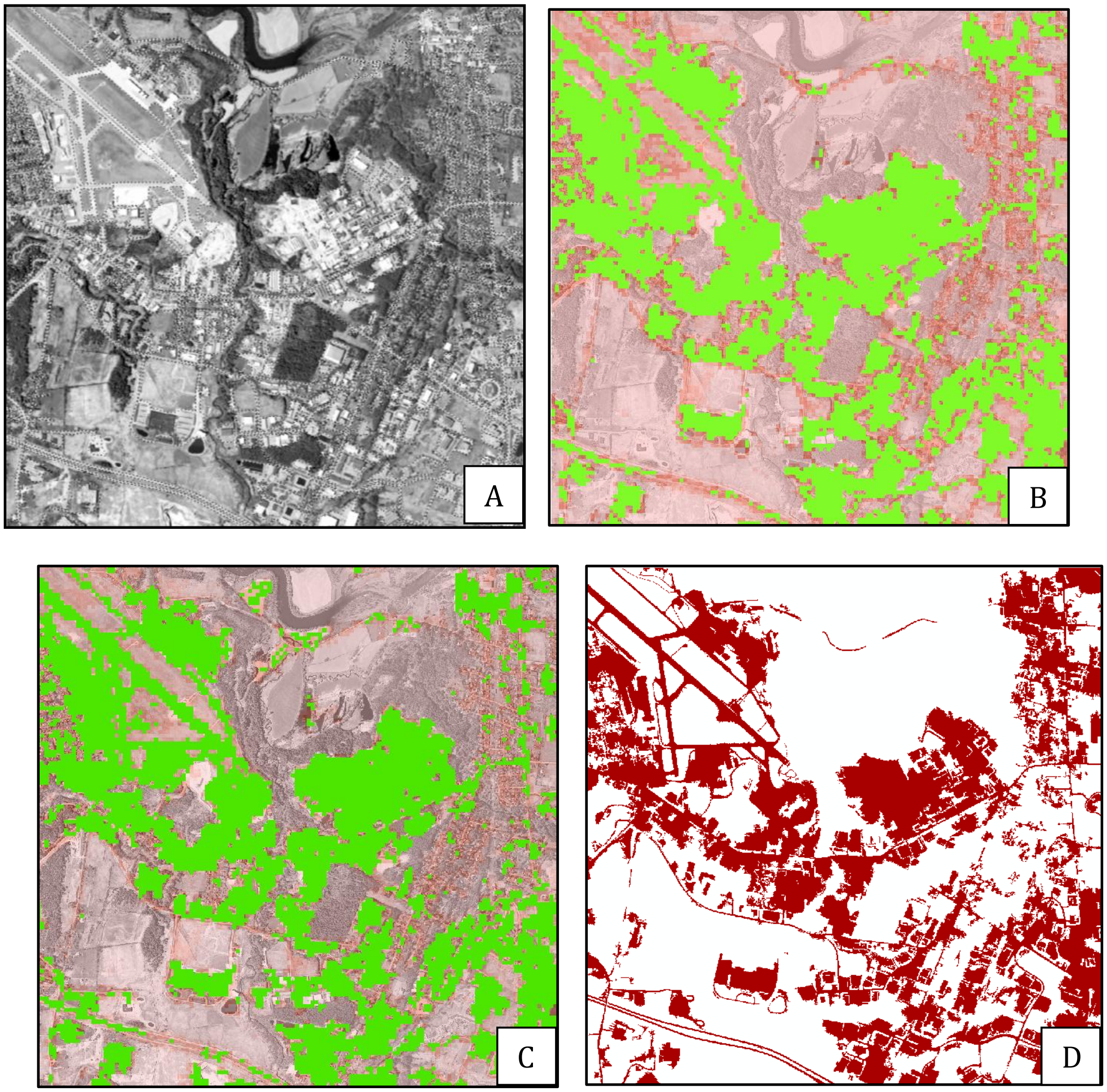

Figure 7. The calculated impervious percent varies by method. In A, manual digitization yields an impervious area of 30.1%. B and C are the NLCD 2001 and 2006 impervious layers, which have impervious areas of 33.3% and 34.3% respectively. The method I will be using in the future is the eCognition object based oriented software, shown in D, which yields an impervious area of 33.1%.

Impervious Detection of Muddy Brook Subwatershed

	1962	1988	1999	2001*	2006*	2011
Impervious Area	2.90%	4.60%	6.60%	5.50%	5.60%	7.10%

* Values from NLCD

Table 2. This table is a summary of the impervious detection of the Muddy Brook Subwatershed. The results show that the percent of impervious area has consistently increased from 2.9% to 7.1% over the past 49 years.

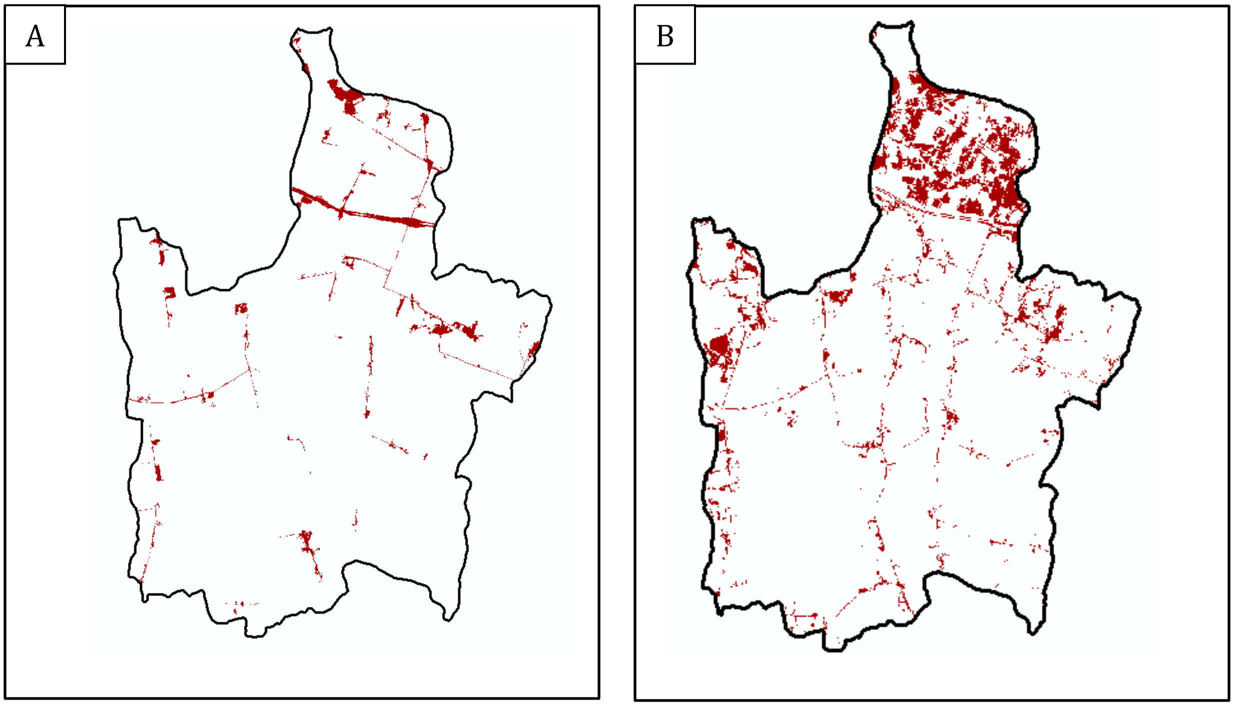

Figure 8. This set of photos shows the difference in impervious surface (shown in red) between 1962 (A) and 2011 (B). The impervious area increased from 2.9% to 7.1%.

The amount of impervious surface I detected is higher than that found in the NLCD impervious layer – 5.6% for the 2006 NLCD versus 7.1% for the impervious area of the 2011 aerial photos. While the small test area discussed earlier was within 1.2% of the NLCD, the difference in measurement for the entire subwatershed was only 1.5%. This shows that eCognition can detect impervious areas with similar accuracy to the NLCD. What appears to contribute most to the difference in impervious area is eCognition's ability to isolate small roads and homes, particularly in rural areas (Figure 9).

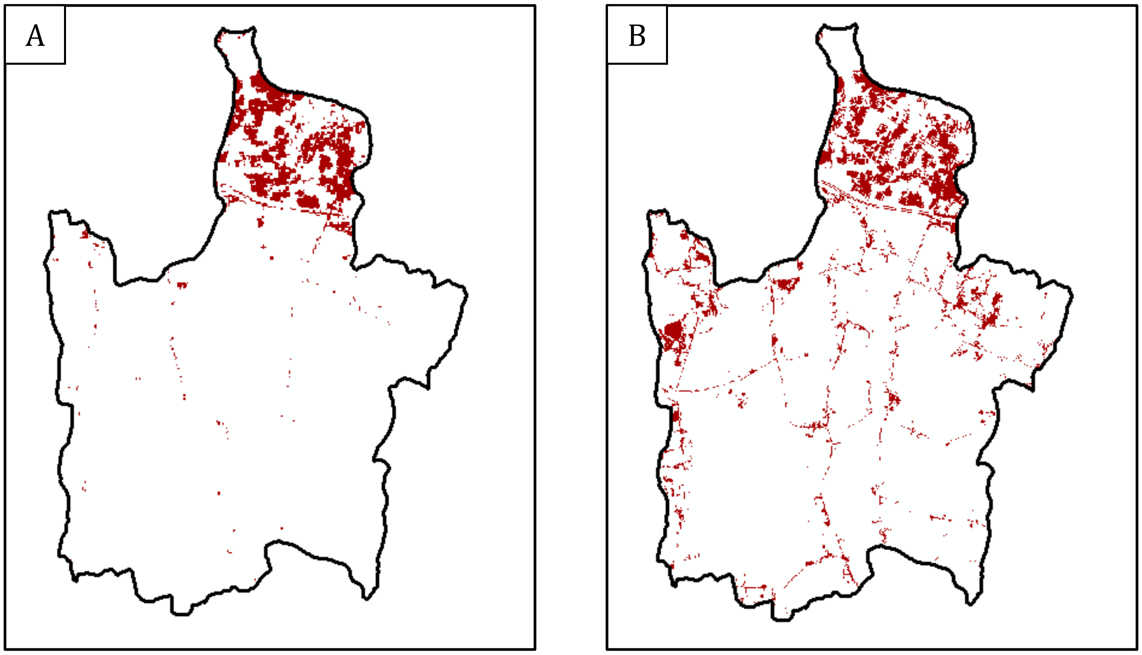

Figure 9. This is a side by side comparison of the 2006 NLCD impervious layer (A) (highlighted are pixels that are at least 50% impervious) and the results of the 2011 impervious detection (B). The NLCD impervious layer yielded a value of 5.6% impervious area, while the 2011 impervious detection yielded a value of 7.1%. Much of this difference appears to come from the ability of eCognition to detect small roads and homes in rural areas.

Remaining Work

I will choose another 2 subwatersheds whose interstate related development level is different than Muddy Brook's to use as additional study sites. Once rectification and impervious detection has been performed, I will then use the values I find as inputs to the Hydraulic Engineering Center's Hydraulic Modeling System (HEC-HMS). Using HEC-HMS, I will be able to simulate storm events for time steps in each of the subwatersheds. The program will generate synthetic runoff and hydrograph data. If the increase in impervious area results in a detectable change in peak flow and run off volume, I will then try to relate this to changes in stream planform and incision.

Timeline for Completion

11/27/12	Progress Report
12/15/12	Subwatersheds chosen and imagery acquired
1/15/13	All remaining interstate photos processed
2/1/13	Imagery Rectified
2/1/13	Meet with NEH committee to review banners
2/15/13	20 NEH banners out to printing
3/15/13	Impervious detection complete
3/18/13	Present at NE GSA
4/1/13	Modeling in HEC-HMS complete
5/1/13	Full draft of thesis due
7/1/13	Thesis Defense
8/1/13	Final draft due to UVM

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