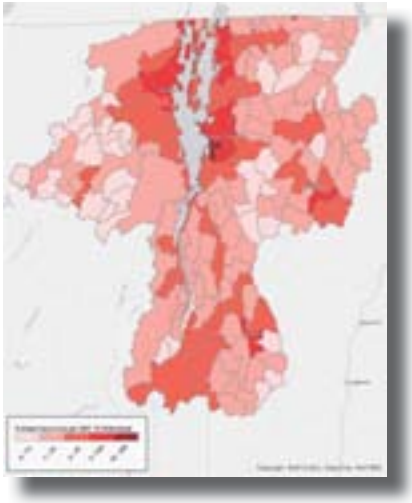
Lake Champlain Basin Program

TECHNICAL REPORT NO. 76

Mapping Impervious Surfaces in the Lake Champlain Basin



October 2013

Final Report

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For:
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New England Interstate Water Pollution Control Commission

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FINAL REPORT

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Organization Name: University of Vermont

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EXECUTIVE SUMMARY

Impervious surfaces are important anthropogenic landscape factors affecting stormwater runoff volume and water quality. To facilitate study and management of these features in the Lake Champlain Basin of New York and Vermont, a new impervious surfaces map was created using 1-meter resolution multispectral imagery and object-based image analysis techniques. Two classes were mapped: Roads\Railroads and Other Impervious Surfaces. The latter category included driveways, sidewalks, parking lots, buildings, and quarries, but natural impervious surfaces such as rock outcroppings and mountain summits were excluded. The resulting map effectively discriminated impervious features from other landscape elements, illustrating the Basin-wide distribution and density of these surfaces. In statistical terms, an accuracy assessment indicated a Basin-wide classification rate of 99%, with similar rates for the individual New York and Vermont portions of the study area. Analysis of impervious surfaces by watershed confirmed that lakeshore areas on both sides of Lake Champlain have the highest concentrations of developed features, particularly the Burlington-St. Albans corridor in Vermont and the Plattsburg area in New York. Similar analyses can be performed with many other geographies of interest, at multiple scales, aiding study, monitoring, and regulation of impervious surfaces across the Lake Champlain Basin.

INTRODUCTION

The nature, extent, and distribution of impervious surfaces are important landscape factors affecting water quality and stormwater runoff volume. Accordingly, municipalities, planning agencies, state governments, and other entities are increasingly interested in monitoring these variables, their change over time, and their effect on natural resources. They are also interested in these variables at multiple scales, from regional landscapes to individual neighborhoods and ownership parcels. Effective monitoring thus requires periodic development of high-resolution maps that are accurate at divergent scales, but until recently only moderate- or coarse-scale source datasets were available to map impervious surfaces across large geographic extents. Now, however, high-resolution source datasets are commonly available and affordable, and improved mapping techniques permit analysis of multiple data sources simultaneously. This report describes high-resolution mapping of impervious surfaces in the Lake Champlain Basin, covering portions of Vermont and New York (suitable imagery for Quebec could not be obtained). Using 1-meter aerial imagery and various thematic vector GIS datasets, two impervious classes were mapped: 1) Roads\Railroads; and 2) Other Impervious Surfaces. The latter category included parking lots, driveways, sidewalks, buildings, and quarries. As originally proposed, parking lots were to be assigned to its own class, but preliminary testing indicated that these features could not be reliably distinguished from driveways and buildings in the available source imagery. Natural impervious surfaces such as rock outcroppings and mountain summits were not mapped because they are permanent landscape features whose contribution to stormwater runoff is generally impractical to mitigate. The final map was considered current as of summer 2011 ground conditions.

METHODS

The primary data source used to derive a new impervious surfaces layer was 1-meter resolution (nominal scale 1:40,000) National Agricultural Imagery Program (NAIP) data acquired on multiple dates in 2011. The NAIP datasets covering the study area were 4-band aerial imagery, meaning that they contained a Near Infrared (NIR) band in addition to the visible bands (Red, Green, Blue). The NIR band improved the utility of the imagery, permitting use of vegetation indices that rely on non-visible wavelengths (e.g., Normalized Difference Vegetation Index). All of the Vermont NAIP imagery was acquired during the 2011 growing season, capturing leaf-on conditions. In contrast, however, the New York NAIP imagery was acquired across a wider interval of 2011 dates, including at least one date early in the growing season before trees had leafed out completely. As described below, this variability in the NAIP imagery necessitated development of different feature extraction criteria. Ancillary data sources included various thematic vector GIS datasets, including the Lake Champlain Basin watershed boundary (2009), lakes (2010), stream centerlines (2010), road centerlines (2012), railroad centerlines (Vermont only, 2003), driveways (Vermont only, 2011), and building points (Vermont only, 2011).

The first step in the mapping workflow included automated feature extraction using object-based image analysis techniques (OBIA). In this project, the OBIA software program eCognition 8.7 (Trimble) was used for all automated mapping. OBIA systems work by grouping pixels into objects based on their spectral and spatial properties. Another hallmark of OBIA is its ability to simultaneously incorporate other source imagery or secondary datasets, including boundaries imposed by existing vector datasets. In eCognition, a rule-based expert system was designed to effectively mimic the process of manual image analysis by incorporating the elements of image interpretation (color/tone, texture, pattern, location, size, and shape) into the classification process. A series of morphological procedures were then used to ensure that the end product was both accurate and cartographically coherent.

For example, Figure 1 shows a representative area on the New York side of the Basin, an area where the available NAIP imagery was acquired early in the 2011 growing season. Before an image can be classified, it first must be segmented into objects that represent meaningful objects on the ground, and in this case a Multiresolution Segmentation was applied to the

FIGURE 1. NAIP IMAGERY FOR A REPRESENTATIVE AREA IN THE NEW YORK PORTION OF THE LAKE CHAMPLAIN BASIN.

FIGURE 2. NAIP IMAGERY SEGEMENTED INTO HIGH-RESOLUTION OBJECTS REPRESENTING INDIVIDUAL LANDSCAPE FEATURES.

NAIP imagery to create small objects encompassing fine-scale impervious surfaces (Figure 2). The segmented image was then classified using the spectral and spatial properties of the objects, creating a set of preliminary land-cover classes for landscape features (Figure 3). Although the focus of this mapping effort was impervious surfaces, trees, grasses and shrubs, water, and bare soil were also mapped to facilitate contextual evaluation of preliminary classes in subsequent error checking routines (e.g., impervious surfaces are unlikely to occur surrounded by vegetation and isolated from roads). Where available, thematic vector datasets were also used to evaluate landscape context; for example, road centerlines were used to develop road density maps that helped identify areas where impervious surfaces are most likely to occur (Figure 4). After applying error-checking routines and morphological steps intended to improve the representation of

individual objects, a draft map was created containing the final impervious classes of interest, Roads\Railroads and Other Impervious (Figure 5).

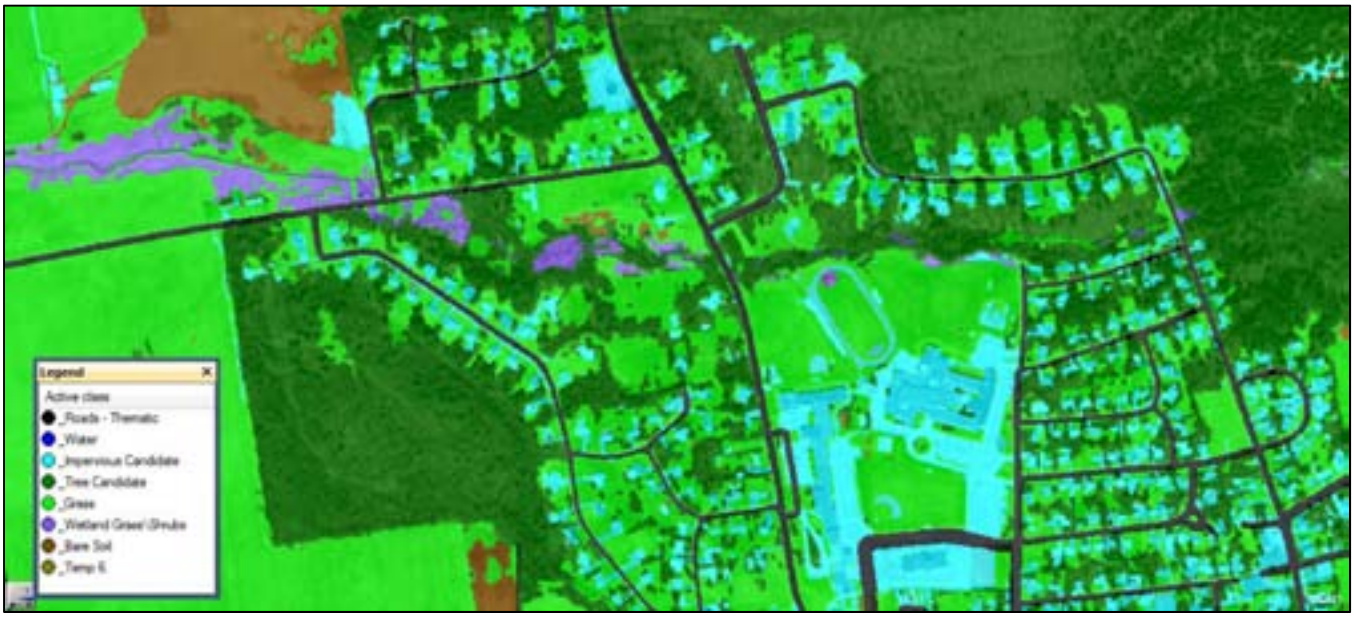

FIGURE 3. PRELIMINARY CLASSIFICATION OF IMPERVIOUS SURFACES AND OTHER LANDSCAPE FEATURES.

FIGURE 4. ROAD DENSITY MAP USED IN CONTEXT-BASED ERROR CHECKING; DEVELOPED FROM THEMATIC ROAD CENTERLINE DATA.

The Vermont and New York sides of the Lake Champlain Basin were processed separately with customized OBIA rule sets. This step was necessitated by several factors: 1) spectral differences between the NAIP datasets for the two states, acquired on different dates in 2011; and 2) the availability of ancillary vector datasets. The separate Vermont and New York rule sets were thus tailored to the specific spectral conditions apparent in the source NAIP datasets. In particular, different NDVI thresholds were required when discriminating impervious surfaces from grass, shrubs, and trees. Furthermore, the New York imagery was sufficiently variable, with a combination of leaf-on and leaf-off conditions, to warrant separate sub-

routines accommodating divergent spectral properties in different parts of the Basin. The available vector datasets also varied by state; for Vermont, road centerlines, railroad centerlines, hydrology, approximate building locations, and approximate driveway locations were incorporated into automated feature extraction, but only road centerlines and hydrology were available for mapping on the New York side of the Basin. The vector datasets provided important contextual information that facilitated classification of impervious surfaces, including the density of developed features (e.g., roads, buildings) and the distance to both developed and natural features (e.g., roads, hydrology). With more vector datasets available for Vermont, more contextual information was thus available for its side of the Basin, improving initial classification of some impervious features. Note, however, that the rule sets for both sides of the Basin largely featured the same flow and logic, modified as necessary to accommodate state-specific spectral properties and vector-data availability.

FIGURE 5. FINAL SET OF IMPERVIOUS SURFACES CLASSES AS MAPPED BY AUTOMATED FEATURE EXTRACTION.

It is important to note that the mapping protocol described above was a "top-down" approach: impervious surfaces were mapped when they were visible in the available aerial imagery. In practical terms, impervious surfaces were generally not captured by the mapping process when they were substantially obscured by tree canopy. Although this modeling limitation means that the total area of extant impervious surfaces would be underestimated in subsequent analyses, it also provides a better estimate of surfaces whose environmental effects are not mitigated by overhanging vegetation. Indeed, one of the well-known benefits of trees is that they absorb or slow rainwater before it hits the ground, so the top-down approach is a reasonable and effective method for mapping the impervious surfaces that most affect stormwater runoff volume.

The second step in the mapping protocol was manual review and correction of obvious errors in the initial classification as produced by automated feature extraction. Independently, the draft impervious map for each side of the Basin was extensively reviewed for accuracy, coherence, and aesthetic quality, and errors of omission and commission were fixed as necessary. The scale of review was approximately 1:3,500, and all corrections were performed in ArcGIS 10.1. More than 1,030 hours of staff time were devoted to manual correction of the draft classification for the Vermont side of the Basin, with about 550 hours for New York. Less time was required for the New York portion, despite fewer vector datasets available for this area, because it encompassed a higher proportion of rural areas, including substantial sections of the Adirondack Park. In particular, these corrections eliminated errors of commission in semi-rural areas where the bare soil of agricultural fields was sometimes confused with impervious surfaces during automated feature extraction. Although such features are very different functionally, spectrally they can be very similar, and context-based error checking is less efficient

in semi-rural areas where agricultural fields are interspersed with developed features. These corrections also improved the overall representation of the map, eliminating obvious inconsistencies that can erode end-user confidence in the final product even when classification accuracy is very high. The two state datasets were then compiled into a single, Basin-wide layer.

In the third step, a stratified sampling approach was used to calculate the overall, producer's and user's accuracies for the combined New York and Vermont Basin area, the New York portion of the Basin, and the Vermont portion of the Basin. For each of the two states, 1,000 points were randomly placed on locations assigned to one of the two impervious classes and another 1,000 points were randomly placed on locations not classified as impervious. This created 4,000 total accuracy assessment points, 2,000 for New York and 2,000 for Vermont. A stratified sampling approach was used instead of a purely random approach because the random method would have underestimated errors in the impervious classes due to the rural nature of the Basin. Each point was independently assigned to the appropriate class by an experienced image analyst using only the NAIP data as the reference.

To illustrate patterns in the Basin-wide distribution of impervious surfaces, the final layer was summarized according to HUC 12 (Hydrologic Unit Codes, 12 Digits) watershed boundaries developed by the USDA Natural Resources Conservation Service. These results were mapped by HUC 12 subunits and summarized in tables.

RESULTS

The final layer provided a comprehensive mapping of impervious surfaces for the New York and Vermont portions of the Lake Champlain Basin, as delineated from 1-meter resolution aerial imagery (Figure 6). The two impervious surface types, Roads\Railroads and Other Impervious, were mapped consistently and accurately over a broad range of landscapes. And crucially, the final product was both statistically defensible and aesthetically coherent. The minimum mapping unit was approximately 4 m^2 (0.000988 acres).

FIGURE 6. FINAL IMPERVIOUS SURFACES LAYER FOR AN AREA NEAR PERU, NY, ON LEFT, DISPLAYED RELATIVE TO THE SOURCE NAIP DATA, ON RIGHT; BOTH IMAGES DISPLAYED AT A SCALE OF 1:10,000.

The accuracy assessments indicated an overall classification accuracy of 99% for the combined area of Vermont and New York (Table 1), 99% for New York alone (Table 2), and 99% for Vermont alone (Table 3). User's accuracies for Roads\Railroads, Other Impervious, and Not Impervious for the combined New York\Vermont area were 98%, 98%, and 100%, respectively. Individual accuracy assessments for both New York (Table 2) and Vermont (Table 3) similarly showed remarkable consistency in the user's, producer's and overall accuracies. These estimates thus indicated a very high classification accuracy for the Impervious classes versus the Not Impervious class (i.e., all other landscape features), for both the Lake Champlain Basin as a whole in addition to the Vermont and New York sections. The map is also likely to be accurate at finer units of analysis (e.g. subwatersheds, towns, parcels), but conducting multiple accuracy assessments was beyond the scope of this project. A qualitative assessment of the final impervious surfaces map identified several issues worth noting: 1) narrowly-configured surfaces such as sidewalks were occasionally missed or only partially represented; 2) road edges, particularly in areas with overhanging tree canopy, were similarly missed or only partially represented on occasion; and 3) small patches of grass were sometimes misclassified as impervious in dense residential areas.

TABLE 1. ERROR MATRIX FOR THE COMBINED NEW YORK AND VERMONT PORTIONS OF THE BASIN DEVELOPED FROM A STRATEFIED SAMPLING ROUTINE OF 4000 POINTS.

		Reference Data				
		Roads/Railroads	**Other Impervious**	**Not Impervious**	**Total**	
Map Data	**Roads/Railroads**	**740**	11	4	**755**	**98%**
	Other Impervious	22	**1214**	8	**1244**	**98%**

	Not Impervious	3	7	1991	2001	100%
	Total	765	1232	2003	4000	
		97%	99%	99%		99%

TABLE 2. ERROR MATRIX FOR THE NEW YORK PORTION OF THE BASIN DEVELOPED FROM A STRATEFIED SAMPLING ROUTINE OF 2000 POINTS.

		Reference Data				
		Roads/Railroads	Other Impervious	Not Impervious	Total	
Map Data	Roads/Railroads	**363**	7	2	372	98%
	Other Impervious	8	**617**	4	629	98%
	Not Impervious	0	5	**994**	999	99%
	Total	371	629	1000	2000	
		98%	98%	99%		99%

TABLE 3. ERROR MATRIX FOR THE VERMONT PORTION OF THE BASIN DEVELOPED FROM A STRATEFIED SAMPLING ROUTINE OF 2000 POINTS.

		Reference Data				
		Roads/Railroads	Other Impervious	Not Impervious	Total	
Map Data	Roads/Railroads	**377**	4	2	383	98%
	Other Impervious	14	**597**	4	615	97%
	Not Impervious	3	2	**997**	1002	100%
	Total	394	603	1003	2000	
		96%	99%	99%		99%

Analysis of HUC 12 watersheds showed that the highest proportions of impervious surfaces were observed along the Lake Champlain shoreline, particularly in watersheds encompassing the urban areas of Burlington and St. Albans in Vermont and

Plattsburgh in New York (Figure 7 and Appendix A). For example, impervious surfaces in a small watershed draining the Burlington waterfront (Lakeshore-Shelburne Bay to Colchester Point) constituted 33% of the watershed's land area, the highest proportion observed in the Basin. Inland watersheds on both sides of the Basin generally contained much smaller proportions of impervious landscape features, usually less than 2%. Note that similar Basin-wide summaries can be performed for any geographic unit of interest, including ones as fine as U.S. Census blocks or ownership parcels.

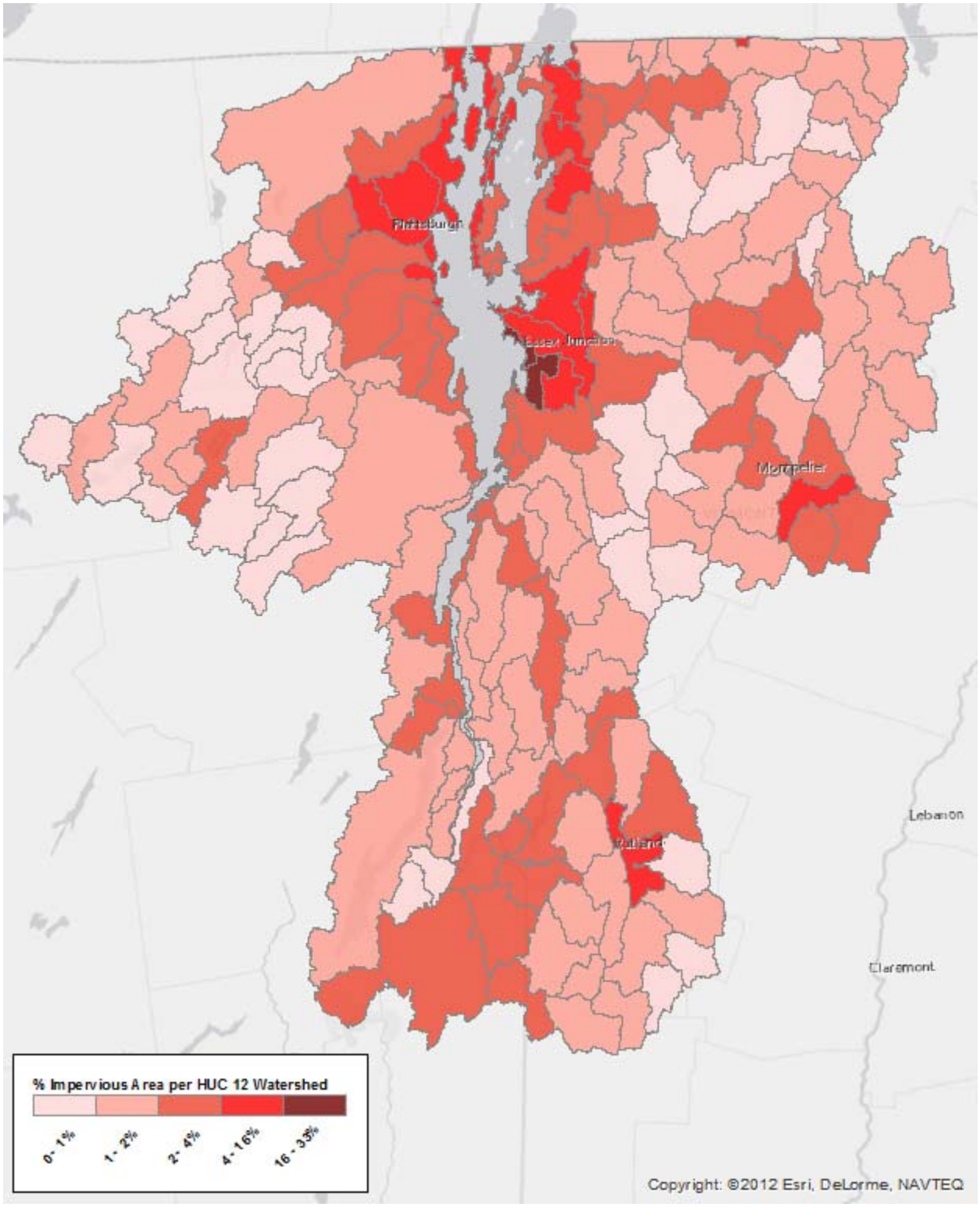

FIGURE 7. PERCENT AREA OF IMPERVIOUS SURFACES BY HUC 12 WATERSHED, LAKE CHAMPLAIN BASIN, VERMONT AND NEW YORK.

CONCLUSIONS

The combination of automated feature extraction and manual corrections produced a highly accurate and detailed representation of anthropogenic impervious features for the Lake Champlain Basin in a cost-effective manner. This approach accommodated spectral variability in the available NAIP imagery as well as the differential availability of ancillary thematic datasets, establishing a repeatable method for evaluating impervious surfaces in the Basin. Based on 1-meter source data, the new impervious map can be used at scales as fine as individual property ownerships; it is thus pertinent to a wide variety of studies examining the distribution of impervious surfaces and their effect on municipal infrastructure, water quality, and ecosystem function. It can also serve as a baseline dataset for monitoring future changes in the Basin-wide pattern of impervious surfaces as the region adapts to evolving land uses, improved green-infrastructure planning, and global climate change. Subsequent updates to the impervious surfaces map would benefit from the availability of LiDAR, which could facilitate discrimination of buildings from ground-level surfaces and pavement from vegetation, especially in areas that are shaded by trees and buildings in multispectral imagery.

APPENDIX A – SUMMARY OF IMPERVIOUS SURFACES BY HUC 12 WATERSHED

HUC12 Watershed	HUC12	Watershed Area (acres)	Other Impervious (acres)	Roads/ Railroads (acres)	Total Impervious (acres)	Other Impervious (% Area)*	Roads/ Railroads (% Area)	Total Impervious (% Area)
New York Watersheds								
Alder Brook	041504060302	15,780	21.4	80.6	102.0	0.1	0.5	0.6
Ausable River	041504040302	31,096	380.2	588.5	968.8	1.2	1.9	3.1
Behan Brook-Saranac River	041504060502	27,360	232.7	338.5	571.1	0.9	1.2	2.1
Black Brook	041504040205	20,122	58.8	134.7	193.6	0.3	0.7	1
Chubb River	041504040201	26,480	480.5	258.1	738.7	1.8	1	2.8
Cold Brook	041504060103	12,593	0.4	0.0	0.4	0	0	0
Dead Creek	020100081601	27,547	749.4	628.7	1,378.1	2.7	2.3	5
Fish Creek Ponds	041504060101	21,764	17.0	77.9	94.9	0.1	0.4	0.4
Great Chazy River-	020100081500	188,889	1,397.0	1,694.8	3,091.8	0.7	0.9	1.6
Headwaters East Branch Ausable River	041504040101	27,084	16.6	23.9	40.5	0.1	0.1	0.1
Johns Brook	041504040102	12,563	6.4	12.4	18.8	0.1	0.1	0.1
Kelly Brook-Saranac River	041504060503	18,676	269.9	233.5	503.4	1.4	1.3	2.7
Lake George	020100080201	149,254	1,343.3	1,054.3	2,397.7	0.9	0.7	1.6
Lakeshore-McKenzie Brook to Port Henry Boat Ramp	020100080305	19,245	233.1	242.9	476.0	1.2	1.3	2.5
Lakeshore-Mill Brook to Ticonderoga Creek on NY side	020100080105	22,734	76.8	307.6	384.4	0.3	1.4	1.7
Lakeshore-Port Henry Boat Ramp to Split Rock Point on NY side	020100080602	44,716	406.1	435.4	841.5	0.9	1	1.9
Lakeshore-Split Rock Point to Ausable River	020100081604	31,615	300.9	383.9	684.8	1	1.2	2.2
Lakeshore-Ticonderoga Creek to Putnam Creek	020100080304	11,981	223.3	194.5	417.8	1.9	1.6	3.5
Little Ausable River	020100081300	47,625	485.8	553.4	1,039.2	1	1.2	2.2
Little Chazy River	020100081602	34,004	339.7	399.7	739.4	1	1.2	2.2
Lower East Branch Ausable	041504040105	24,261	159.7	201.9	361.6	0.7	0.8	1.5

River								
Lower North Branch Saranac River	041504060304	18,734	67.6	152.8	220.4	0.4	0.8	1.2
Lower Saranac Lake-Saranac River	041504060104	31,655	132.6	155.5	288.2	0.4	0.5	0.9
Lower West Branch Ausable River	041504040206	20,805	66.6	131.7	198.3	0.3	0.6	1
Middle East Branch Ausable River	041504040104	37,785	107.6	210.9	318.5	0.3	0.6	0.8
Middle North Branch Saranac River	041504060303	28,727	61.4	98.3	159.7	0.2	0.3	0.6
Middle West Branch Ausable River	041504040203	35,456	182.1	230.4	412.5	0.5	0.6	1.2
Mill Brook	020100080104	7,401	27.1	74.9	102.0	0.4	1	1.4
Moose Creek-Saranac River	041504060203	30,056	252.4	194.7	447.1	0.8	0.6	1.5
Mount Hope Brook	020100080101	15,930	10.9	45.9	56.8	0.1	0.3	0.4
Outlet Taylor Pond	041504040204	11,798	16.8	61.6	78.4	0.1	0.5	0.7
Palmer Brook-Ausable River	041504040301	20,147	119.7	159.9	279.6	0.6	0.8	1.4
Putnam Creek	020100080302	39,552	166.0	253.8	419.8	0.4	0.6	1.1
Ray Brook	041504060201	10,091	90.4	61.3	151.7	0.9	0.6	1.5
Salmon River	020100081400	43,368	435.6	637.8	1,073.4	1	1.5	2.5
Saranac River	041504060504	24,076	1,480.6	876.7	2,357.3	6.1	3.6	9.8
Silver Lake-Saranac River	041504060402	15,339	35.2	76.5	111.7	0.2	0.5	0.7
South Bay	020100080102	13,181	37.7	76.4	114.1	0.3	0.6	0.9
Sumner Brook	041504060202	35,520	233.8	300.3	534.1	0.7	0.8	1.5
Ticonderoga Creek	020100080202	17,804	287.8	210.2	498.0	1.6	1.2	2.8
True Brook	041504060501	14,330	40.4	91.7	132.1	0.3	0.6	0.9
undetermined	020100010100	127,682	2,923.1	1,784.4	4,707.5	2.3	1.4	3.7
undetermined	020100080700	176,613	732.6	1,374.3	2,106.9	0.4	0.8	1.2
Union Falls Pond-Saranac River	041504060401	42,181	71.0	187.9	258.9	0.2	0.4	0.6
Upper West Branch Ausable River	041504040202	36,273	133.7	109.0	242.7	0.4	0.3	0.7

Upper East Branch Ausable River	041504040103	25,044	109.9	150.9	260.8	0.4	0.6	1
Upper North Branch Saranac River	041504060301	18,285	70.3	50.7	121.0	0.4	0.3	0.7
Upper Saranac Lake	041504060102	26,792	132.6	149.4	282.1	0.5	0.6	1.1
Vermont Watersheds								
Baldwin Creek	020100020202	11,602	55.6	55.9	111.5	0.5	0.5	1
Big Branch	020100020102	16,708	2.0	29.7	31.6	0	0.2	0.2
Black Creek-Fairfield River to mouth	020100070603	25,817	186.4	193.2	379.6	0.7	0.7	1.5
Black Creek-headwaters to Fairfield River	020100070601	35,623	151.2	221.9	373.2	0.4	0.6	1
Browns River-headwaters to Lee River	020100050201	24,631	295.4	190.5	485.9	1.2	0.8	2
Browns River-Lee River to mouth	020100050202	34,444	433.2	268.3	701.4	1.3	0.8	2
Castleton River-headwaters to Pond Hill Brook	020100010303	30,608	272.5	279.7	552.3	0.9	0.9	1.8
Castleton River-Pond Hill Brook to mouth	020100010304	32,917	514.0	370.7	884.7	1.6	1.1	2.7
Clarendon River	020100020108	30,302	258.1	201.9	460.0	0.9	0.7	1.5
Cold River	020100020106	23,483	102.2	87.2	189.4	0.4	0.4	0.8
Dead Creek	020100020501	38,380	337.9	276.2	614.1	0.9	0.7	1.6
Dog River-headwaters to Union Brook	020100030401	34,234	281.2	326.9	608.1	0.8	1	1.8
Dog River-Union Brook to mouth	020100030402	25,281	226.0	219.3	445.3	0.9	0.9	1.8
East Creek	020100020107	39,242	862.5	380.4	1,242.9	2.2	1	3.2
East Creek	020100080301	20,526	143.1	151.9	295.0	0.7	0.7	1.4
Fairfield Pond-Dead Creek	020100070602	15,408	111.4	101.5	212.9	0.7	0.7	1.4
Flower Brook	020100010202	12,079	87.0	74.6	161.6	0.7	0.6	1.3
Furnace Brook	020100020301	28,349	238.5	166.2	404.7	0.8	0.6	1.4
Gihon River	020100050301	41,450	388.5	286.2	674.7	0.9	0.7	1.6
Green River	020100050105	12,365	37.5	22.8	60.4	0.3	0.2	0.5
Hubbardton River	020100010306	28,392	165.4	179.0	344.4	0.6	0.6	1.2

Hungerford Brook	020100070702	12,495	188.0	141.0	329.0	1.5	1.1	2.6
Huntington River	020100030701	42,578	210.5	189.5	400.0	0.5	0.4	0.9
Jail Branch	020100030102	30,794	461.2	305.5	766.6	1.5	1	2.5
Jewett Brook	020100081202	14,814	735.7	291.6	1,027.2	5	2	6.9
Kingsbury Branch	020100030203	33,945	216.4	298.4	514.8	0.6	0.9	1.5
Lake Carmi	020100081001	6,990	52.4	52.9	105.4	0.8	0.8	1.5
Lakeshore-Crane Point to Little Otter Creek	020100080601	7,118	113.1	97.7	210.9	1.6	1.4	3
Lakeshore-East Creek to Crane Point	020100080303	21,157	195.6	143.9	339.5	0.9	0.7	1.6
Lakeshore-Eastern Shore of Shelburne Bay	020100080802	10,021	1,182.0	528.1	1,710.0	11.8	5.3	17.1
Lakeshore-Goose Bay to Riviere Aux Brochets	020100081102	2,361	41.2	63.0	104.2	1.7	2.7	4.4
Lakeshore-Jewett Brook to Mississquoi Bay	020100081205	9,803	188.3	110.2	298.5	1.9	1.1	3
Lakeshore-Lamoille River to Jewett Brook	020100081204	17,844	304.5	246.8	551.3	1.7	1.4	3.1
Lakeshore-Malletts Bay-mainland portion	020100080901	33,535	1,149.3	645.4	1,794.6	3.4	1.9	5.4
Lakeshore-Malletts Bay-South Hero Island portion	020100080902	1,846	39.0	20.5	59.6	2.1	1.1	3.2
Lakeshore-Mississquoi Bay portion of Hog Island	020100081104	3,522	26.6	36.4	63.0	0.8	1	1.8
Lakeshore-Northeast Arm portion of Alburg Peninsula	020100081208	3,607	75.1	60.0	135.1	2.1	1.7	3.7
Lakeshore-Northeast Arm portion of North Hero Island	020100081207	4,216	104.1	70.6	174.7	2.5	1.7	4.1
Lakeshore-Northeast Arm portion of South Hero Island	020100081206	12,176	293.6	179.8	473.4	2.4	1.5	3.9
Lakeshore-Riviere aux Brochets to Northeast Arm	020100081103	1,722	21.0	23.9	44.9	1.2	1.4	2.6
Lakeshore-Shelburne Bay to Colchester Point	020100081605	3,931	977.8	317.8	1,295.6	24.9	8.1	33
Lakeshore-South Bay to	020100080106	14,123	51.3	69.0	120.3	0.4	0.5	0.9

Ticonderoga Creek on VT side								
Lakeshore-Thompsons Point to Shelburne Point	020100081603	8,928	199.4	123.8	323.2	2.2	1.4	3.6
Lakeshore-Town Farm Bay	020100080603	5,542	107.2	79.0	186.2	1.9	1.4	3.4
Lakeshore-Western Shore of Shelburne Bay	020100080803	525	21.3	8.6	29.9	4.1	1.6	5.7
Lamoille River-Bailey Brook to Hardwick Lake Dam	020100050102	37,354	321.0	322.7	643.7	0.9	0.9	1.7
Lamoille River-Browns River to mouth	020100050306	33,393	614.9	490.5	1,105.4	1.8	1.5	3.3
Lamoille River-Gihon River to Seymour River	020100050303	36,044	308.2	203.7	511.9	0.9	0.6	1.4
Lamoille River-Green River to Kenfield Brook	020100050106	31,713	623.2	384.4	1,007.6	2	1.2	3.2
Lamoille River-Hardwick Dam to Green River	020100050104	27,345	185.2	177.1	362.3	0.7	0.6	1.3
Lamoille River-headwaters to Bailey Brook	020100050101	37,681	199.0	246.5	445.6	0.5	0.7	1.2
Lamoille River-Kenfield Brook to Gihon River	020100050107	26,927	255.4	206.8	462.1	0.9	0.8	1.7
Lamoille River-Seymour River to Stones Brook	020100050304	32,802	258.9	235.3	494.2	0.8	0.7	1.5
Lamoille River-Stones Brook to Browns River	020100050305	21,717	298.9	186.2	485.1	1.4	0.9	2.2
LaPlatte River	020100080801	33,906	713.7	427.1	1,140.8	2.1	1.3	3.4
Leicester River	020100020305	24,076	139.0	116.3	255.3	0.6	0.5	1.1
Lewis Creek-headwaters to Pond Brook	020100080501	24,808	159.7	124.1	283.8	0.6	0.5	1.1
Lewis Creek-Pond Brook to mouth	020100080502	26,304	287.0	199.1	486.2	1.1	0.8	1.8
Little Otter Creek-headwaters to Mud Creek	020100080401	28,926	337.2	228.0	565.2	1.2	0.8	2
Little Otter Creek-Mud Creek to mouth	020100080402	17,461	189.3	159.6	348.9	1.1	0.9	2
Little River-Gold Brook to mouth	020100030603	37,029	319.7	227.3	547.0	0.9	0.6	1.5

Little River-headwaters to Gold Brook	020100030602	34,678	581.6	290.6	872.3	1.7	0.8	2.5
Lower Lemon Fair River	020100020402	30,062	256.0	216.8	472.8	0.9	0.7	1.6
Mad River-Clay Brook to High Bridge Brook	020100030502	24,371	317.9	172.3	490.3	1.3	0.7	2
Mad River-headwaters to Clay Brook	020100030501	25,382	119.6	127.2	246.8	0.5	0.5	1
Mad River-High Bridge Brook to mouth	020100030504	31,373	278.1	228.0	506.1	0.9	0.7	1.6
Mettawee River-headwaters to Flower Brook	020100010201	28,054	190.8	116.3	307.0	0.7	0.4	1.1
Middlebury River	020100020306	40,213	239.3	223.3	462.5	0.6	0.6	1.2
Mill Creek-East Wallingford to mouth	020100020105	28,757	224.5	280.1	504.6	0.8	1	1.8
Mill Creek-headwaters to East Wallingford	020100020104	16,851	82.1	85.9	168.0	0.5	0.5	1
Mill River	020100081201	14,783	373.6	233.3	606.9	2.5	1.6	4.1
Mississquoi mainstem-Trout River to Black Creek	020100070502	31,578	372.0	275.7	647.7	1.2	0.9	2.1
Mississquoi River mainstem-Canada to Trout River	020100070304	31,449	228.4	236.9	465.3	0.7	0.8	1.5
Mississquoi River-Beetle Brook to Mud Creek	020100070105	31,945	300.6	265.5	566.1	0.9	0.8	1.8
Mississquoi River-Black Creek to Hungerford Brook	020100070701	15,994	263.1	169.0	432.1	1.6	1.1	2.7
Mississquoi River-headwaters to McAllister Pond Brook	020100070101	20,804	105.9	118.6	224.5	0.5	0.6	1.1
Mississquoi River-Hungerford Brook to mouth	020100070703	16,147	437.7	310.1	747.8	2.7	1.9	4.6
Mississquoi River-McAllister Pond Brook to Mineral Spring Brook	020100070102	14,497	66.9	79.5	146.3	0.5	0.5	1
Mississquoi River-Mineral Spring Brook to Beetle Brook	020100070103	21,661	132.9	112.0	244.9	0.6	0.5	1.1

Mud Creek	020100070104	22,988	215.2	192.4	407.6	0.9	0.8	1.8
Mud Creek	020100081203	5,580	54.4	43.1	97.5	1	0.8	1.7
Muddy Brook	020100030703	13,611	710.6	262.3	973.0	5.2	1.9	7.1
Neshobe River	020100020303	12,981	168.4	105.4	273.8	1.3	0.8	2.1
New Haven River-Baldwin Creek to mouth	020100020203	31,230	361.5	195.5	557.0	1.2	0.6	1.8
New Haven River-headwaters to Baldwin Creek	020100020201	31,631	107.5	119.2	226.7	0.3	0.4	0.7
North Branch Lamoille River	020100050302	38,959	113.4	130.3	243.8	0.3	0.3	0.6
North Branch Winooski River-headwaters to Minister Brook	020100030301	21,480	41.3	87.6	128.9	0.2	0.4	0.6
North Branch Winooski River-Minister Brook to mouth	020100030302	28,308	255.4	218.5	474.0	0.9	0.8	1.7
Otter Creek mainstem-Lemon Fair River to mouth	020100020502	21,838	387.7	214.7	602.4	1.8	1	2.8
Otter Creek-Big Branch to Mill River	020100020103	32,296	253.1	252.7	505.8	0.8	0.8	1.6
Otter Creek-Furnace Brook to Neshobe River	020100020302	22,361	263.6	204.2	467.8	1.2	0.9	2.1
Otter Creek-headwaters to Big Branch	020100020101	21,727	121.6	149.8	271.5	0.6	0.7	1.2
Otter Creek-Leicester River to Lemon Fair River	020100020308	33,049	686.0	355.7	1,041.7	2.1	1.1	3.2
Otter Creek-Mill River to Furnace Brook	020100020109	24,677	1,098.9	539.3	1,638.2	4.5	2.2	6.6
Otter Creek-Neshobe River to Leicester River	020100020304	15,649	145.9	130.9	276.8	0.9	0.8	1.8
Pike River	020100081002	12,425	108.1	86.6	194.7	0.9	0.7	1.6
Poultney River-headwaters to Finel Hollow Brook	020100010301	23,846	146.2	146.4	292.6	0.6	0.6	1.2
Riviere Aux Brochets-Riviere Aux Brochets Nord to Ruiss Coslett	020100081005	5,676	47.9	41.3	89.3	0.8	0.7	1.6
Riviere Mississquoi-Riviere	020100070302	3,829	12.8	9.5	22.2	0.3	0.2	0.6

Mississquoi Nord to Lucas Brook								
Riviere Sutton	020100070303	1,095	33.7	17.0	50.7	3.1	1.6	4.6
Rock River	020100081101	22,873	207.5	194.7	402.2	0.9	0.9	1.8
Shepard Brook	020100030503	11,031	52.0	36.4	88.4	0.5	0.3	0.8
Stevens Branch-headwaters to Jail Branch	020100030101	22,277	519.8	339.2	859.0	2.3	1.5	3.9
Stevens Branch-Jail Branch to mouth	020100030103	20,664	858.6	583.2	1,441.8	4.2	2.8	7
Trout River-headwaters to West Hill Brook	020100070401	36,554	164.8	158.5	323.3	0.5	0.4	0.9
Trout River-West Hill Brook to mouth	020100070402	16,938	91.8	95.0	186.8	0.5	0.6	1.1
Tyler Branch	020100070501	37,100	217.0	229.5	446.5	0.6	0.6	1.2
Upper Lemon Fair River	020100020401	27,968	208.7	180.8	389.5	0.7	0.6	1.4
Wild Branch	020100050103	25,230	122.4	171.4	293.8	0.5	0.7	1.2
Winooski River mainstem-North Branch to Mad River	020100030403	20,989	226.5	236.4	463.0	1.1	1.1	2.2
Winooski River-Alder Brook to mouth	020100030704	31,511	2,570.8	1,101.7	3,672.5	8.2	3.5	11.7
Winooski River-headwaters to Mollys Brook	020100030201	31,330	212.6	234.9	447.5	0.7	0.7	1.4
Winooski River-Huntington River to Alder Brook	020100030702	37,537	494.6	438.3	932.9	1.3	1.2	2.5
Winooski River-Kingsbury Branch to North Branch	020100030204	22,222	466.4	320.3	786.6	2.1	1.4	3.5
Winooski River-Little River to Huntington River	020100030604	33,020	111.3	214.4	325.7	0.3	0.6	1
Winooski River-Mad River to Little River	020100030601	25,747	441.5	308.3	749.8	1.7	1.2	2.9
Winooski River-Mollys Brook to Kingsbury Branch	020100030202	41,101	221.3	274.8	496.1	0.5	0.7	1.2
Watersheds in Both New York and Vermont								
Indian River	020100010204	23,702	315.8	219.9	535.7	1.3	0.9	2.3
Lakeshore-Ausable River to Isle La Motte	020100081606	43,885	1,225.7	1,188.9	2,414.6	2.8	2.7	5.5

Lakeshore-Little Chazy River and Alburg to Richelieu River	020100081607	14,778	394.9	300.4	695.3	2.7	2	4.7
Mettawee River-Flower Brook to Indian River	020100010203	33,474	380.1	263.3	643.4	1.1	0.8	1.9
Mettawee River-Indian River to mouth	020100010205	37,578	478.4	444.1	922.5	1.3	1.2	2.5
Poultney River-Castleton River to Hubbardton River	020100010305	9,979	106.1	108.5	214.6	1.1	1.1	2.2
Poultney River-Finel Hollow Brook to Castleton River	020100010302	24,460	338.4	232.5	570.8	1.4	1	2.3
Poultney River-Hubbardton River to mouth	020100010307	27,287	311.9	322.2	634.0	1.1	1.2	2.3

*Percent Area of HUC 12 Watershed

APPENDIX B – METADATA FOR FINAL IMPERVIOUS SURFACES LAYER (IMPERVIOUS_2011_LAKECHAMPLAINBASIN_VTNY)


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Basin, Vermont and New York.  Two impervious classes were mapped: (1)
Roads\Railroads; and (2) Other Impervious.  The latter category included
parking lots, driveways, sidewalks, and buildings.  Pertinent imagery could
```

not be obtained for the Quebec portion of the Lake Champlain Basin, which was thus excluded from the final product.

The primary source used to derive this impervious surfaces layer was 1-meter resolution National Agricultural Imagery Program (NAIP) data acquired in 2011. The NAIP datasets covering the study area were 4-band aerial imagery, meaning that they contained a Near Infrared band in addition to the visible bands (i.e., Red, Green, Blue). This band improved the utility of the imagery, permitting use of vegetation indices that rely on the Near Infrared and Red bands (e.g., Normalized Difference Vegetation Index). Ancillary data sources included various thematic vector GIS datasets, including the Lake Champlain Basin watershed boundary, lakes, stream centerlines, road centerlines, railroad centerlines, and building points. This impervious surfaces dataset is considered current as of 2011.

Object-based image analysis techniques (OBIA) were used to extract impervious surfaces using the best available remotely-sensed and vector GIS datasets. OBIA systems work by grouping pixels into meaningful objects based on their spectral and spatial properties while taking into account boundaries imposed by existing vector datasets. Within the OBIA environment, a rule-based expert system was designed to effectively mimic the process of manual image analysis by incorporating the elements of image interpretation (color/tone, texture, pattern, location, size, and shape) into the classification process. A series of morphological procedures were used to ensure that the end product was both accurate and cartographically coherent.

It is important to note that the mapping protocol described above was a "top-down" approach: impervious surfaces were mapped when they were visible in the available aerial imagery. In practical terms, impervious surfaces were not captured by the mapping process when they were obscured by tree canopy. Although this modeling limitation means that the total area of extant impervious surfaces would be underestimated in subsequent analyses, it also provides a better estimate of surfaces whose environmental effects are not mitigated by overhanging vegetation. Indeed, one of the well-known benefits of trees is that they absorb or slow rainwater before it hits the ground, so the top-down approach is a reasonable and effective method for mapping the impervious surfaces that most affect stormwater runoff volume.

The draft impervious maps produced by automated feature extraction were extensively reviewed for accuracy, coherence, and aesthetic quality, and errors of omission and commission were fixed as necessary. Accuracy assessments were then conducted separately for the two sides of the Basin, indicating an overall accuracy of 99% for Vermont and 99% for New York. The overall accuracy for the combined area was also 99%. The user's accuracies for Roads/Railroads, Other Impervious, and Not Impervious were 98%, 98%, and 100% respectively.</abstract>
<purpose>This dataset provides a high-resolution estimate of the distribution and area of impervious surfaces in the Lake Champlain Basin, Vermont and New York. At the time of its creation, this dataset represented the most current, detailed, and accurate estimate of impervious surfaces in the Vermont and New York portions of the Lake Champlain Basin.</purpose>

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The Vermont and New York sides of the Lake Champlain Basin were processed
separately with customized OBIA rule sets. This step was necessitated by
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two states, acquired on different dates in 2011; and 2) the availability of
ancillary vector datasets. All of the Vermont NAIP imagery was acquired
during the 2011 growing season, capturing leaf-on conditions. However, the
New York NAIP imagery was acquired across a wider interval of 2011 dates,
including at least one date early in the growing season before trees had

leafed out completely. The separate Vermont and New York rule sets were thus tailored to the specific spectral conditions apparent in the source NAIP datasets. In particular, different NDVI criteria were required when discriminating impervious surfaces from grass, shrubs, and trees. Furthermore, the New York imagery was sufficiently variable, with a combination of leaf-on and leaf-off conditions, to warrant separate sub-routines accommodating divergent spectral properties in different parts of the Basin. The available vector datasets also varied by state; for Vermont, road centerlines, railroad centerlines, hydrology, approximate building locations, and approximate driveway locations were incorporated into automated feature extraction, but only road centerlines and hydrology were available for mapping on the New York side of the Basin. The vector datasets provided important contextual information that facilitated classification of impervious surfaces, including the density of developed features (e.g., roads, buildings) and the distance to both developed and natural features (e.g., roads, hydrology). With more vector datasets available for Vermont, more contextual information was thus available for its side of the Basin, improving initial classification of some impervious features. Note, however, that the rule sets for both sides of the Basin largely featured the same flow and logic, modified as necessary to accommodate state-specific spectral properties and vector-data availability.
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The scale of review was approximately 1:3,500. More than 1,030 hours of staff time were devoted to the Vermont side of the Basin, with about 550 hours for New York. Less time was required for the New York portion, despite fewer vector datasets available for this area, because it encompassed a higher proportion of rural areas, including substantial sections of the Adirondack Park.</procdesc>
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