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Lake Champlain Basin Program

Updating the Lake Champlain Basin Land Use Data to Improve Prediction of Phosphorus Loading

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Final Report

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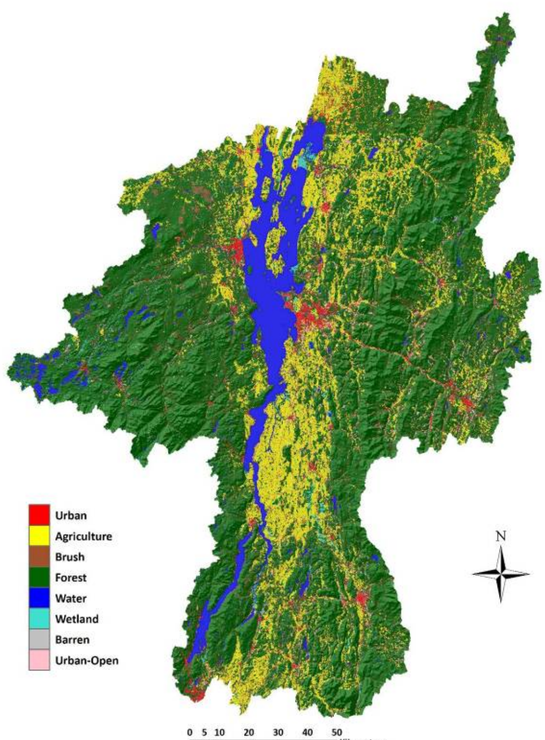

Executive Summary

The Lake Champlain Basin Program's management plan for the Lake Champlain Basin has a strong focus on reducing phosphorus loading from non-point sources. In order to quantify how much phosphorus is entering the lake, it is crucial to have an accurate representation of land use for the Basin. Prior to this mapping effort, the most recent land-use data layer was based on circa 1993 satellite imagery. We created an updated digital land-use/land-cover map for the entire Lake Champlain Basin, referred to as LCB 2001. This updated land-use/land-cover layer was generated by using an expert system that integrated the publicly-available 2001 National Land Cover Database (NLCD) with circa 2001 Landsat satellite imagery and additional Geographic Information System (GIS) datasets.

A primary focus of this expert system was to improve the mapping accuracy of the agriculture land-use class by better differentiating it from urban open space, including large-lot exurban development. An accuracy assessment was performed by comparing the classification to high-resolution imagery. The overall accuracy of LCB 2001 was 88%. The user's accuracies (indicating the probability that a sample from the land-cover map is correctly classified) for the urban and agricultural classes, which are considered to be the greatest sources of phosphorous, were 84% and 89% respectively. Using LCB 2001, a retrospective classification was performed to generate a revised circa 1992 land-use/land-cover layer (LCB-R 1992). This layer was generated by incorporating existing circa 1996 change-detection information, circa 1992 Landsat satellite imagery, the previously-developed 1993 layer, and NLCD 1992. Comparative analysis of the new 2001 and 1992 land-use/land-cover layers indicated change was most pronounced in three classes: urban (+1.9%), agriculture (-5.4%), and brush (4.5%). The revised 1992 data were processed to make them compatible with NLCD 2001 and to facilitate analysis of land-use change using future NLCD releases. Both layers are stored as digital GIS data.

Using the new land-cover/land-use layers and methods developed by Hegman et al. (1999), we calculated non-point source phosphorus loading and export coefficients for the Basin. We then compared phosphorus loads between the two time periods. Two well-known estimation procedures were used: the export method and the loading method. The export method links the Lake's annual phosphorus load directly to the area of three aggregated land-cover/land-use classes: urban, agriculture, and forest. Because precipitation is not factored into this analysis, the export method represents average conditions in the Basin. The loading method is more involved, depending on runoff concentrations of phosphorus from aggregated land-use/land-cover classes and runoff volume. Precipitation is a key factor in the loading method. In this method, runoff concentrations are calculated for each land use based on annual precipitation data collected from across the Basin. Accordingly, the loading-method estimates better represent the actual phosphorus load in a given year.

With the loading method, we calculated year-specific estimates of 479,000 kg (1992) and 561,000 kg (2001). These totals reflect actual precipitation levels during

corresponding phosphorus sampling periods (calendar year 1991 and hydrological year 2001-2002). The export-method estimates were 754,000 kg (1992) and 780,000 kg (2001). These totals are larger than previous estimates by Hegman et al. (1999) because they reflect average precipitation over a longer time period, and thus a wider range of meteorological conditions. The difference between the export estimates is a better indicator of change in phosphorus loads over time because this method holds everything but LULC constant.

According to the export method analysis, developed land, including urban, exurban, suburban land, and roadways, contributed about 53% of the total phosphorus runoff to Lake Champlain in 2001, while agricultural land contributed 39%. The remainder came from forested land uses. These percentages represent a shift from the previous estimates by Hegman et al. (1999), who assigned 51% of the Basin-wide nonpoint source load to agricultural sources and 37% to urban sources. Factors that contributed to the increased proportion of the load attributed to urban sources included corrections for previous underestimates of urban land cover, changes in export coefficients resulting from recalibration of the multiple regression model to a longer time period of monitoring data, and actual land-use conversion.

The difference in annual phosphorus load between 1992 and 2001 was about 26,000 kg. In conjunction with the landscape-change analysis, this finding suggests that land-use changes in the Basin have increased phosphorus levels in Lake Champlain, especially conversion of agricultural areas and forests to developed uses. Urban and suburban land types have a disproportionately large effect on phosphorus loading, and phosphorus levels in Lake Champlain could increase even more as additional areas in the Basin are converted to developed uses. While urban land areas are the largest nonpoint source of phosphorus in the Basin overall, the proportion varies greatly among subwatersheds. For example, agricultural sources are still the highest contributor (about 68%) in the Missisquoi Bay watershed in Vermont.

The updated phosphorus estimates developed in this report reflect not only the influence of land-use conversion, but also the effect of improved land-use classification and use of phosphorus measurements collected over a longer study period. These analyses will permit managers to target regions of the Basin that currently contribute high phosphorus loads as well as regions that are likely to experience increased loads in the future. This information will be directly relevant to the Pressure-State-Response indicator framework that may soon be available to Basin planners and managers.

Chapter 1: Land Cover Mapping

Introduction

Purpose

The land-cover mapping effort focused on developing two datasets for the Lake Champlain Basin: 1) a new circa 2001 land-use/land-cover (LULC) layer (LCB 2001); and 2) a revised circa 1992 LULC layer (LCB-R 1992) that is comparable with LCB 2001 and that resolves some of the technical issues identified with the original 1993 LULC layer (LCB 1993) commissioned by the Lake Champlain Basin Program (LCBP; see Table 1-1 for a list of commonly-used acronyms). An additional criterion was that the data layers be spatially consistent (pixel size, pixel alignment, and coordinate system) with the 2001 National Land Cover Database (NLCD 2001). LCB 2001 and LCB-R 1992 were developed with the understanding that the primary use of these layers would be to update the phosphorous loading coefficients for Lake Champlain.

Table 1-1. List of acronyms used in this report.

Acronym	Definition
CLU	USDA common land units
HUC	Hydrologic unit code
LCB	Lake Champlain Basin
LCB 2001	Circa 2001 LULC layer for the Lake Champlain Basin
LCB-R 1992	Revised circa 1992 LULC classification generated from a retrospective analysis of LCB 2001
LCB 1993	The original circa 1992 LULC layer released in 1997
LULC	Land use / land cover
NLCD	National Land Cover Database

Personnel and Facilities

All land cover mapping was performed by the University of Vermont's Spatial Analysis Laboratory (SAL), part of the Rubenstein School of the Environment and Natural Resources. This project built upon the work carried out by the National Oceanographic and Atmospheric Administration's (NOAA) Coastal Change Analysis Program (C-CAP). NOAA C-CAP developed the NLCD 2001 layer for the areas encompassing the Lake Champlain Basin. We are grateful to NOAA C-CAP for providing us with the preliminary data for evaluation purposes and for releasing the data for the portion of the Lake Champlain Basin that falls outside of the continental United States.

Previous LULC Mapping Efforts

Prior to the start of this project there existed two LULC layers that provided complete or nearly complete coverage for the Basin. LCB 1993 was developed by researchers at Mount Holyoke College for the LCBP using circa 1993 Landsat satellite imagery. NLCD 1992, available for only the portion of the Basin that falls within the United States, was developed by the USGS using circa 1992 imagery. LCB 1993 was the layer used to derive the previous phosphorous loading estimates in 1999 (Hegman et al. 1999). Both these layers have noted inaccuracies. In the case of NLCD 1992 these concerns are reflected in the official NLCD accuracy assessment, which reports an overall accuracy of 47% in region 1 (includes Vermont) and 62% in region 2 (includes New York) (USGS 2006). Although the overall accuracy assessment of the LCB 1993 layer was much higher, 85.9% (VCGI 1997), unpublished analyses of the layer reported overall accuracy assessments as low as 65.6% for the Mad River Watershed. The layer has also been noted to incorrectly classify vegetation located in the vicinity or urban areas as urban areas as urbanized land (Figure 1-1 and Figure 1-2). This problem appears to be due to the reliance of ancillary data depicting urban boundaries. It is unclear to what extent this leads to an overestimation of urban land, but this methodology does result in an unrealistic representation of the landscape. Both LCB 1993 and NLCD 2001 layers also suffer from class confusion in the agricultural classes, with many isolated agricultural pixels often found in upland forested areas (Figure 1-3). Another problem with LCB 1993 was over-representation of water features. LCB 1993 displays many very small tributary streams that may be little more than a meter in width, but its minimum-mapping unit is 30-m pixels. Hence, these small streams end up being represented by a far larger surface area than they actually do. Errors for both NLCD 1992 and LCB 1993 can largely be attributed to the limitations of the methodologies employed at the time.

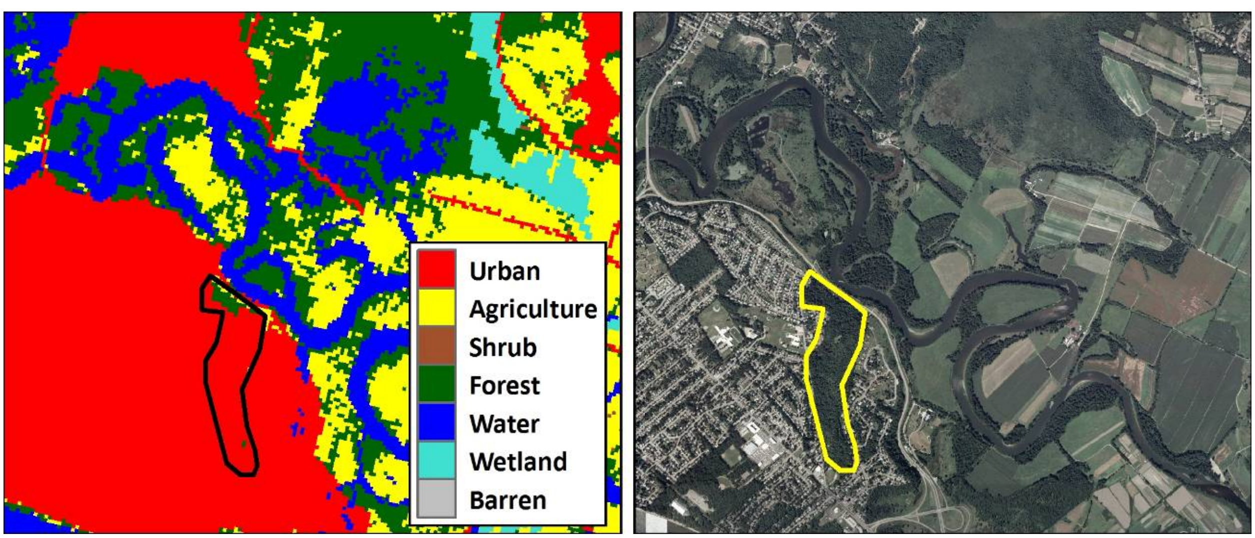

Figure 1-1. Example of incorrectly classified urban land in LCB 1993. The outlined area on the left is Ethan Allen Park in Burlington, VT as classified in LCB 1993; on the right is a 2003 orthophoto. Although the area is highly forested and has been so for decades, it is classified as urban.

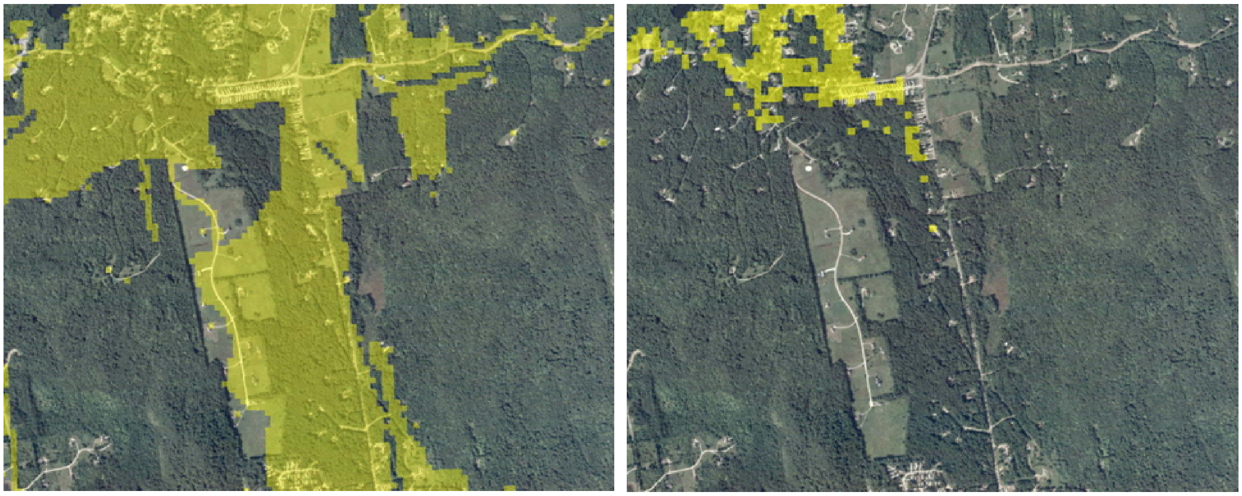

Figure 1-2. Classified urban pixels (transparent yellow) from LCB 1993 overlaid on 2003 orthophotos; right: yellow pixels show what NLCD 1992 classifies as urban for the same scene. The left image indicates the large size of the swath around isolated structures that is classified as urban.

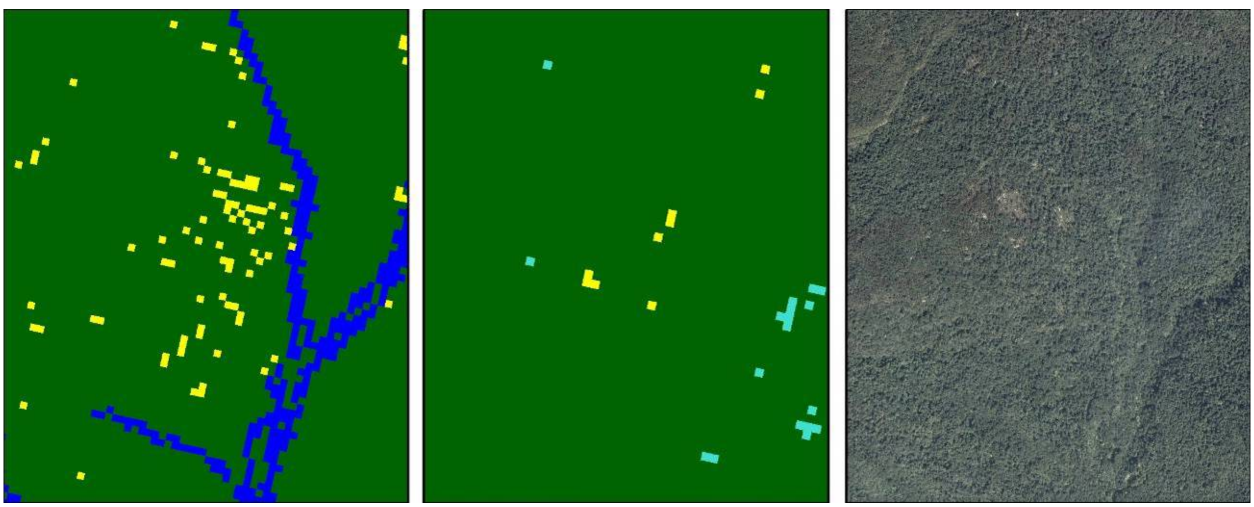

Figure 1-3. Examples of isolated agricultural pixels in upland forested areas in LCB 1993 (left) and NLCD 1992 (center), when compared with 2003 aerial imagery (right). Patches in this upland forested area in Bolton, VT are erroneously classified as agriculture, despite that this is an isolated area with no recent history of agriculture. Note also the presence of pixels representing a small tributary that is clearly smaller than the width of those pixels in LCB 1993.

Classification Scheme

LULC was mapped in seven categories, with urban land subdivided into urban and urban-open (urban areas dominated by vegetation), resulting in a total of eight classes.

Table 1-2 lists the classification scheme, along with class descriptions. The scheme was designed with several objectives in mind. The first was to accurately map features with distinct phosphorous loading coefficients. The second was to adhere as closely as possible to the aggregate classes used in NLCD 2001. The final was to address a concern expressed by some stakeholders that urban land comprised mostly of vegetation would be confused with agriculture due to the similar spectral properties of lawn grasses and agricultural cover types.

Table 1-2. LULC Classification Scheme

Class	Code	Description
Urban	1	Areas dominated entirely by constructed materials or a mix of constructed materials and vegetation. Impervious surfaces generally constitute >20% of total land cover.
Agriculture	2	Land use dominated by the production of crops or for the grazing of livestock.
Brush/Shrub	3	Areas in transition where early-successional species dominate.
Forest	4	Areas dominated by tree canopy.
Water	5	Open water.
Wetland	6	Areas dominated by wetland vegetation, often with saturated soils and standing water.
Barren	7	Exposed soil or bare rock.
Urban-Open	8	Areas dominated by vegetation, typically lawn grass, where the use is anthropogenic. This includes many suburban and exurban properties with large lawns on former farm fields

Methods

LCB 2001 was largely based on NLCD 2001. Ancillary data sources and Landsat imagery were used to improve the accuracy of the original layer. An overview of the methods used to derive LCB 2001 is presented in Figure 1-4.

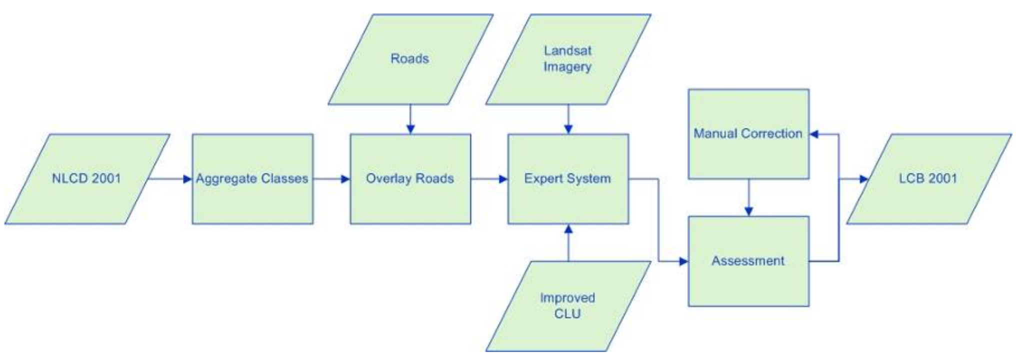

Figure 1-4. Overview of the methods used to generate LCB 2001.

LCB-R 1992 was generated by performing a rule-based, retrospective change detection on LCB 2001 using existing change-detection data, Landsat imagery, LCB

1993, and NLCD 1992. An overview of the methods used to generate LCB-R 1992 from LCB 2001 is presented in Figure 1-5.

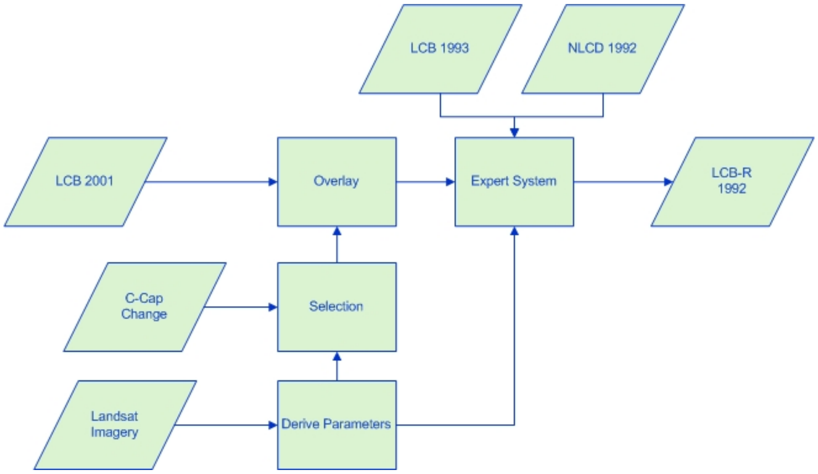

Figure 1-5. Overview of the methods used to generate LCB-R 1992.

Data

National Land Cover Database (NLCD) 2001

NLCD 2001 served as the starting point for LCB 2001 class assignments. All subsequent processing focused on improving the accuracy of NLCD 2001. NLCD 2001 is a 29-class land cover layer for the United States (MRLC Consortium 2006). For the mapping zones that intersect the Lake Champlain Basin, NLCD 2001 was developed by NOAA C-CAP. The principal source of data for NLCD 2001 was multi-temporal imagery from the Landsat satellite series. Of the 29 classes, 19 are found within the Lake Champlain Basin. NLCD 2001 was assessed using both quantitative and qualitative techniques. Overall, NLCD 2001 was determined to be a highly accurate product at the level of categorical aggregation needed for this project. Table 1-3 presents the results of a preliminary accuracy assessment of NLCD 2001 carried out at the start of this project based on the eight LCP 2001 classes. Producer's accuracies refer to the percentage of pixels of a given category that were actually classified as that category (i.e. measures errors of omission), and user's accuracies refer to the percentage of pixels classified as a given category that really are in that category (i.e. errors of commission). The purpose was to identify possible deficiencies in NLCD 2001. At the time the accuracy assessment was conducted, data were only available for the Vermont portion of the Basin and the data were in "pre-release" status.

Table 1-3. Accuracy assessment of pre-release NLCD 2001 data for the Vermont portion of the Lake Champlain Basin. 50 reference points were sampled for each aggregate LULC class, aside from barren (13). National Agricultural Imagery Program (NAIP) orthophotographs acquired in August/September 2003 served as the ground truth. The similarity between the row totals and the diagonals of the matrix indicate the level of producer's accuracy and the similarity between the column totals and the diagonals indicate the user's accuracy. Note: this accuracy assessment was based on pre-release data and should not be used as reference for determining the accuracy of NLCD 2001.

Ground Truth \ NLCD 2001	Urban	Agriculture	Brush	Forest	Water	Wetland	Barren	Urban-Open	Totals	Producer's Accuracy
Urban	**38**	2	0	7	0	0	0	3	50	76%
Agriculture	1	**35**	2	0	0	0	0	12	50	70%
Brush	0	3	**40**	6	0	0	0	1	50	80%
Forest	0	0	2	**43**	0	5	0	0	50	86%
Water	0	0	0	0	**49**	1	0	0	50	98%
Wetland	0	1	0	1	4	**44**	0	0	50	88%
Barren	1	2	1	0	0	0	**9**	0	13	69%
Urban-Open	0	11	0	3	0	0	0	**36**	50	72%
Totals	40	54	45	60	53	50	9	52	Overall Accuracy	
User's Accuracy	95%	65%	89%	72%	92%	88%	100%	69%	81%	

Even in its pre-release state, NLCD 2001 appeared to have an acceptable degree of overall accuracy. The principal sources of error were in the agricultural and urban-open classes. Specifically urban-open land was often misclassified as agricultural land, resulting in an unacceptable user's accuracy (65%) for agriculture and an unacceptable producer's accuracy (72%) for urban-open. Problems of overhanging canopy on roads resulted in values below 80% for the user's accuracy of the forest class and the producer's accuracy of the urban class. The overlay of road networks was used to correct for this problem (see below). All five errors in which forest pixels were misclassified as wetland occurred due to the palustrine forested wetland class (NLCD 2001 class #91) being aggregated to the wetland class. Based on the difficulty of differentiating between forests and forested palustrine wetlands, we decided to aggregate the palustrine forested wetland class with the forested class for this analysis (Table 1-4).

Table 1-4. Aggregation of NLCD 2001 classes. Complete class descriptions for NLCD 2001 are available on the MRLC web site - http://www.mrlc.gov/nlcd_definitions.asp.

LCB 2001 Class	NLCD 2001 Classes
Urban	Developed, Low Intensity (22) Developed, Medium Intensity (23) Developed, High Intensity (24)
Agriculture	Grassland/Herbaceous (71) Pasture/Hay (81) Cultivated Crops (82)
Brush/Shrub	Shrub/Scrub (52)
Forest	Deciduous Forest (41) Evergreen Forest (42) Mixed Forest (43) Palustrine Forested Wetland (91)
Water	Open Water (11) Palustrine Aquatic Bed (98)
Wetland	Palustrine Scrub/Shrub Wetland (92) Estuarine Forested Wetland (93) Estuarine Scrub/Shrub Wetland (94) Estuarine Emergent Wetland (97)
Barren	Barren Land (31)
Urban-Open	Developed, Open Space (21)

As the goal of the project was to maintain as much consistency with NLCD 2001 as possible, the layer was maintained in its original coordinate system: USA Albers Equal Area Conic, USGS Version, NAD83 datum (meters).

Road Networks

Given the importance of roads as a land cover feature and the fact that the accuracy assessment of the NLCD pre-release data identified problems in which roads were obscured by overhanging tree canopy, road vector data were obtained for the entire study area and were considered the overriding class in a pixel. That is, if a road vector was present in a pixel, it was assigned to the urban class, regardless of the proportion of the pixel it accounted for. Table 1-5 lists the sources from which the road data were obtained. Preprocessing performed on the road data included: 1) projecting the data to the USA Albers Equal Area Conic, USGS Version, NAD83 datum coordinate system, 2) editing the data to resolve overshoots and undershoots at the edges of the three regions, and 3) edits to insure alignment with the Landsat imagery at locations where roads were visible on the imagery.

Table 1-5. Sources of road vector data for the three regions of the Lake Champlain Basin.

Region	Organization	Layer Citation
New York	New York State Office of Cyber Security & Critical Infrastructure Coordination	NYS Streets
Quebec	Statistics Canada	Road Network File, Census
Vermont	Vermont Center for Geographic Information	E911 Road Centerlines

Satellite Imagery

Satellite imagery was acquired to fulfill two purposes: 1) classification refinement and 2) change detection. Complete Landsat coverage of the Lake Champlain Basin (LCB) required three Landsat scenes from the following path/rows: 13/29, 14/29, and 14/30

Landsat scenes were acquired from the Multi-Resolution Land Characteristics (MRLC) Consortium (http://www.mrlc.gov/download_data.asp) and were already corrected for geometric and atmospheric distortions. The scenes acquired were the same ones used to generate NLCD 1992 and NLCD 2001. For each path/row an early spring (May) and late summer (August/September) scene was acquired for the 1992 and 2001 time periods. An exception to this was in the case of path 13, row 29 where a July scene had to be substituted for the 1992 year because no May scene existed in the MRLC archives. The scenes obtained from the MRLC Consortium were those used to produce the National Land Cover Dataset (NLCD) for 1992 and 2001. Table 1-6 summarizes the scenes acquired for this project.

Table 1-6. Landsat satellite scenes used for classification refinement and change detection.

Path	Row	Date Acquired	Original Projection	Landsat Satellite
13	29	9/2/1991	UTM	5
13	29	7/2/1992	UTM	5
14	29	5/9/1993	UTM	5
14	29	8/29/1993	UTM	5
14	30	9/9/1991	UTM	5
14	30	5/9/1993	UTM	5
13	29	8/31/1999	ALBERS EQUAL AREA	7
13	29	5/8/2001	ALBERS EQUAL AREA	5
14	29	9/25/2000	ALBERS EQUAL AREA	7
14	29	5/7/2001	ALBERS EQUAL AREA	7
14	30	9/23/1999	ALBERS EQUAL AREA	7
14	30	5/7/2001	ALBERS EQUAL AREA	7

Scenes from the 1992 period, acquired in the UTM coordinate system, were geometrically corrected and projected to match their corresponding 2001 scene. The RMS tolerance for the geometric correction was ½ a pixel. No fewer than 300 tie points were used for each scene. A second-order polynomial function was used for the geometric model with cubic convolution as the resampling method.

Examination of the scenes showed defects consisting of spurious returns. Spurious returns were only noted in two fall scenes from the 1992 time period, 13/29 and 14/30. The spurious returns typically consisted of clumps of 4-6 pixels that have markedly higher returns of one of the following three types when compared to neighboring pixels and the scene in general: bands 1 and 2, band 3, and band 4. This information was used to exclude these pixels from the change-detection process.

Five scenes were found to have clouds present: 13/29 – spring 1992, 14/29 – spring 1993, 14/29 – fall 2000, 14/29 – fall 1993, 14/30 fall 1999. Cloud pixels were excluded from the class refinement and change-detection process.

Agricultural and Urban Open Space Data

As agricultural land (particularly pasture) and urban open space land have similar spectral profiles in Landsat imagery, the classification errors identified in the preliminary accuracy assessment of NLCD 2001 (Table 1-3) were unavoidable and could not be resolved using Landsat imagery. In addition the LCBP's Technical Advisory Committee (TAC) strongly recommended the use of all available ancillary data sources to improve the classification of agricultural land. The USDA Farm Service Agency (FSA) maintains digital layers of agricultural land boundaries as part of the Common Land Unit (CLU) database. While CLU data is spatially detailed (3-m tolerance), it lacks attribute data. This is problematic as CLU polygons represent all land owned by someone who participates in USDA programs, regardless of whether that land is actually being used for agriculture. The result is that CLU polygons may represent buildings, woodlots, or brush. Land-cover data that the USDA maintains as part of the CLU-mapping process are not releasable outside of USDA.

The need to create an improved CLU layer, one that would more accurately depict agricultural land in addition to developing an urban open space layer, was balanced against the fact that the development of such a dataset would require extensive manual editing and photointerpretation, a time-consuming process. To focus this effort, counties where agricultural land had been replaced by urban land were identified using a combination of US Census (US Census Bureau 2006) and National Agricultural Statistics Service (NASS) agricultural census (USDA 2002) data. Increases in the number of households and change in acreage of land in farms were examined for each county that intersected the Basin (Figure 1-6). The assumption was that decreases in land in farms, particularly when there was a corresponding increase in the number of households, would indicate the presence of tracts of urban open land that could easily be confused with agriculture when using Landsat satellite imagery as the basis for classification.

Addison, Chittenden, Franklin, Grand Isle, and Rutland Counties in Vermont were prioritized for improved CLU development and urban open space delineation based upon the analysis in Figure 1-6, the availability of CLU data, and the capacity to leverage previous improvements in the CLU layer carried out by the SAL as part of a separate project. Franklin County in New York and Caledonia County in Vermont did have relatively large reductions in land devoted to farms, but CLU data were not available until late in the project for Franklin County and only a small percentage of Caledonia County falls within the Basin.

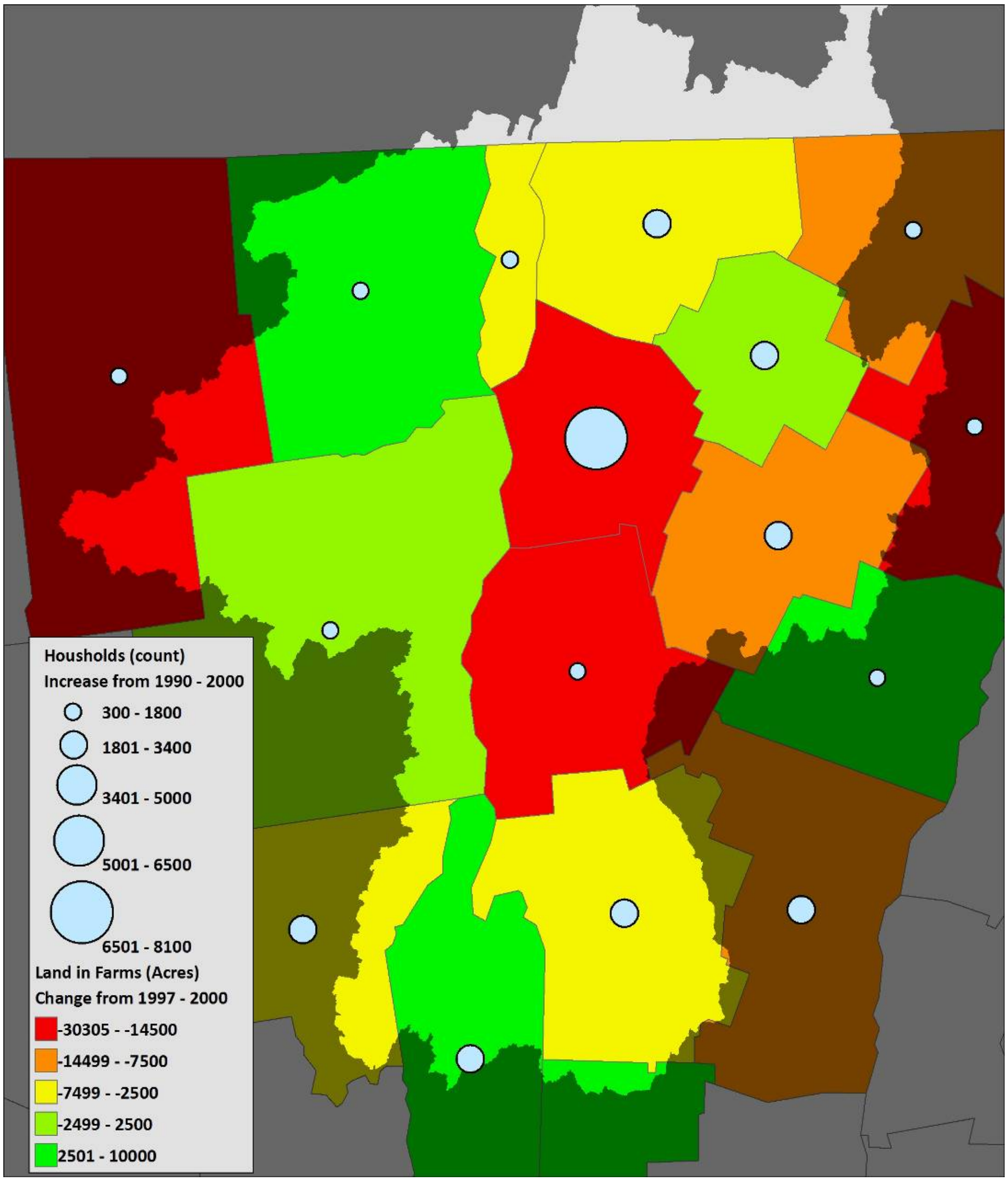

Figure 1-6. Increase in households and change in land in farms for all counties that intersect the Lake Champlain Basin. Household data values are symbolized using an equal-interval distribution; land if farm data values are symbolized using a quantile distribution.

The Improved CLU layer was generated by removing CLU polygons that were not in agricultural land use, editing CLU polygons that did not accurately depict field boundaries, and digitizing urban open space land. The reference data for this work were the 2003 true-color NAIP orthophotographs. For Addison, Chittenden, Franklin, Grand Isle, and Rutland Counties in Vermont, the Improved CLU layer consisted of polygons labeled as either "confirmed agriculture" or "confirmed urban open space" (Figure 1-7). For all other counties, the layer consisted of polygons labeled as "possible agriculture," as the original CLU polygons were used, which indicate the land is owned by a farmer but not necessarily in agricultural land use. It should be noted that no CLU data were available for the Quebec portion of the Basin. However, the need to differentiate between urban open land and agricultural land is less in the Champlain Basin portion of Quebec, given its relatively small amount of suburban and exurban residential development and its very high proportion of working agricultural lands.

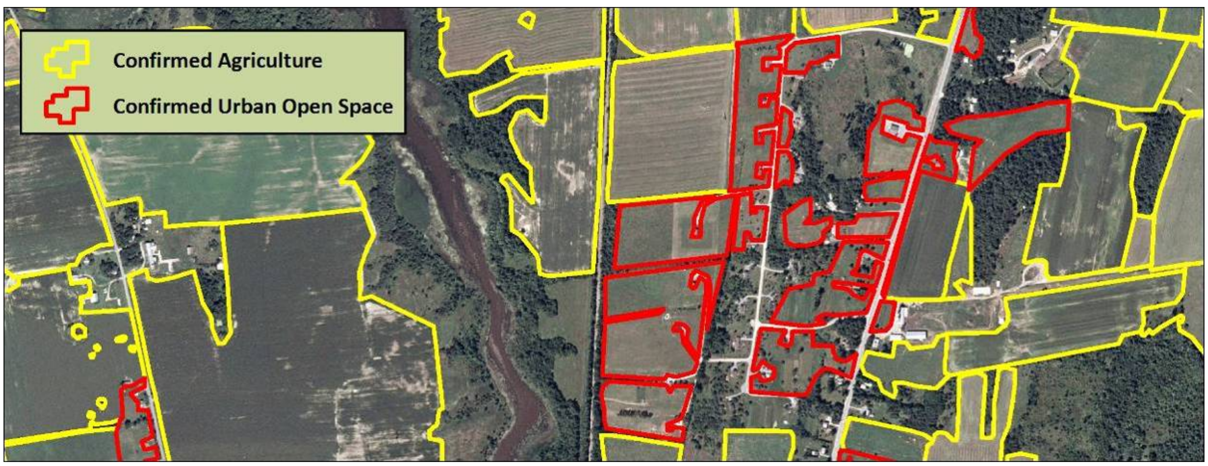

Figure 1-7. Example of the Improved CLU / Urban Open Spaced layer for a portion of Addison County, Vermont.

LCB 2001

LCB 2001 was produced largely by improving NLCD 2001 using ancillary data. The process of generating LCB 2001 was comprised of three phases: 1) overlay of roads, 2) expert system classification, and 3) assessment and manual correction (Figure 1-4). Phase 1 was carried out using the aggregate 8-class version of NLCD 2001 (Table 1-4). The corrected road vector lines were converted to a raster layer with a cell size and alignment matching that of NLCD 2001. The road pixels were incorporated into the NLCD 2001 layer using standard raster overlay procedures in which any pixel in NLCD 2001 that corresponded with a road pixel was reassigned to the urban category. An example of this process is shown in Figure 1-8.

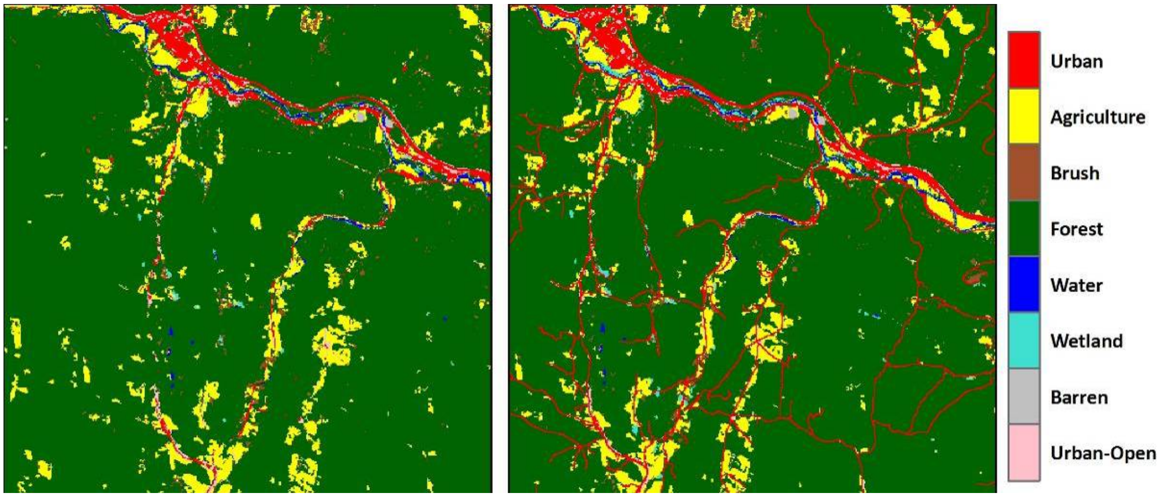

Figure 1-8. Comparison of aggregated 8-class NLCD 2001 (left) to the version with the roads overlaid (right).

The expert system was employed largely to deal with the accuracy issues surrounding agriculture and urban open land (Table 1-3). Edge effects and registration differences between NLCD 2001 and the Improved CLU layer made simply overlaying the two an unacceptable solution. To overcome this limitation, the expert system was developed and deployed using Definiens Professional software (Definiens AG, Munich, Germany). The expert system took advantage of Definiens Professional's ability to "segment" object polygons from image and thematic raster layers. Image object polygons are groups of pixels with similar spectral and spatial characteristics. Image object polygons allow for the inclusion of rules based on complex topological relationships. For this project the image objects were derived from both the spring and fall circa 2001 Landsat satellite scenes, but were constrained to the boundaries of the Improved CLU layer and NLCD 2001. Thus, each object polygon consisted of groups of pixels that were spectrally and spatially similar and share the same attributes with respect to the Improved CLU layer and the NLCD 2001 layer.

The rules employed by the expert system are illustrated graphically in Figure 1-9. The expert system first evaluated whether the object fell into the confirmed agriculture or urban-open categories based on the Improved CLU layer. If either of these tests proved true, the object was assigned to the corresponding class. If the test failed, the alternate scenarios were evaluated. For objects originally classified as agriculture in NLCD 2001, the object was assigned to the output agriculture class only if the object bordered an object already classified as agriculture (to deal with edge effects and layer alignment issues) or if the object was also in the Improved CLU layer's possible agriculture category. This rule ran in an iterative loop to compensate for the fact that, once objects were classified as agriculture, they would influence other border objects. The rule only stopped executing once all objects were finished changing their class assignment. If the object was not assigned to the output agriculture class at this stage (those classified as agriculture in NLCD 2001, but not in LCB 2001) it was evaluated using a series of spectral and spatial rules to assign it to the output brush or urban-open classes. This set of spectral and spatial rules applied a fuzzy-class assignment. The object was more likely to be brush the darker it was and the further it was from urban areas. The object was more likely to be urban if it was near urban areas and brighter. For all other classes, the objects adopted the NLCD 2001 class. Following the running of the expert system, the output classification was manually compared to the Landsat imagery and any objects that appeared to be misclassified were reassigned.

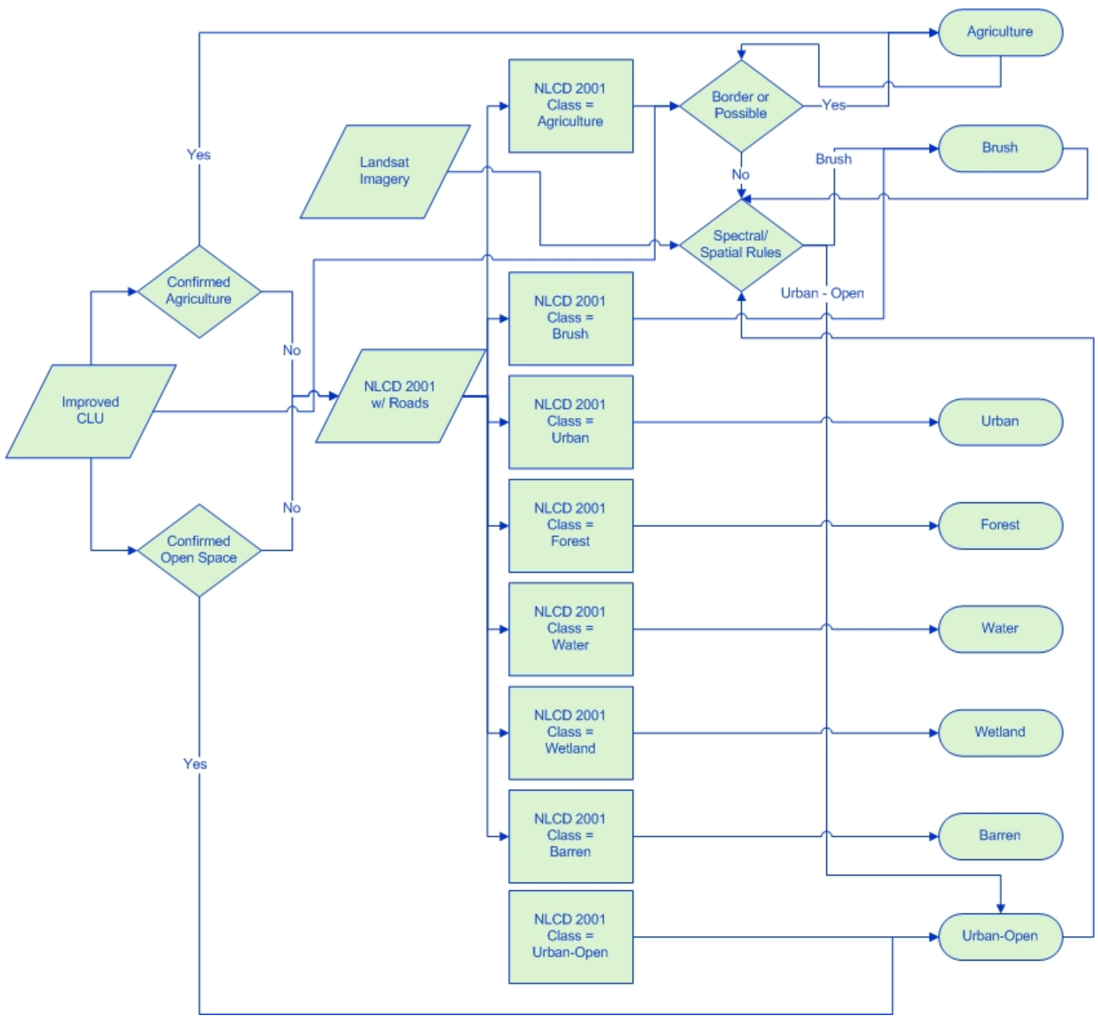

Figure 1-9. Rule set employed by the expert system to generate LCB 2001 class assignments.

LCB-R 1992

LCB-R 1992 was generated by performing a retrospective change detection on LCB 2001 using circa 1992 imagery, circa 1996 change detection data, and existing LULC (LCB 1993 and NLCD 1992). As with LCB 2001, a rule-based expert system was employed that classified objects based on a combination of reflectance from imagery and thematic layers. Prior to running the expert system, existing change detection data from NOAA C-CAP's change analysis product (NOAA 2007) were incorporated. The C-CAP change analysis product depicts thematic change between circa 1996 and 2001 (NLCD 2001) land-cover products. The limitation of the C-CAP change detection dataset is that errors were not taken into account when the change detection was performed, resulting in unrealistic change patterns in certain cases (e.g. urban in 1996 to forest in 2001). The change patterns that were considered realistic, and were used to reclassify pixels in LCB 2001 to the new class in LCB-R 1992, are listed in Table 1-7. It should be noted that C-CAP change analysis data were only available for the portion of the Basin that fell within the United States.

Table 1-7. Decision rules for assessing "realistic" C-CAP changes as applied to LCB 2001.

2001 Class	1996 Class
Urban	Agriculture
Urban	Brush
Urban	Forest
Urban	Wetland
Urban	Barren
Urban	Urban-Open
Agriculture	Brush
Agriculture	Forest
Agriculture	Wetland
Brush	Agriculture
Brush	Forest
Forest	Brush
Urban-Open	Agriculture
Urban-Open	Brush
Urban-Open	Forest
Urban-Open	Wetland
Urban-Open	Barren

Following the overlay of the C-CAP change analysis data, LCB 2001, LCB 1993, NLCD 1992, and the Landsat imagery (consisting of spring and fall scenes for the circa 1992 and 2001 periods) were integrated into an expert system (Figure 1-5) based on Civco et al. (2002) and employing tasseled-cap coefficients (Crist and Kauth 1986) to look for changes in brightness, wetness, and greenness across the sets of images. This information was integrated with both the LCB 1993 and NLCD 1992 layers which, although they suffer from accuracy issues, still contain valuable information.

The rule-based expert system computed the likelihood of an object changing from its assigned class in 2001 based on the scenarios presented in Table 1-7. Take, for example, an object that was classified as urban in 2001. If the tasseled-cap coefficients for brightness and greenness were virtually identical to a fall circa 1992 Landsat image object, but greenness values were much higher, this would indicate that the object was likely agriculture in 1992. This pattern is logical based on the assumption that haying a field could expose the soil during one time period for a given year, resulting in high brightness and low greenness values, but the presence of hay would give the object a higher greenness values at the other time period in the year. The expert system then effectively flagged the object as "possibly agriculture in 1992." Final LCB-R 1992 class assignment for this object would be contingent on the object containing agricultural pixels from both NLCD 1992 and LCB 1993.

Accuracy Assessment

Accuracy assessment was only performed on the LCB 2001 layer due to the lack of available ground truth data for the circa 1992 time period. The ground truth source data for LCB 2001 consisted of 2003 NAIP orthophotos for Vermont, 2003 color-infrared orthophotos for New York, and a high-resolution 2001 IKONOS satellite image for Quebec. Accuracy assessment procedures were performed in accordance with Congalton and Green (1999). A completely randomized sampling would have forced an unmanageable number of ground truth points for the entire Basin to be generated in order to reach Congalton and Green's (1999) recommended minimum sample size of 50 per class due to the overwhelming presence of forest. It would have also led to a situation in which the error matrix would have largely reflected LCB 2001's accuracy with respect to the forest class. As the forest class contributes relatively little to phosphorus loading compared to agricultural and urban areas, the LCB 2001 layer was stratified into forested and non-forested areas for the purposes of sampling. For the forested areas, 500 random sample points were generated while 700 points were generated for the non-forested areas. Of these 1,200 points, 83 had to be discarded due to unavailability of ground truth imagery (Table 1-8). This was particularly a problem in Quebec, where available high-resolution satellite imagery only covered a small portion of the study area. Each point was assigned a class based on the reference data and compared to its class assignment in LCB 2001. If the class assignment was incorrect, the data were examined to determine if the error was caused by an actual error in the LCB 2001 layer or if it was due to georeferencing errors between the ground truth imagery and LCB 2001. If the analyst had a high degree of certainty, based on the spatial pattern of pixels in LCB 2001, and a correctly classified pixel lay within 45m (the diagonal distance from the center of one pixel to the next), the analyst had the discretion to change the class assignment for the ground truth point.

Table 1-8. Ground truth point totals, by LULC class, for LCB 2001.

LULC Class	Original	Retained
Urban	107	102
Agriculture	275	233
Brush	55	54
Forest	500	472
Water	135	130
Wetland	55	53
Barren	11	11
Urban-Open	62	62
Totals	1200	1117

Results and Discussion

Circa 2001 LULC

A map layout of LCB 2001 is shown in Appendix A. As is indicated in Figure 1-10, the majority of the Basin (66%) is forested. Excluding water, the next largest classes are agriculture (14%) and urban areas (5%).

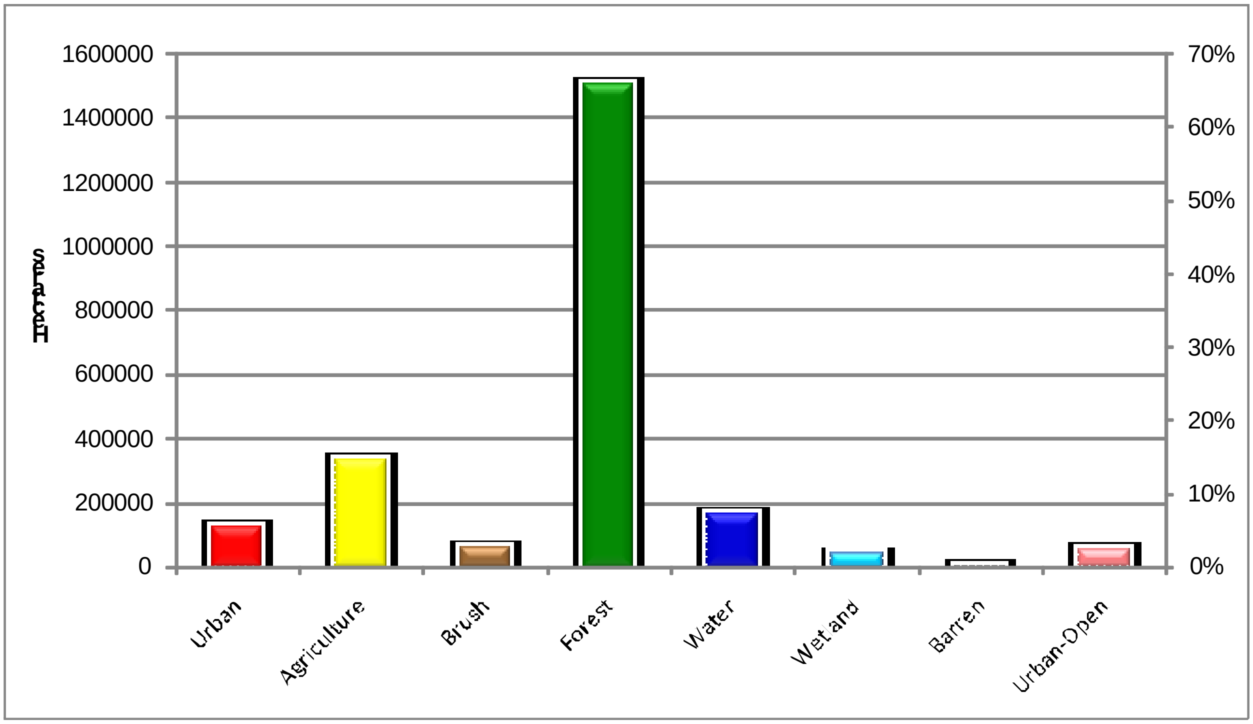

Figure 1-10. Area summaries for LCB 2001.

There are some considerable differences between LCB 2001 and NLCD 2001 worth noting (Figure 1-11). Urban area was 121% greater in LCB 2001 compared to NLCD 2001 due to the overlaying of road data, a process that is also largely responsible for the 3% decrease in forested area. There were a number of differences in LCB 2001 relative to NLCD 2001 due to refinement of the agricultural class using the Improved CLU layer, including a 16% decrease in measured agricultural land area, a 12% increase in brush area, a 34% decrease in barren land area, and a 297% increase in urban open land. An example of the impact of overlaying roads and using the expert system to refine the agricultural class is presented in Figure 1-12. The reliance of NLCD 2001 on spectral information causes roads that are obscured by tree canopy to be ignored and very low density residential areas to be misclassified as agriculture. The improvements in LCB 2001 present a more accurate portrayal of the landscape.

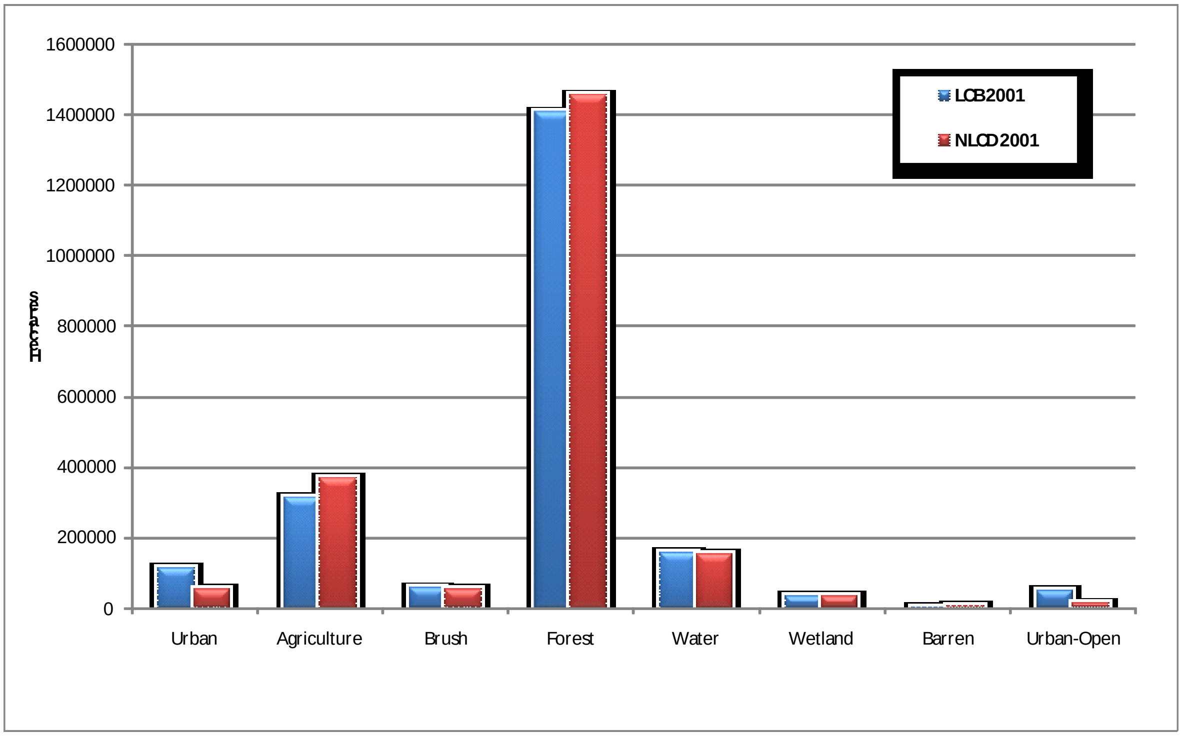

Figure 1-11. Comparison of LCB 2001 and NLCD 2001.

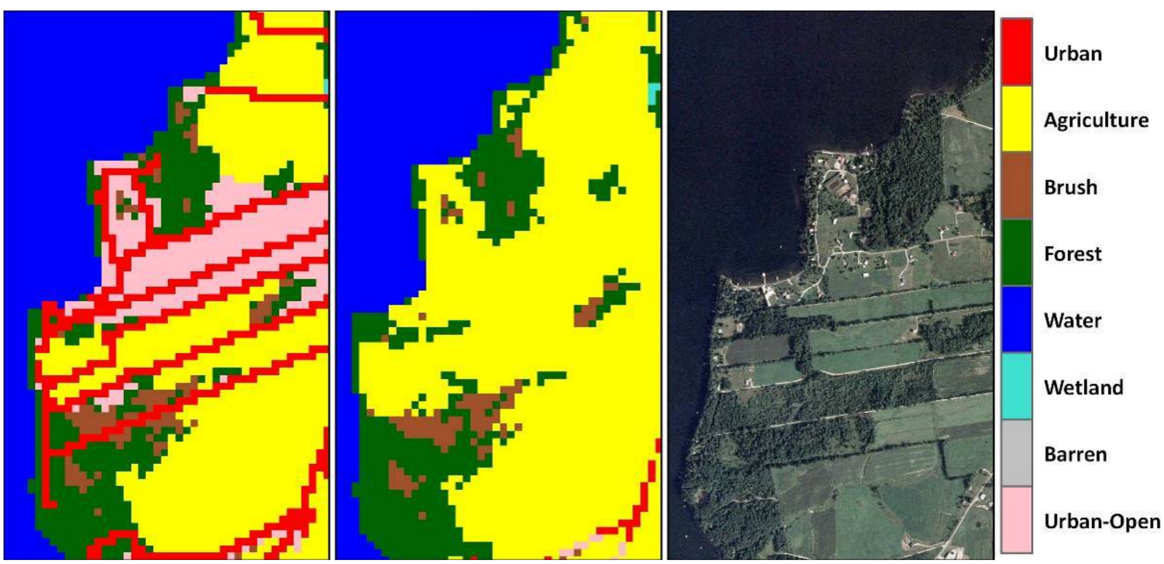

Figure 1-12. Comparison of LCB 2001 (left) and NLCD 2001 (center). The reference image (right) is a 2003 NAIP orthophotograph. The overlay of roads and refinement of the agricultural class in the LCB 2001 layer more accurately depicts ground conditions, resulting in higher area totals for the urban and urban-open classes and a reduction in the area of agricultural and forested land.

Revised Circa 1992 LULC

A map of LCB-R 1992 is presented in Appendix B. Differences in LCB-R 1992 and LCB 1993 are shown in Figure 1-13. Note that estimates of urban land were 23% greater in LCB-R 1992 relative to LCB 1993 and estimates of agricultural land were 5% lower. Without access to imagery from the 1992 period, which is necessary for a detailed comparison, it is impossible to quantitatively assess which layer more accurately depicts LULC in the early 1990s. As pointed out earlier, there are issues with LCB 1993 that could explain the greater estimates for urban, agriculture, and water. However, it is also quite likely that LCB-R 1992 is underestimating change, particularly in the agricultural class where the spectral variability of the class and the lack of circa 1992 CLU data make it difficult to confirm change. There is evidence that a more detailed roads layer, particularly for the New York portion of the Basin contributes, to differences in the urban estimates. Differing techniques for mapping wetlands between the two layers affected both the forest and wetland estimates.

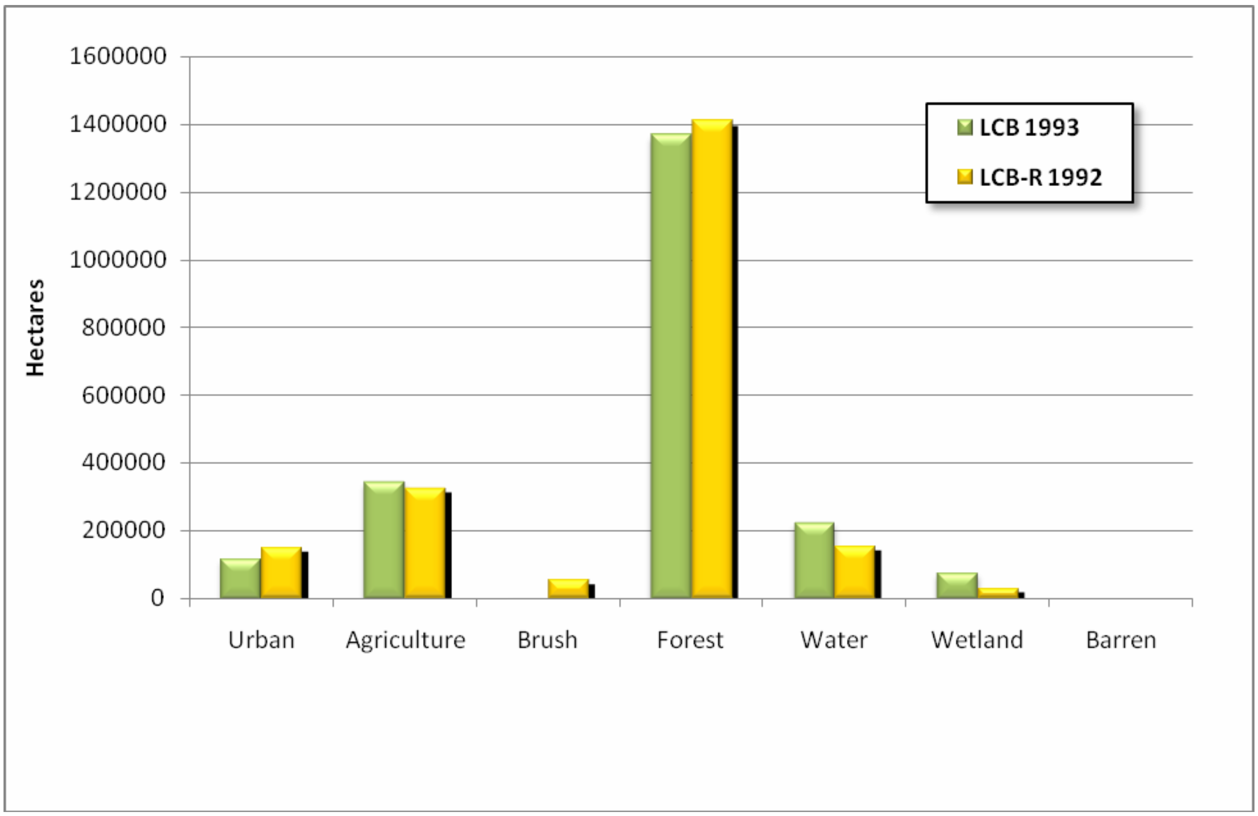

Figure 1-13. Comparison between LCB-R 1992 and LCB 1993. Differences in methodologies and accuracies lead to vastly different LULC estimates.

Change Detection

Comparisons of area, by LULC class, between LCB 2001 and LCB-R 1992 are shown in Figure 1-14. Summaries of Basin-wide percent change and area change are presented in Figure 1-15 and Figure 1-16, respectively. LULC area summaries and change summarized by HUC 12 watersheds (Vermont, including portions of New York and Quebec), HUC 11 watershed (New York and portions of Quebec), HUC 8 watersheds, lake segment, monitored tributary, state, and town are presented in Appendix D through Appendix J.

The increase in urban land should be accepted with the understanding that, without the Improved CLU ancillary data, it is likely that some of change detected is actually urban-open land being misclassified as agriculture. The relatively small changes in overall LULC over time can be attributed to three factors: 1) a conservative rule for defining change in the expert system, 2) the concentration of change in specific regions occupying a relatively small portion of the Basin, and 3) the inherent challenges of remote sensing-based change detection.

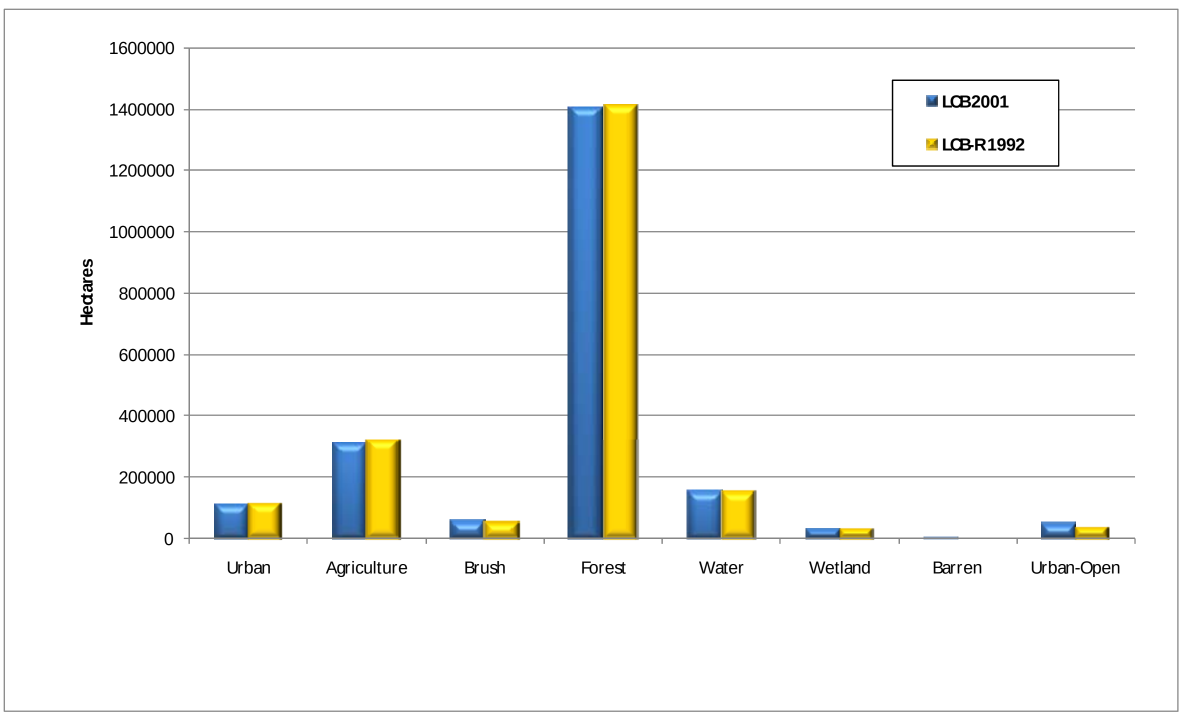

Figure 1-14. Comparison of LULC area, by class, between LCB 2001 and LCB-R 1992.

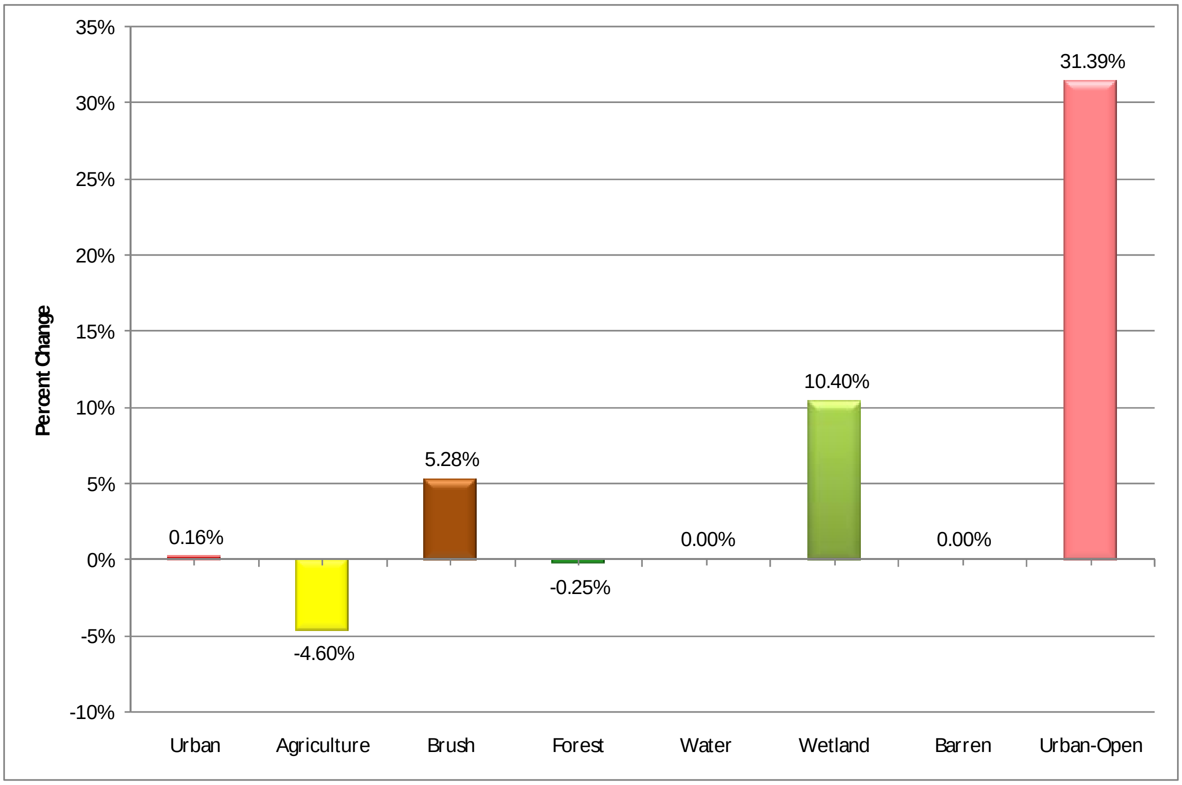

Figure 1-15. Percent change by LULC class for the Lake Champlain Basin.

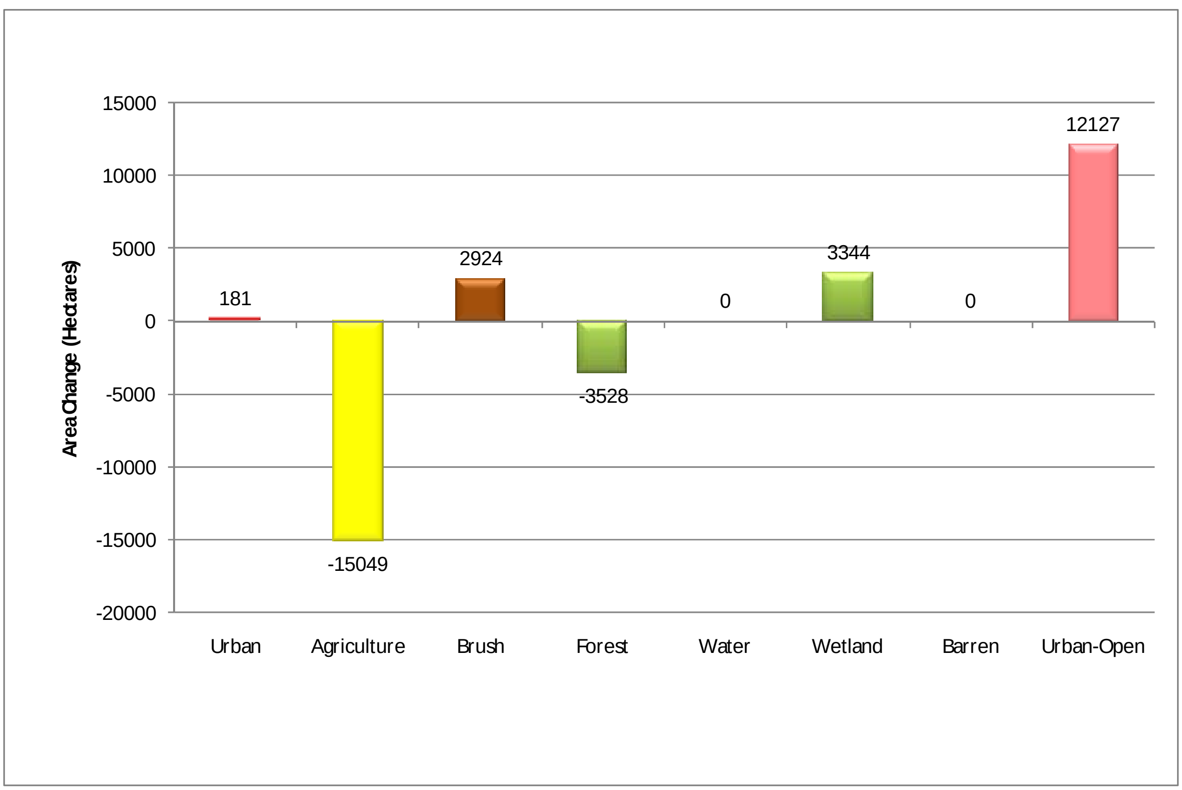

Figure 1-16. Area change by LULC class for the Lake Champlain Basin

Accuracy Assessment

The overall accuracy of LCB 2001 is 88% (Table 1-9). LCB 2001 has an acceptable overall accuracy. From an end user's perspective, which that matters most for calculating phosphorous coefficients, there are several areas that warrant further discussion. The overlaying of roads resulted in an overestimation of the urban class at the expense of forest. The inherent limitations of taking a linear feature, such as a road, and converting it to a raster format, make such overestimations inevitable. Brush proved difficult to classify correctly, largely because it is a class that can appear spectrally similar to both forest and agriculture. Confusion with forest (i.e., assignment of the NLCD 2001 palustrine forest class to forest rather than wetland) largely contributed to the 60% user's accuracy for the wetland class. Although the user's accuracy for the urban-open class is quite low at 69%, most of the confusion occurred with the urban class; because these classes are aggregated for phosphorous modeling, the user's accuracy for the aggregated class would be 87%. A value of 89% for the agricultural class can be considered to be very successful and is likely attributable to implementation of the Improved CLU layer using the expert system. Although no CLU layer was available for the Quebec portion of the Basin, there was no evidence that this data gap reduced accuracy, presumably because the landscape is more homogeneous (i.e., this region is dominated by agricultural land uses and has little topographic variation).

Table 1-9. Error matrix for LCB 2001.

Ground Truth \ LCB 2001	Urban	Agriculture	Brush	Forest	Water	Wetland	Barren	Urban-Open	Totals	Producer's Accuracy
Urban	**81**	4	1	1	0	0	3	12	102	79%
Agriculture	3	**207**	6	2	0	2	0	13	233	89%
Brush	0	6	**37**	9	0	2	0	0	54	69%
Forest	12	1	9	**418**	0	29	0	3	472	89%
Water	0	0	0	0	**127**	3	0	0	130	98%
Wetland	0	0	0	0	0	**53**	0	0	53	100%
Barren	0	1	0	0	0	0	**11**	0	12	92%
Urban-Open	0	14	2	2	0	0	0	**62**	80	78%
Totals	96	233	55	432	127	89	14	90	Overall Accuracy	
User's Accuracy	84%	89%	67%	97%	100%	60%	79%	69%	88%	

End Products

LULC layers were generated for both the 2001 and 1992 time periods. Maps showing LCB 2001 and LCB-R 1992 are shown in Appendix A through C. Both layers are stored as 8-bit raster data in ERDAS IMAGINE (.img) format and include attributes defining the class, color, and area totals for each class. Metadata adhering to Federal Geographic Data Committee (FGDC) standards are managed internally as an XML file (based on the ESRI Metadata template) and stored as an external text file. LCBP is the final custodian of the data, with the SAL retaining copies to distribute at LCBP's discretion.

To assist users without access to costly GIS software, both data layers will be made available as part of an ArcReader project. LCBP is the custodian of the ArcReader project, with the SAL distributing copies at LCBP's discretion. Summary data, by watershed, are also being made available in Keyhole Markup Language (KML) for display using freely virtual globes capable of reading KML formats such as Google Earth and ArcGIS Explorer.

Chapter 2: Phosphorous Modeling

Introduction

Non-point pollution in Lake Champlain, long recognized as an important environmental issue, remains a threat to the lake's ecological integrity and to the many natural resources it provides adjacent communities. Nutrients and other pollutants from a variety of sources are annually exported to the lake in runoff emanating from its surrounding watersheds, and phosphorus is a particular concern because of its effect on algal growth and lake euthrophication (LCBP 2003). In an initial assessment of non-point phosphorus pollution in Lake Champlain, Budd and Meals (1994) estimated the allocation of phosphorus from different land-use categories, finding that agricultural lands export more phosphorus than other land types but that urban lands exert a disproportionately large effect on total export values. In a follow-up assessment, Hegman et al. (1999) refined the analysis of land use and phosphorus export, finding similar results but noting the increased importance of urban areas as more forests and agricultural lands are converted to urban and suburban uses. Hegman et al. based their analysis on land-use data developed from 1993 Landsat satellite imagery, which is now almost a decade and a half old. Consequently, an updated analysis based on more recent and improved land-cover data is needed to provide new basin-wide phosphorus estimates and to further elucidate the relationship between landscape characteristics and phosphorus pollution.

In the following section, we present revised phosphorus estimates based on an analysis of the new LULC map for 2001, or LCB 2001, and regression models developed from estimated phosphorus loading to Lake Champlain. For comparison, we also present new phosphorus estimates for the early 1990s using the revised 1992 LULC map, or LCB-R 1992. Both analyses use the estimation methods presented in Hegman et al., including development of separate phosphorus export and loading coefficients for equations predicting the mass of phosphorus annually transported to Lake Champlain. The export method develops coefficients that are representative values for the mass of phosphorus exported per unit area per year (kg/ha/yr); it is based directly on the area of aggregated LULC classes in individual watersheds. The loading method uses coefficients equivalent to runoff concentrations (mg/L) from aggregated LULC classes *and* interpolated runoff volume based on measured rainfall at stations located throughout the Basin. Note that full descriptions of the analytical methods will not be provided here; for more information see Hegman et al. (1999).

Estimating Export and Loading Coefficients

Methods

Data Sources

Land-use data necessary for estimating new export and loading coefficients were obtained from LCB 2001. The 8 LULC classes represented in the new maps were aggregated into 3 categories that share known or potential functional characteristics: Urban (URB), Agriculture (AG), and Forest (FOR) (Table 2-1). The original Wetlands category was excluded from these aggregates because wetlands likely serve as phosphorus sinks, rather than sources, in the region (Weller et al. 1996). The Barren and Water categories were also excluded. For comparative analyses, the same aggregated LULC classes were used with LCB-R 1992.

Table 2-1. Aggregated LULC categories for updated phosphorus modeling.

Urban (URB)	Agriculture (AG)	Forest (FOR)
Urban	Agriculture	Forest
Urban Open Space	Brush/Transitional	

Non-point source phosphorus measurements collected in 30 Basin watersheds were obtained from the Vermont Department of Environmental Conservation (VTDEC) (Eric Smeltzer, personal communication). These measurements included estimates for the year 1991 that were originally collected as part of a Diagnostic Feasibility Study conducted jointly by VTDEC and the New York State Department of Environmental Conservation (NYDEC) (VTDEC/NYSDEC 1997). The 1991 estimates were the phosphorus measurements used by Hegman et al. VTDEC also provided data for 5 subsequent hydrological years (measured October 1-September 30) through the period 2001-2002; these annual estimates were based on a 2-year average of phosphorus measurements from consecutive hydrological years (e.g., the phosphorus load listed for 1993-1994 was the average of measurements for hydrological years 1992-1993 and 1993-1994). However, only 1991 measurements were available for all 30 watersheds; since 1991 only 17 of the largest Basin watersheds from the original 30 have been measured in each hydrological year (Table 2-2). These watersheds constitute 85% (1,715,729 ha) of the Basin. Note that the 30 watersheds analyzed by Hegman et al. constituted 91% of the Basin; excluded areas in the earlier study pertained to watersheds that drain directly into the lake without an identified first-order stream and one small watershed (Little Ausable River) that was not sufficiently well delineated to permit GIS analysis. The watersheds excluded by Hegman et al. were also excluded in this study. See Medalie and Smeltzer (2004) for more information on phosphorus export estimation methods.

Table 2-2. Lake Champlain Basin watersheds with phosphorus measurements (1991-2002).

Watershed	Area (ha)	Phosphorus Data
Ausable	132,864	1991, 93-94[a], 95-96, 97-98, 99-00, 01-02
Bouquet	70,436	1991, 93-94, 95-96, 97-98, 99-00, 01-02
East	8,277	1991
Great Chazy	77,361	1991, 93-94, 95-96, 97-98, 99-00, 01-02
Highland Furgeh	3,003	1991
Hosington	2,831	1991
Indian Brook	3,055	1991
LaChute	55,927	1991
Lamoille	187,237	1991, 93-94, 95-96, 97-98, 99-00, 01-02
LaPlatte	13,721	1991, 93-94, 95-96, 97-98, 99-00, 01-02
Lewis	20,999	1991, 93-94, 95-96, 97-98, 99-00, 01-02
Little Chazy	13,814	1991, 93-94, 95-96, 97-98, 99-00, 01-02
Little Otter	18,898	1991, 93-94, 95-96, 97-98, 99-00, 01-02
Mallets Creek	7,553	1991
Mettawee/Barge Canal	109,832	1991, 93-94, 95-96, 97-98, 99-00, 01-02
Mill	5,992	1991
Mill (Port Henry)	7,236	1991
Mill (Putnam Station)	2,976	1991
Missisquoi	224,043	1991, 93-94, 95-96, 97-98, 99-00, 01-02
Mt. Hope	3,604	1991
Otter	244,458	1991, 93-94, 95-96, 97-98, 99-00, 01-02
Pike	66,748	1991, 93-94, 95-96, 97-98, 99-00, 01-02
Poultney	68,078	1991, 93-94, 95-96, 97-98, 99-00, 01-02
Putnam	16,005	1991, 93-94, 95-96, 97-98, 99-00, 01-02
Rock	14,648	1991
Salmon	17,525	1991, 93-94, 95-96, 97-98, 99-00, 01-02
Saranac	159,205	1991, 93-94, 95-96, 97-98, 99-00, 01-02
Stevens	6,116	1991
Stonebridge	3,111	1991
Winooski	275,362	1991, 93-94, 95-96, 97-98, 99-00, 01-02

[a]Hydrological year.

Most precipitation datasets used in runoff- and loading-coefficient calculations were previously developed by Hegman et al., who compiled annual precipitation measurements from 57 stations in the Basin for the period 1951-1996 and then converted them into a single raster layer representing the mean for the period (IDW method, 12 nearest neighbors, power of 2). Hegman et al. also acquired annual precipitation data (39 stations) for 1991 and used them to produce a precipitation layer that coincided with phosphorus measurements for that calendar year. To match the new LULC datasets, we converted the existing precipitation layers from a cell size of 25x25m to 30x30m. We also acquired annual precipitation data for 2001-2002 (48 stations); data for Vermont and New York were obtained from the National Climate Data Center at the National Oceanic and Atmospheric Administration (www.ncdc.noaa.gov/oa/climate/research/monitoring.html) and data for Quebec were obtained from the National Climate Archive at Environment Canada (www.climate.weatheroffice.ec.gc.ca). We then used IDW to convert them into an interpolated precipitation layer that coincided with the 2001-2002 phosphorus export estimates from VTDEC. Streamflow data used in runoff-coefficient calculations were also adapted from Hegman et al., who obtained mean annual stream volume (Q) measurements for 11 watersheds with USGS streamwater gauging stations. These data contained readings for observations for 7 to 75 years, and most of the 11 watersheds contained at least 40 years of readings.

Statistical and Spatial Analyses

We used multiple linear regression analysis to develop coefficients for separate export and loading equations. All regression analyses were performed in S-Plus 7.0 (Insightful Corp. 2005) with unweighted and untransformed variables. All spatial analyses were performed in ArcGIS 9.1 (ESRI 2005), and where possible export and loading calculations were automated in this program's ModelBuilder module. ModelBuilder models are easily transferable and can be used in future analyses.

Calculation of Export Coefficients

The export method examines the general relationship between phosphorus measurements and land-cover patterns; predictive equations vary greatly depending on many factors leading to phosphorus emissions in the watershed, including the precipitation received in a given sampling period, intensity of spring peak runoff, actual management practices in each LULC category, etc. With phosphorus measurements available for 6 separate sampling periods, however, it was possible to develop export coefficients that average out variation in precipitation. Accordingly, we initially developed separate regression equations for each of the 6 available sampling periods. LULC summaries from LCB-R 1992 and LCB 2001 were used for the beginning and ending sampling periods, respectively, but we estimated LULC totals per watershed for intervening sampling periods using linear extrapolation. Assuming a linear rate of change in LULC area totals between 1992 and 2001, we divided the difference between each watershed-specific LULC class by the number of time intervals (5) and then sequentially added this incremental change to each class. This procedure produced a coarse but usable estimate of LULC totals per sampling period.

We regressed the area of each aggregated LULC category in each watershed against phosphorus measurements for the 6 available sampling periods, identifying the best-fitting individual model for each actual and extrapolated LULC dataset. All aggregated LULC categories (URB, AG, FOR) were included in final regression models to illustrate the relationship among them, regardless of variable significance. However, the y-intercept was forced through zero. We then averaged the coefficients for the best dataset-specific models to derive a general equation relating phosphorus export to LULC classes. Coefficients were averaged across different LULC datasets only when each regression model contained the same variables.

All export coefficient calculations were based on 15 of the 17 watersheds for which phosphorus measurements have been collected continuously during the period 1991-2002. The Missisquoi and Pike watersheds were excluded *a priori* from these calculations because Hegman et al. (1999) identified them as consistent outliers in their analysis. They demonstrated that the intensive nature of agricultural operations in these watersheds overwhelmed the phosphorus/land-use area relationship. To accommodate highly agricultural watersheds, Hegman et al. used animal-unit data to adjust final phosphorus estimates; watersheds with a disproportionately high number of agricultural animals were assumed to export more phosphorus than predicted by the AG regression coefficient. However, the animal-unit adjustment method was not used in this study because we could not obtain recent animal-unit data for the entire Basin. Instead, we simply adjusted the AG regression coefficient for the Pike and Missisquoi by solving numerically for the coefficient that would produce the observed phosphorus export. Because the Missisquoi and Pike were excluded from all final regression models, we averaged the adjusted AG coefficients to produce a single adjusted value for each watershed.

Calculation of Runoff Coefficients

Runoff coefficients necessary for generating LULC-specific runoff volumes (used later in loading models) were developed from historical streamflow data and long-term precipitation data (1951-1996). Mean annual stream volume (m^3) for 11 gauged watersheds in the Basin was first calculated by multiplying the area of each watershed (m^2) by mean annual flow (Q, in m), which is the estimated annual depth of the water running off a watershed. The precipitation volume (m^3) per aggregated LULC class in each watershed was then calculated by multiplying the area of each class by mean annual precipitation (long-term precipitation surface). Last, the relationship between long-term streamflow and precipitation was examined in a regression equation with annual streamflow as the dependent variable and the precipitation volumes for the LULC classes as independent variables. We performed this analysis with both LCB-R 1992 and LCB 2001, developing unique runoff coefficients for each LULC map. Only significant regression variables ($p < 0.10$) were used in final regression equations for runoff.

Calculation of Loading Coefficients

The loading method estimates watershed P output by incorporating the volume of precipitation in an individual sampling period to estimate runoff in that period. Consequently, we calculated unique loading coefficients for LCB-R 1992 and LCB 2001 using the phosphorus sampling periods that most closely match them (1991 and 2001-2002, respectively). As with the export method, loading-coefficient calculations were based on 15 watersheds, with the Missisquoi and Pike excluded *a priori*. First, we estimated the total annual precipitation that fell on each LULC category in each watershed, on a cell-by-cell basis in ArcGIS, using the year-specific precipitation layers. Second, we calculated the runoff volume from each LULC category by multiplying the annual precipitation totals by the runoff coefficients determined for each LULC dataset. We then regressed phosphorus measurements against runoff volume to produce a sampling period-specific equation (i.e., one equation for LCB-R 1992 based on 1991 precipitation data and one equation for LCB 2001 based on 2001-2002 precipitation data).

Variance Analysis

To confirm the fundamental assumption that the loading method provides a better estimate of year-specific phosphorus pollution, we used the coefficients developed for the export and loading methods to examine the amount of variance between observed and predicted phosphorus estimates. Because the loading method directly incorporates precipitation, presumably it provides a more precise phosphorus estimate (i.e., less variance). If true, this pattern would also support the analytical design that we selected for developing final export coefficients (i.e., calculation of year-specific coefficients for each of the 6 actual or extrapolated LULC datasets by followed by averaging) by demonstrating that annual fluctuations in phosphorus measurements are indeed attributable to a process effect (i.e., precipitation) rather than solely measurement error. Under this scenario, an alternative analytical method that averages phosphorus measurements prior to regression analysis would be biased by the amount of rainfall and runoff that occurred in the years chosen for sampling. Performing regressions on individual sampling years allows some estimation of year-to-year variance in coefficients due to runoff variability; thus, both a range and a mean for desired land-use coefficients can be estimated. Export coefficients could also be weighted according to how close individual sampling years were to the long-term runoff average, producing coefficients that are perhaps more useful from a management perspective because they better represent typical runoff conditions.

Using the average export coefficients described above, we calculated predicted phosphorus totals for the set of 15 watersheds used in regression modeling and then calculated the deviation between each estimate and the actual phosphorus measurement. We performed this analysis for both LCB-R 1992 and LCB 2001 (and the corresponding phosphorus measurements for 1991 and 2001-2002) and then calculated the variance in the mean deviations for the two datasets. For the loading method, we performed a similar analysis using a single set of loading coefficients developed by averaging the year-specific regression equations for LCB-R 1992 and LCB 2001. Again note, however, that loading coefficients were not averaged prior to calculating final phosphorus estimates; average loading coefficients were used only in the variance analysis to permit standardized comparison of observed and predicted phosphorus values.

Sensitivity Analysis for the FOR Coefficient

Although Hegman et al. (1999) found that the FOR coefficient was not significant in regression modeling, they kept this coefficient in their final export and loading equations because it fell within a low range of values identified from previous studies. Because similar non-significant coefficients were possible in this study, we conducted a sensitivity analysis on the effect of different FOR coefficient values on phosphorus estimates. In conjunction with methods described later in the section "Applying

Coefficients to Estimate Phosphorus Loading to Lake Champlain," we first used average export coefficients as calculated above to develop Basin-wide phosphorus estimates. We then substituted the average FOR coefficient with values from the literature and re-calculated Basin-wide estimates. Relying on a literature review by Hegman et al. (1999), we used 0.10 kg/ha/yr as a mid-range value for the FOR coefficient and 0.39 kg/ha/yr as a high-range value. We compared the resulting phosphorus estimates, and the contribution of FOR to these totals, to determine the most appropriate FOR value for final Basin-wide phosphorus modeling using the export method.

Results and Discussion

Export Coefficients

Export equations developed for individual sampling periods varied widely, especially the URB and AG coefficients (Table 2-3). The FOR coefficient was not significant in any of the models and generally had a much smaller effect on estimated phosphorus, but it was included in the models to illustrate the relative effects of the 3 aggregated LULC categories.

Table 2-3. Phosphorus export regression coefficients calculated for 6 separate sampling periods and LULC datasets.

LULC	Period	Model	R^2
LCB-R 1992	91	P export (kg/yr) = 1.89*URB + 0.37*AG - 0.04*FOR	0.97
Extrapolated	93-94	P export (kg/yr) = 1.45*URB + 0.92*AG + 0.06*FOR	0.95
Extrapolated	95-96	P export (kg/yr) = 2.15*URB + 0.57*AG + 0.14*FOR	0.92
Extrapolated	97-98	P export (kg/yr) = 3.83*URB + 1.19*AG + 0.04*FOR	0.98
Extrapolated	99-00	P export (kg/yr) = 3.82*URB + 0.32*AG + 0.01*FOR	0.97
LCB 2001	01-02	P export (kg/yr) = 1.95*URB + 0.30*AG + 0.05*FOR	0.97
Average		**P export (kg/yr) = 2.5*URB + 0.61*AG + 0.04*FOR**	

- Where URB is the land area (ha) of the aggregate Urban category in each represented watershed, and AG and FOR are the areas for the aggregate Agriculture and Forest categories, respectively.
- Underline indicates that a coefficient was significant at $p < 0.05$; italics indicate that a coefficient was significant at $p < 0.10$; all other URB and AG coefficients were marginally significant at $p < 0.15$; no FOR coefficients were significant.
- Export coefficients are expressed as kg/ha/yr.
- Phosphorus export is expressed in kg/yr.

The wide range of coefficient values in both the regular and extrapolated sets was likely a reflection of the high annual variability in phosphorus output measurements (Appendix K), which in turn was a function of the variability in annual runoff. This fundamental relationship was particularly evident in the close tracking of measured non-point phosphorus (Figure 2-1) and gauged river flows (Figure 2-2). Not surprisingly, a regression equation linking these variables indicated a strong association (Non-point phosphorus= 0.2285*Flow – 1241; R^2 = 0.97). The initial sampling year, 1991, was a period of relatively low flows, and the low phosphorus measurements reflected this pattern. Subsequent sampling periods generally had higher phosphorus totals, in some cases much higher (e.g., 1997-1998), and the magnitude of the URB coefficients roughly followed these fluctuations. The AG coefficient did not follow this pattern as closely, but its highest value coincided with the highest-flow year. Because the dominant inter-annual variance in phosphorus loading to Lake Champlain is driven by fluctuations in precipitation, this outcome was not unexpected. However, a better predictor of inter-annual variation might be peak spring runoff volume. Consequently, the use of export coefficients might be improved by taking into account annual runoff conditions. In years with high precipitation, URB and AG coefficients can be much higher than in years with average or low precipitation. This fundamental weakness in the export models drives use of the loading approach and its direct incorporation of runoff.

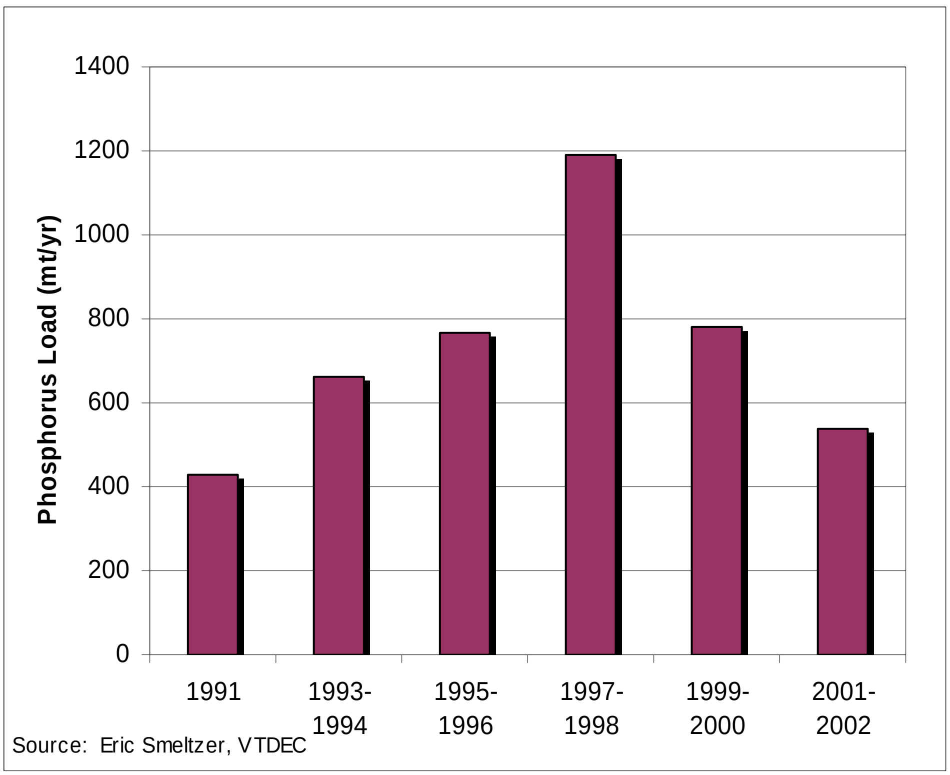

Figure 2-1. Total annual non-point phosphorus loading into Lake Champlain for 6 sampling periods, 1991-2002 (annual estimates based on an average of two years of phosphorus measurements, except 1991).

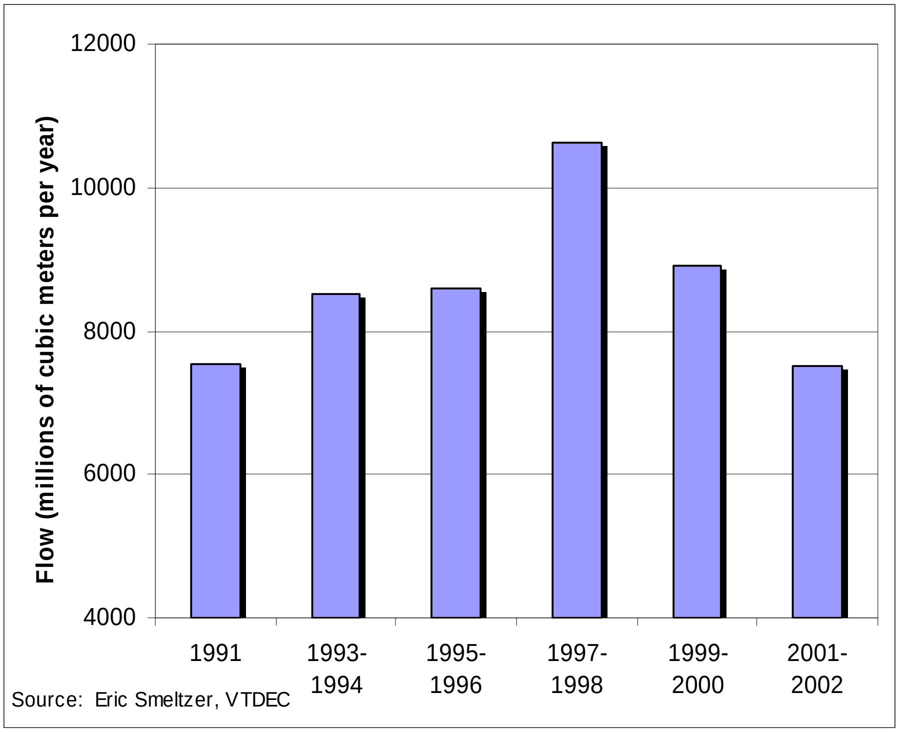

Figure 2-2. Annual gauged river flows into Lake Champlain for 6 sampling periods, 1991-2002 (annual estimates based on an average of two years of flow data, except 1991).

The adjusted AG coefficients for the Missisquoi and Pike watersheds also varied widely but roughly showed the same pattern illustrated by total measured phosphorus and stream flow (Table 2-4). Furthermore, they suggest that Basin-wide regression equations under-predict phosphorus export from these watersheds; both adjusted coefficients were about 3 times the magnitude of the regular AG coefficient.

Table 2-4 . Adjusted average export regression equations for the Missisquoi and Pike watersheds.

LULC	Period	Model	Watershed
LCB-R 1992	91	P export (kg/yr) = 2.52*URB + 1.24*AG + 0.04*FOR	Missisquoi
Extrapolated	93-94	P export (kg/yr) = 2.52*URB + 1.71*AG + 0.04*FOR	Missisquoi
Extrapolated	95-96	P export (kg/yr) = 2.52*URB + 1.24*AG + 0.04*FOR	Missisquoi
Extrapolated	97-98	P export (kg/yr) = 2.52*URB + 3.42*AG + 0.04*FOR	Missisquoi
Extrapolated	99-00	P export (kg/yr) = 2.52*URB + 1.69*AG + 0.04*FOR	Missisquoi
LCB 2001	01-92	P export (kg/yr) = 2.52*URB + 1.87*AG + 0.04*FOR	Missisquoi
Average		**P export (kg/yr) = 2.52*URB + 1.86*AG + 0.04*FOR**	**Missisquoi**
LCB-R 1992	91	P export (kg/yr) = 2.52*URB + 1.53*AG + 0.04*FOR	Pike
Extrapolated	93-94	P export (kg/yr) = 2.52*URB + 1.58*AG + 0.04*FOR	Pike
Extrapolated	95-96	P export (kg/yr) = 2.52*URB + 1.61*AG + 0.04*FOR	Pike
Extrapolated	97-98	P export (kg/yr) = 2.52*URB + 4.08*AG + 0.04*FOR	Pike
Extrapolated	99-00	P export (kg/yr) = 2.52*URB + 0.78*AG + 0.04*FOR	Pike
LCB 2001	01-92	P export (kg/yr) = 2.52*URB + 0.65*AG + 0.04*FOR	Pike
Average		**P export (kg/yr) = 2.52*URB + 1.70*AG + 0.04*FOR**	**Pike**

- Where URB is the land area (ha) of the aggregate Urban category in each represented watershed, and AG and FOR are the areas for the aggregate Agriculture and Forest categories, respectively.
- Export coefficients are expressed as kg/ha/yr.
- Phosphorus export is expressed as kg/yr.

Hegman et al. (1999) reported an URB coefficient of 1.5 kg/ha/yr and an AG coefficient of 0.42 kg/ha/yr (URB/AG ratio = 3.6). Given the range of annual precipitation that they encompass, the average URB and AG coefficients reported here were predictably larger than the values reported by Hegman et al. Although the 1991 coefficients derived in this study, 1.89 kg/ha/yr for URB and 0.37 kg/ha/yr for AG (Table 2-3), were reasonably consistent with Hegman's values, the phosphorus measurements from 1991 represented the lowest phosphorus output among the 6 years of available data. Furthermore, average streamflow for the gauging stations used in this study (see "Calculation of Runoff Coefficients" in the Methods section) was 24% higher for the 6 sampling periods compared to the long-term average for the same gauging stations. Because the export method does not directly incorporate annual runoff, the average export coefficients reported in Table 2-3 are probably a little high for modeling average annual phosphorus output from land use/land cover alone.

Nonetheless, the URB/AG ratio of 4.1 for average export coefficients in this study (Table 2-3) was quite close to ratio of 3.6 reported by Hegman et al. (based on 27 watersheds). This comparison suggests that, regardless of precipitation and runoff conditions, the fundamental relationship between phosphorus export and land-use/land-cover conditions does not vary substantially. The higher URB vs. AG coefficients in Table 2-3 reflect real differences in the processes exporting phosphorus to Lake Champlain. Variation in the URB/AG ratio for the 6 individual sampling periods probably reflects the precision at which watershed outputs of phosphorus can be measured for a single year, making the ratio somewhat sensitive to small changes in phosphorus output from each watershed. Thus, the most stable way to estimate the ratio is likely through use of average URB and AG coefficients.

Runoff Coefficients

Regression equations relating long-term average streamflow to runoff per LULC category predictably indicated a strong, positive relationship between these phenomena, with R^2 values approaching 100% for both LCB-R 1992 and LCB 2001 (Table 2-5).

Table 2-5. Runoff coefficients calculated for LCB-R 1992 and LCB 2001.

LULC	Model	R^2
LCB-R 1992	Streamflow (m^3) = *0.95**URB + *0.53**AG + <u>0.54</u>*FOR	0.998
LCB 2001	Streamflow (m^3) = *0.89**URB + *0.53**AG + <u>0.54</u>*FOR	0.998

- Where URB is the amount of precipitation (m^3) falling on all aggregated Urban land-use categories in each of the 11 gauged watersheds; AG and FOR are the precipitation amounts falling on the aggregated Agriculture and Forest categories, respectively.
- Underline indicates that a coefficient was significant at $p < 0.05$; italics indicate that a coefficient was significant at $p < 0.10$.
- Runoff coefficients are unitless (i.e., they represent the proportion of precipitation falling on each watershed that ultimately runs into a first-order stream where flow is measured).

Although the URB and FOR coefficients were comparable to the values reported by Hegman et al., the AG coefficients for both LCB-R 1992 and LCB 2001 were substantially less than Hegman's value (0.75). The availability of improved LULC maps was a likely factor in this discrepancy, especially improved delineation of urban areas adjacent to agricultural zones and the corresponding reduction of the AG category. These higher-yielding runoff areas, when removed from the AG category, likely decreased the estimated runoff yield from agricultural areas. The LULC-specific runoff coefficients were later used to estimate runoff volumes in both loading regression analyses and final phosphorus estimates.

Loading Coefficients

Relative to the results of the export method, loading equations for both LCB-R 1992 and LCB 2001 (Table 2-6) were much closer to the regression model developed by Hegman et al., who reported an URB coefficient of 0.16 mg/L/yr and an AG coefficient of 0.07 mg/L/yr. In accordance with export results, however, the URB coefficient for LCB-R 1992 was larger than the value reported by Hegman et al., as was the URB/AG ratio (3.3 vs.

2.3). These differences indicate a greater contribution of the URB category to phosphorus loading than previously reported. Better representation of the URB and AG classes in LCB-R 1992 was again the likely factor in this shift. For LCB 2001, the URB/AG ratio (2.1) was slightly lower, but given the expected variance in our estimates, we did not consider this discrepancy noteworthy. Note that average loading coefficients are provided in Table 2-6 for comparison and possible use in subsequent management efforts. However, average coefficients were not used in final Basin-wide phosphorus estimates because the year-specific coefficients reflect meteorological conditions in individual years and thus provide the best possible estimate of total phosphorus loading in those years.

Table 2-6. Phosphorus loading regression coefficients calculated for 2 separate sampling periods and LULC datasets, LCB-R 1992 and LCB 2001.

LULC	Period	Model	R^2
LCB-R 1992	91	P loading (mg/yr) = 0.20*URB + 0.06*AG – 0.004*FOR	0.96
LCB 2001	01-02	P loading (mg/yr) = 0.17*URB + 0.08*AG + 0.01*FOR	0.97
Average		**P loading (mg/yr) = 0.19*URB + 0.07*AG + 0.003*FOR**	

- Where URB is the runoff volume (L) from the aggregate Urban category in each represented watershed, and AG and FOR are the runoff volumes for the aggregate Agriculture and Forest categories, respectively.
- Underline indicates that a coefficient was significant at $p < 0.05$.
- Loading coefficients are expressed as mg/L/yr; this unit is used because it is the standard measure of comparison for the loading method (the coefficients are unwieldy if expressed in $kg/m^3/yr$, e.g., 0.00022 $kg/m^3/yr$).
- Phosphorus loading is expressed as mg/yr (to convert to kg/yr divide by 1,000,000).

The adjusted AG coefficients for the Missisquoi and Pike watersheds were generally much larger than the Basin-wide coefficients, again highlighting the contribution of intensive agriculture to phosphorus loading (Table 2-7). The lone exception to this pattern was the AG coefficient for the Pike using LCB 2001, which was larger than the Basin-wide value but several or more times smaller than the other adjusted coefficients.

Table 2-7. Adjusted loading regression equations for the Missisquoi and Pike watersheds.

LULC	Period	Model	Watershed
LCB-R 1992	91	P loading (mg/yr) = 0.20*URB + 0.23*AG – 0.004*FOR	Missisquoi
LCB-R 1992	91	P loading (mg/yr) = 0.20*URB + 0.30*AG – 0.004*FOR	Pike
LCB 2001	01-02	P loading (mg/yr) = 0.17*URB + 0.29*AG + 0.01*FOR	Missisquoi
LCB 2001	01-02	P loading (mg/yr) = 0.17*URB + 0.11*AG + 0.01*FOR	Pike

- Where URB is the runoff volume (L) from the aggregate Urban category in each represented watershed, and AG is runoff volume for the aggregate Agriculture category.
- Loading coefficients are expressed as mg/L/yr.
- Phosphorus loading is expressed as mg/yr.

<u>Variance Analysis</u>

The variance analysis demonstrated that the loading method provides a much more precise estimate of phosphorus output; variance between observed and predicted phosphorus measurements was lower by an order of magnitude compared to the export method (Table 2-8). This result supports the assumption that the loading method provides a better year-specific assessment of total phosphorus by directly incorporating precipitation. It also supports the assumption that annual variability in phosphorus measurements is primarily a process effect attributable to environmental conditions rather than sampling error.

Accordingly, we believe that the analytical approach of calculating a separate set of regression coefficients for each available phosphorus sampling year is appropriate; by treating sampling years as individual data points, this approach creates coefficients that reflect year-specific conditions. Because the export method provides a generalized interpretation of phosphorus output, it is then reasonable to average multiple sets of year-specific coefficients, producing a single set of coefficients that accommodate annual variability in phosphorus measurements. This approach reduces potential bias by focusing on the central tendency of the export coefficients rather than the central tendency of the phosphorus measurements, avoiding an underestimate of the magnitude of annual phosphorus fluctuations.

A possible criticism of this approach is that, although annual phosphorus measurements are independent data points, the LULC datasets with which they are matched are not, especially the four extrapolated datasets. However, we believe that a linear rate of land-use change is a reasonable assumption for the 10-year interval between LCB-R 1992 and LCB 2001. Furthermore, the LULC datasets were not used as data points in inferential statistics, which would require strict data independence. In this case the key consideration is the effect of annual variability on export coefficients, and extrapolated LULC datasets permit use of the entire set of available phosphorus measurements.

Note that the results of the variance analysis also theoretically support use of average loading coefficients, but we instead chose to focus on the utility of the loading method in calculating year-specific phosphorus estimates. Loading coefficients (and corresponding runoff coefficients) developed for individual years produce the best possible estimate of phosphorus loading in those years, providing an informative contrast to the general conditions represented by export method. Consequently, only year-specific loading and runoff coefficients were used in final Basin-wide phosphorus estimates.

Table 2-8. Variance analysis for 1991 and 2001-2002 phosphorus measurements (15 watersheds) using LCB-R 1992 and LCB 2001.

	Export Method	Loading Method
Datasets	*Total Deviations*[a]	*Total Deviations*[b]
LCB-R 1992, 1991 P Data	190,155	54,738
LCB 2001, 2001-2002 P Data	139,825	73,824
	Mean = 164,990	Mean = 64,281
	Variance = 1.27 x 10^9	**Variance = 1.82 x 10^8**

[a]Predicted phosphorus estimates (kg) based on equation: P export = 2.52*URB + 0.61*AG + 0.04*FOR.
[b]Predicted phosphorus estimates (kg) based on equation: P loading = 0.19*URB + 0.07*AG + 0.003*FOR.

Sensitivity Analysis for the FOR Coefficient

The average FOR coefficient (export method) identified by regression analysis (0.04 kg/ha/yr) produced a predicted phosphorus contribution of about 60,000 kg for both LCB-R 1992 and LCB 2001, or almost 8% of the total contribution for these LULC datasets (Table 2-9). Considering that the FOR category changed relatively little during the 10-year interval, the similarity of these results was not unexpected and was also observed with the other FOR-coefficient values used for comparison. However, the mid-range literature value of 0.10 kg/ha/yr more than doubled the FOR contribution, to more than 16% for both LULC datasets, and the high-range value (0.39 kg/ha/yr) increased the FOR contribution by 5 times. The high-range value clearly exaggerated the FOR contribution, but we believe that the mid-range value also inflated it unnecessarily; only one FOR coefficient from the 6 year-specific export equations exceeded the mid-range value (0.14 kg/ha/yr for 1995-1996 data) and the remaining coefficients had a value of 0.06 or smaller. Furthermore, the average value of 0.04 corresponds to a value determined previously for the Basin by Hegman et al. (1999) and is within the low-range literature values identified by these authors. We thus decided to use this value in all subsequent phosphorus modeling with the export method.

Table 2-9. Sensitivity analysis for the effect of different FOR coefficients on total predicted phosphorus (export method).

	LCB-R 1992			LCB 2001		
FOR coefficient (kg/ha/yr)	Predicted P from FOR (kg)	Total Predicted P[a] (kg)	% Total Contributed by FOR	Predicted P from FOR (kg)	Total Predicted P[a] (kg)	%Total Contributed by FOR
0	0	693,989	0	0	720,084	0
0.04	59,791	753,781	7.9	59,793	779,877	7.7
0.10	140,356	834,345	16.8	140,360	860,444	16.3
0.39	547,387	1,241,376	44.1	547,403	1,267,487	43.2

[a]Assuming URB coefficient = 2.52 kg/ha/yr and Ag coefficient = 0.61 kg/ha/yr (except AG coefficient for Missisquoi and Pike watersheds = 1.86 and 1.70 kg/ha/yr, respectively.

For the loading method, we likewise concluded that the magnitude of the coefficient values identified by regression analysis was appropriate for the contribution of the FOR category to total phosphorus estimates; the FOR values for both LCB-R 1992 and LCB 2001 (-0.004 and 0.01 mg/L, respectively) were within the low-range literature values reviewed by Hegman et al. (1999). Recognizing the need for a small, positive contribution from the FOR category, however, we substituted the negative value of -0.004 for LCB-R 1992 with a literature value of 0.005 in final Basin-wide phosphorus modeling. We chose this substitute value because it matches the value identified by Hegman et al. (1999) for the same phosphorus sampling period.

Coefficients Selected for Subsequent Phosphorus Modeling

Considering the results of the regression modeling and associated analyses, the final export and loading coefficients selected for use in Basin-wide phosphorus modeling were:

Export Method: P export = 2.52*URB + 0.61*AG + 0.04*FOR
(except AG coefficients of 1.86 and 1.70 for Missisquoi and Pike watersheds, respectively)

Loading Method (LCB-R 1992): P loading = 0.20*URB + 0.06*AG + 0.005*FOR
(except AG coefficients of 0.23 and 0.30 for Missisquoi and Pike watersheds, respectively; further note that the FOR coefficient is a substitute value)

Loading Method (LCB 2001): P loading = 0.17*URB + 0.08*AG + 0.01*FOR
(except AG coefficients of 0.29 and 0.11 for Missisquoi and Pike watersheds, respectively)

Note that the single set of average coefficients was applied to both LCB-R 1992 and LCB 2001 using the export method while the year-specific coefficients were applied separately to these LULC datasets using the loading method. This approach permitted an analysis with two different but complementary goals: 1) estimation of LULC-induced change in annual phosphorus export between 1992 and 2001 using coefficients reflecting average conditions (export method); and 2) calculation of year-specific phosphorus estimates for 1992 and 2001 that reflect actual meteorological conditions in the most closely matched phosphorus sampling periods (loading method). The first goal focused on Basin-wide trends in the volume of phosphorus pollution while the second goal provided the best estimate of phosphorus volume in individual years.

Applying Coefficients to Estimate Phosphorus Loading to Lake Champlain

Methods

Export Method

The export method is a simple but widely used technique that relies on average or representative values of phosphorus non-point pollution exported per unit area per year (Hegman et al. 1999). It is also a method that is easily adapted to raster-based (cells) GIS analysis. Accordingly, we used GIS techniques, in conjunction with the average export equation developed in regression analyses (alternative approach), to produce Basin-wide phosphorus estimates for 1992 and 2001 (the years represented by the new LULC maps). The average export coefficients were assigned to each LULC map on a cell-by-cell basis and then used to produce an export value for each cell in kg/yr. The specific cell-by-cell calculation was:

$$TLD = EC_K * A$$

Where: TLD = total annual load for a cell (kg)

EC_K = export coefficient for land use K

A = area of the cell (constant of 0.09 ha)

For example, for a cell in the AG land-use category (either LCB-R 1992 or LCB 2001) in the Otter watershed, the cell value was:

$$TLD = 0.61 \text{ kg/ha/yr} * 0.09 \text{ ha} = 0.0549 \text{ kg/yr}$$

For the Missisquoi and Pike watersheds, average adjusted coefficients for the AG land-use category were simply substituted for the original coefficients. For example, for a cell in the AG land-use category (LCB-R 1992) in the Missisquoi watershed, the cell value was:

$$TLD = 1.86 \text{ kg/ha/yr} * 0.09 \text{ ha} = 0.1674 \text{ kg/yr}$$

The cell-by-cell values were then summed to produce a total phosphorus export estimate for the Basin and for individual lake segments within the Basin. Note that this procedure was performed for the Basin in it entirety, including the watersheds excluded from the export coefficient-calculations.

Loading Method

The loading method estimates annual phosphorus loading as a function of pollutant runoff concentrations and runoff volume, which in turn is directly affected by precipitation (Hegman et al. 1999). It thus provides a better estimate of actual conditions in a specific sampling year. As with the export method, this method is easily adapted for use in raster-based GIS modeling, so we estimated Basin-wide loading estimates for both LCB-R 1992 and LCB 2001. First, we assigned each cell in the aggregated LULC maps its corresponding runoff coefficient (alternative approach) and then multiplied it by annual precipitation to estimate the volume of runoff emanating from each cell. Note that use of annual precipitation surfaces (1991 and 2001-2002) was a departure from the method used by Hegman et al., who used long-term annual precipitation averages to estimate phosphorus loading; we concluded that year-specific precipitation was appropriate for comparing two distinct sampling periods as part of a change-detection analysis. We then multiplied the runoff volume per cell by its corresponding loading coefficient to estimate the amount of phosphorus contributed by each cell. The specific cell-by-cell calculation was:

$$TLD = P * C1 * A * R_K * L_K * C2 * C3$$

Where: TLD = total annual load for a cell (kg)

P = annual precipitation (in/yr)

C1 = inches to meters conversion (0.0254)

A = area of the cell (constant of 900 m^2)

R_K = runoff coefficient for land use K (mg/L)

L_K = loading coefficient for land use K (unitless)

C2 = mg to kg conversion (0.000001)

C3 = L to m3 conversion (1,000)

For example, for a cell in the AG land-use category (using LCB 2001) in the Otter watershed, the cell value was:

TLD = 35 in/yr * 0.0254 * 900 m^2 * 0.08 mg/L * 0.53 * 0.000001 * 1,000 = 0.0339 kg/yr

For the Missisquoi and Pike watersheds, adjusted coefficients for the AG land-use category were simply substituted for the original coefficients. For example, for a cell in the AG land-use category (using LCB 2001) in the Missisquoi watershed, the cell value was:

TLD = 31 in/yr * 0.0254 * 900 m^2 * 0.29 mg/L * 0.53 * 0.000001 * 1,000 = 0.109 kg/yr

The cell-by-cell values were then summed to produce a total phosphorus loading estimate for the Basin and for individual lake segments comprising the Basin. As with the export method, these calculations were performed for the Basin in its entirety, including all watersheds excluded from the loading-coefficient calculations.

Results and Discussion

Export Method Estimates

Export-method results are reported according to lake segments adopted by the 1993 Lake Champlain Water Quality Agreement (Hegman et al. 1999). Note that export results are also reported according to Diagnostic Feasibility Study watersheds (Appendix L), HUC8 watersheds (Appendix M), New York HUC11 watersheds (Appendix N), Vermont HUC12 watersheds (Appendix O), and Basin towns (Appendix P). For LCB-R 1992, a total Basin-wide estimate of 753,781 kg was calculated, with the Missisquoi Bay-VT, Otter Creek-VT, and Main Lake-VT segments contributing the largest amounts by weight (Table 2-10 and Figure 2-3). Burlington Bay, the smallest lake segment, contributed the highest export per unit area, followed by Shelburne Bay and Port Henry-VT. These small watersheds tend to be the most developed regions in the Basin, with high proportions of the URB category. The URB category was the largest phosphorus source in most of the large lake segment; notable exceptions were the Missisquoi Bay and Isle La Motte segments, where AG contributed more. Across the Basin, URB accounted for 50% of the phosphorus load, followed by 42% for AG and about 8% for the FOR category.

Table 2-10. Phosphorus load estimate by lake segment using LCB-R 1992 – export method.

LCB-R 1992 – Export Method		Pollution Load (year)				Source of Load			Land Use			Area Load
Lake Segment	Area (ha)	URB (kg)	AG (kg)	FOR (kg)	Total (kg)	URB (%)	AG (%)	FOR (%)	URB (%)	AG (%)	FOR (%)	kg/ha
Burlington Bay	1,419	2,979	15	8	3,002	99.2	0.5	0.3	83.5	1.7	13.5	2.12
Cumberland Bay	174,186	25,756	6,841	5,806	38,402	67.1	17.8	15.1	5.9	6.4	78.3	0.22
Isle La Motte-NY	97,332	14,954	16,248	2,586	33,788	44.3	48.1	7.7	6.1	27.3	62.4	0.35
Isle La Motte-QUE	6,022	1,208	2,126	68	3,401	35.5	62.5	2	8	57.6	26.3	0.56
Isle La Motte-VT	6,889	1,705	2,388	86	4,179	40.8	57.1	2.1	9.8	56.6	29.4	0.61
Main Lake-NY	257,944	35,145	10,764	9,358	55,267	63.6	19.5	16.9	5.4	6.8	85.2	0.21
Main Lake-VT	281,542	76,078	20,368	9,058	105,504	72.1	19.3	8.6	10.7	11.8	75.6	0.37
Malletts Bay	201,022	41,631	18,688	6,351	66,670	62.4	28	9.5	8.2	15.2	74.2	0.33
Missisquoi Bay-	131,645	19,846	49,787	3,804	73,437	27	67.8	5.2	6	24.3	67.8	0.56
Missisquoi Bay-VT	180,900	27,898	80,101	4,996	112,995	24.7	70.9	4.4	6.1	25.9	64.8	0.62
Northeast Arm	23,350	5,781	5,976	380	12,138	47.6	49.2	3.1	9.8	41.7	38.2	0.52
Otter Creek-NY	1,071	76	13	43	132	57.4	10.2	32.5	2.8	2	93.8	0.12
Otter Creek-VT	286,559	51,258	50,479	7,393	109,130	47	46.3	6.8	7.1	28.8	60.6	0.38
Port Henry-NY	23,857	4,357	1,693	807	6,857	63.5	24.7	11.8	7.3	11.6	79.4	0.29
Port Henry-VT	3,166	991	1,334	23	2,348	42.2	56.8	1	12.4	68.8	17.1	0.74
Shelburne Bay	17,940	9,338	4,609	269	14,217	65.7	32.4	1.9	20.7	41.9	35.2	0.79
South Lake A-NY	96,487	13,417	3,811	3,025	20,253	66.2	18.8	14.9	5.5	6.4	73.6	0.21
South Lake A-VT	17,394	2,523	6,853	197	9,573	26.4	71.6	2.1	5.8	64.3	26.6	0.55
South Lake B-NY	98,565	20,206	17,777	2,458	40,441	50	44	6.1	8.2	29.4	58.5	0.41
South Lake B-VT	100,314	17,048	12,656	2,919	32,622	52.3	38.8	8.9	6.8	20.6	68.3	0.33
St. Albans Bay	13,056	4,839	4,431	157	9,426	51.3	47	1.7	14.7	55.3	28.2	0.72
Total	**2,020,66**	**377,03**	**316,95**	**59,791**	**753,781**	**50**	**42**	**7.9**	**7.4**	**19**	**69.5**	**0.37**

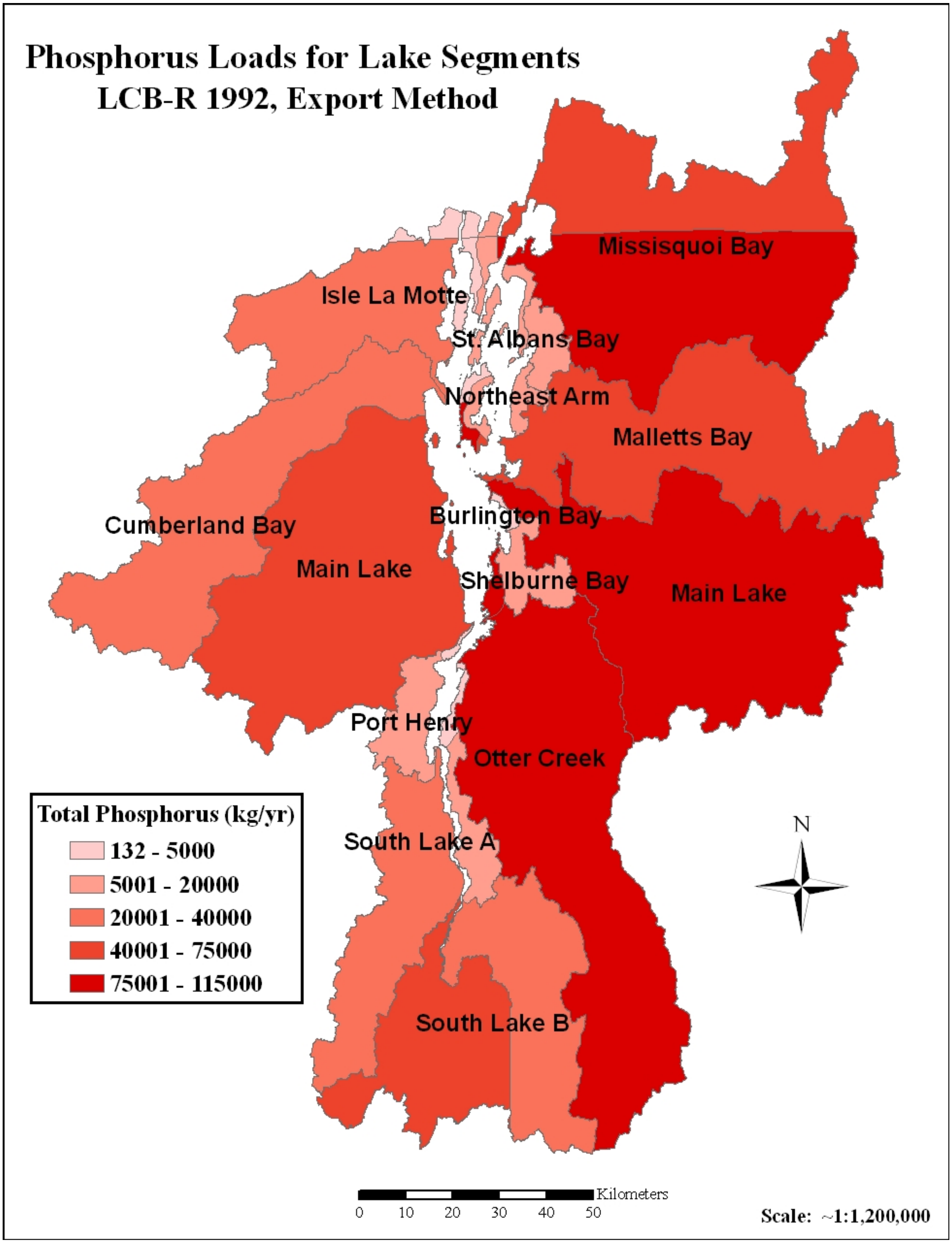

Figure 2-3. Phosphorus loads for Lake Champlain segments using LCB-R 1992 – export method.

The Basin-wide estimate was much larger than the export total of 471,270 kg provided by Hegman et al. (1999), but it undoubtedly reflects the wider range of meteorological conditions inherent in averaged coefficients. Hegman's estimate was based on a single year of phosphorus measurements (1991), which was relatively dry, and subsequent sampling periods recorded higher measurements in most watersheds. In fact, the Basin-wide mean precipitation value for 1991 was 35.8 in, well below the long-term average (38.5 in). The new estimate also likely reflects the better presentation of urban areas in LCB-R 1992; nearly all of the lake segments in this layer had a higher percentage of the URB class compared to LCB 1993.

The export results for LCB 2001 demonstrated a similar pattern among lake segments; Otter Creek-VT, Missisquoi Bay-VT, and Main Lake-VT were again the largest contributors by weight while Burlington Bay, Shelburne Bay, and other smaller watersheds had the highest export per unit area (Table 2-11 and Figure 2-4). URB was the single-largest source of phosphorus in all watersheds except the Missisquoi Bay segments and parts of Isle La Motte and South Lake A, where AG was the largest contributor. Basin-wide, URB contributed to more than 53% of the total phosphorus load; AG contributed about 39% while FOR contributed almost 8%. However, the total export estimate of 779,877 kg was more than 26,000 kg larger than the estimate for LCB-R 1992, a substantial increase in the decade between mapping periods. Because we used the same export coefficients with LCB-R 1992 and LCB 2001 (including outlier watersheds), the primary variables were the maps themselves. Consequently, the increase in total export is likely attributable to land-use changes in the Basin, especially conversion of agriculture and forests to developed uses. In every major lake segment, the proportion of land devoted to the AG category declined while URB increased, and the Basin-wide increase in the URB category was about 0.7%. Although seemingly small, the ultimate effect of this change was an increase of nearly 15,000 ha in the URB category. Combined with the larger magnitude of the URB coefficient, this expansion of the URB land area contributed to the observed increase in total phosphorus export.

Table 2-11. Phosphorus load estimate by lake segment using LCB 2001 – export method.

LCB 2001 – Export Method		Pollution Load (year)				Source of Load			Land Use			Area Load
Lake Segment	**Area (ha)**	**URB (kg)**	**AG (kg)**	**FOR (kg)**	**Total (kg)**	**URB (%)**	**AG (%)**	**FOR (%)**	**URB (%)**	**AG (%)**	**FOR (%)**	**kg/ha**
Burlington Bay	1,419	2,985	14	8	3,007	99.3	0.5	0.3	83.6	1.6	13.5	2.12
Cumberland Bay	174,186	26,709	6,350	5,824	38,882	68.7	16.3	15	6.1	6	78.5	0.22
Isle La Motte-NY	97,332	16,918	15,673	2,592	35,183	48.1	44.5	7.4	6.9	26.3	62.5	0.36
Isle La Motte-QUE	6,022	1,214	2,124	68	3,406	35.7	62.4	2	8	57.6	26.3	0.57
Isle La Motte-VT	6,889	2,040	2,312	86	4,439	46	52.1	1.9	11.8	54.8	29.3	0.64
Main Lake-NY	257,944	36,438	10,312	9,367	56,117	64.9	18.4	16.7	5.6	6.5	85.3	0.22
Main Lake-VT	281,542	83,927	18,640	9,045	111,612	75.2	16.7	8.1	11.8	10.8	75.4	0.4
Malletts Bay	201,022	46,724	17,562	6,343	70,629	66.2	24.9	9	9.2	14.3	74.1	0.35
Missisquoi Bay-QUE	131,645	19,865	49,695	3,806	73,365	27.1	67.7	5.2	6	24.3	67.9	0.56
Missisquoi Bay-VT	180,900	31,812	77,547	4,994	114,353	27.8	67.8	4.4	7	25.1	64.8	0.63
Northeast Arm	23,350	6,462	5,806	381	12,649	51.1	45.9	3	11	40.6	38.3	0.54
Otter Creek-NY	1,071	76	13	43	132	57.4	10.2	32.5	2.8	2	93.8	0.12
Otter Creek-VT	286,559	59,020	48,688	7,386	115,094	51.3	42.3	6.4	8.2	27.7	60.5	0.4
Port Henry-NY	23,857	4,574	1,644	807	7,024	65.1	23.4	11.5	7.6	11.2	79.4	0.29
Port Henry-VT	3,166	1,443	1,224	23	2,690	53.6	45.5	0.9	18.1	63.1	17.1	0.85
Shelburne Bay	17,940	10,594	4,307	269	15,170	69.8	28.4	1.8	23.5	39.2	35.2	0.85
South Lake A-NY	96,487	14,148	3,633	3,025	20,806	68	17.5	14.5	5.8	6.1	73.6	0.22
South Lake A-VT	17,394	3,058	6,726	197	9,981	30.6	67.4	2	7	63.1	26.6	0.57
South Lake B-NY	98,565	21,656	17,477	2,455	41,588	52.1	42	5.9	8.7	28.9	58.5	0.42
South Lake B-VT	100,314	18,732	12,280	2,917	33,928	55.2	36.2	8.6	7.4	20	68.3	0.34
St. Albans Bay	13,056	5,389	4,274	158	9,821	54.9	43.5	1.6	16.4	53.3	28.4	0.75
Total	**2,020,660**	**413,784**	**306,299**	**59,793**	**779,877**	**53.1**	**39.3**	**7.7**	**8.1**	**18.3**	**69.5**	**0.39**

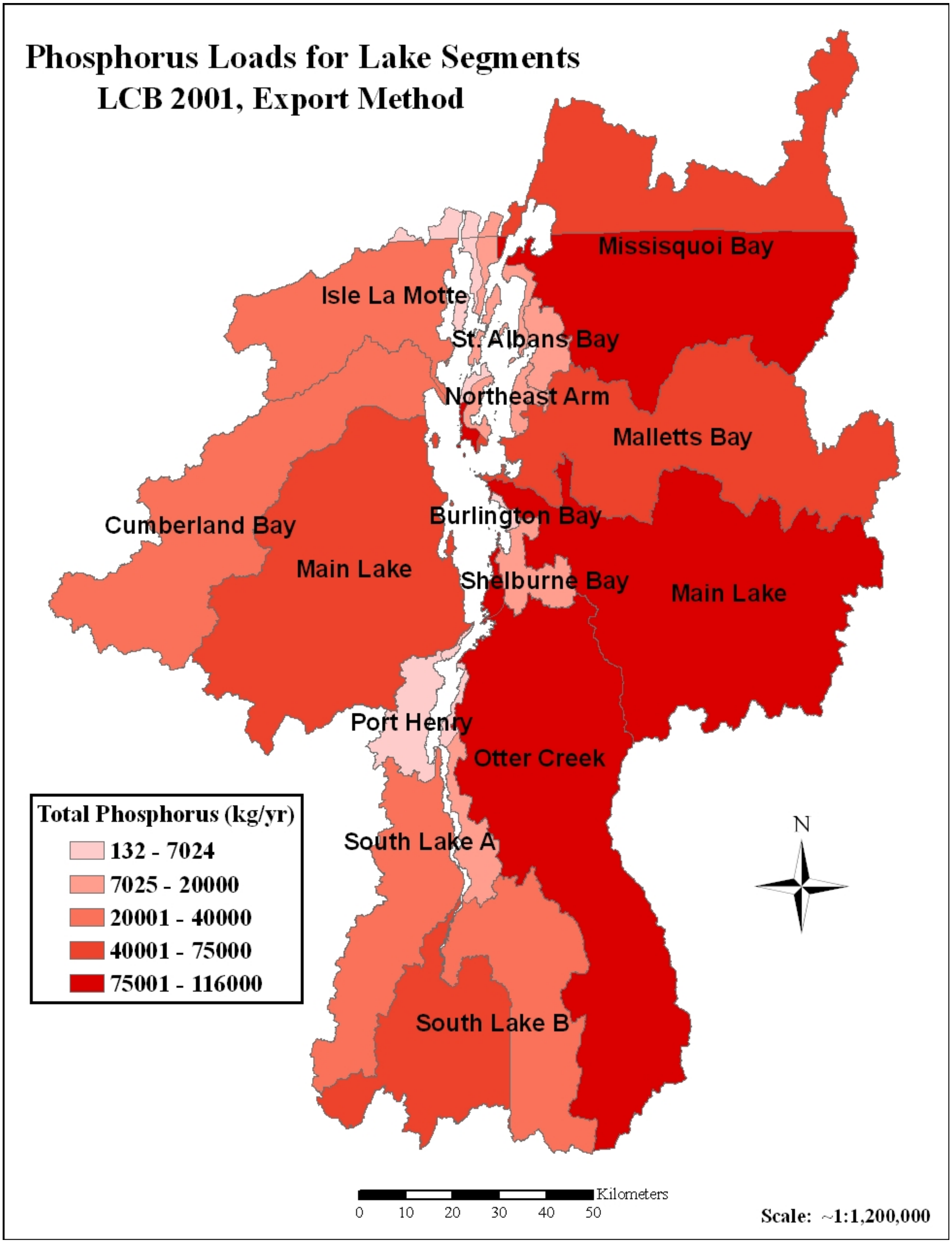

Figure 2-4. Phosphorus loads for Lake Champlain segments using LCB 2001 – export method.

Loading Method Estimates

Loading-method results are also reported by lake segments, Diagnostic Feasibility Study watersheds (Appendix L), HUC8 watersheds (Appendix M), New York HUC11 watersheds (Appendix N), Vermont HUC12 watersheds (Appendix O), and Basin towns (Appendix P). For LCB-R 1992, familiar patterns re-occurred: Missisquoi Bay-VT was the single largest contributor, followed by Otter Creek-VT and Main Lake-VT, and the small segments again had at the highest load per unit area (Table 2-12 and Figure 2-5). Also, URB was the primary phosphorus contributor in all watersheds except the Missisquoi Bay segments and parts of Isle La Motte and South Lake A, where AG accounted for 55-70% of the estimated load. Basin-wide, URB contributed about 55% of the total load, followed by 38% for AG and about 7% for the FOR category.

The total estimated load of 479,238 kg was comparable to the total reported by Hegman for the same period (473,052 kg), even though we used year-specific precipitation totals rather than long-term mean precipitation. This is an important distinction because the annual mean precipitation value for the 1991 sampling period was lower than the long-term precipitation mean for the Basin (35.8 vs. 38.5 in). In fact, use of long-term precipitation data with LCB-R 1992 increased the loading estimate to 516,539 kg. However, we believe that year-specific precipitation provides a more accurate, one-time assessment of actual conditions in the Basin, and all final loading-method results reported here are based on year-specific data. The discrepancy between our estimate and Hegman's is likely attributable, at least in part, to use of a substitute FOR coefficient; the original negative value would have reduced the total phosphorus estimate. Additional factors were the larger URB coefficient for LCB-R 1992 (0.20 vs. the Hegman value of 0.16) and the larger volume of Urban land in the updated LULC map.

Table 2-12. Phosphorus load estimate by lake segment using LCB-R 1992 – loading method.

LCB-R 1992 – Loading Method		Pollution Load (year)				Source of Load			Land Use			Area Load
Lake Segment	**Area (ha)**	**URB (kg)**	**AG (kg)**	**FOR (kg)**	**Total (kg)**	**URB (%)**	**AG (%)**	**FOR (%)**	**URB (%)**	**AG (%)**	**FOR (%)**	**kg/ha**
Burlington Bay	1,419	1,941	7	4	1,953	99.4	0.4	0.2	83.5	1.7	13.5	1.38
Cumberland Bay	174,186	15,305	2,805	3,079	21,190	72.2	13.2	14.5	5.9	6.4	78.3	0.12
Isle La Motte-NY	97,332	7,683	5,955	1,121	14,760	52.1	40.3	7.6	6.1	27.3	62.4	0.15
Isle La Motte-QUE	6,022	713	891	32	1,636	43.6	54.5	2	8	57.6	26.3	0.27
Isle La Motte-VT	6,889	934	941	39	1,913	48.8	49.2	2	9.8	56.6	29.4	0.28
Main Lake-NY	257,944	21,252	4,469	4,950	30,670	69.3	14.6	16.1	5.4	6.8	85.2	0.12
Main Lake-VT	281,542	54,431	10,353	5,508	70,292	77.4	14.7	7.8	10.7	11.8	75.6	0.25
Malletts Bay	201,022	29,114	9,339	3,731	42,184	69	22.1	8.8	8.2	15.2	74.2	0.21
Missisquoi Bay-QUE	131,645	15,495	41,011	2,530	59,036	26.2	69.5	4.3	6	24.3	67.8	0.45
Missisquoi Bay-VT	180,900	20,235	50,607	3,065	73,907	27.4	68.5	4.1	6.1	25.9	64.8	0.41
Northeast Arm	23,350	3,490	2,589	191	6,270	55.7	41.3	3	9.8	41.7	38.2	0.27
Otter Creek-NY	1,071	52	7	24	82	62.7	8	29.3	2.8	2	93.8	0.08
Otter Creek-VT	286,559	38,575	27,089	4,703	70,367	54.8	38.5	6.7	7.1	28.8	60.6	0.25
Port Henry-NY	23,857	3,094	861	473	4,428	69.9	19.4	10.7	7.3	11.6	79.4	0.19
Port Henry-VT	3,166	716	692	14	1,422	50.3	48.7	1	12.4	68.8	17.1	0.45
Shelburne Bay	17,940	6,180	2,226	151	8,558	72.2	26	1.8	20.7	41.9	35.2	0.48
South Lake A-NY	96,487	9,654	1,994	1,797	13,445	71.8	14.8	13.4	5.5	6.4	73.6	0.14
South Lake A-VT	17,394	1,882	3,667	122	5,671	33.2	64.7	2.1	5.8	64.3	26.6	0.33
South Lake B-NY	98,565	14,234	8,969	1,438	24,640	57.8	36.4	5.8	8.2	29.4	58.5	0.25
South Lake B-VT	100,314	12,840	6,858	1,846	21,543	59.6	31.8	8.6	6.8	20.6	68.3	0.21
St. Albans Bay	13,056	3,143	2,045	83	5,271	59.6	38.8	1.6	14.7	55.3	28.2	0.4
Total	**2,020,660**	**260,962**	**183,375**	**34,901**	**479,238**	**54.5**	**38.3**	**7.3**	**7.4**	**19**	**69.5**	**0.24**

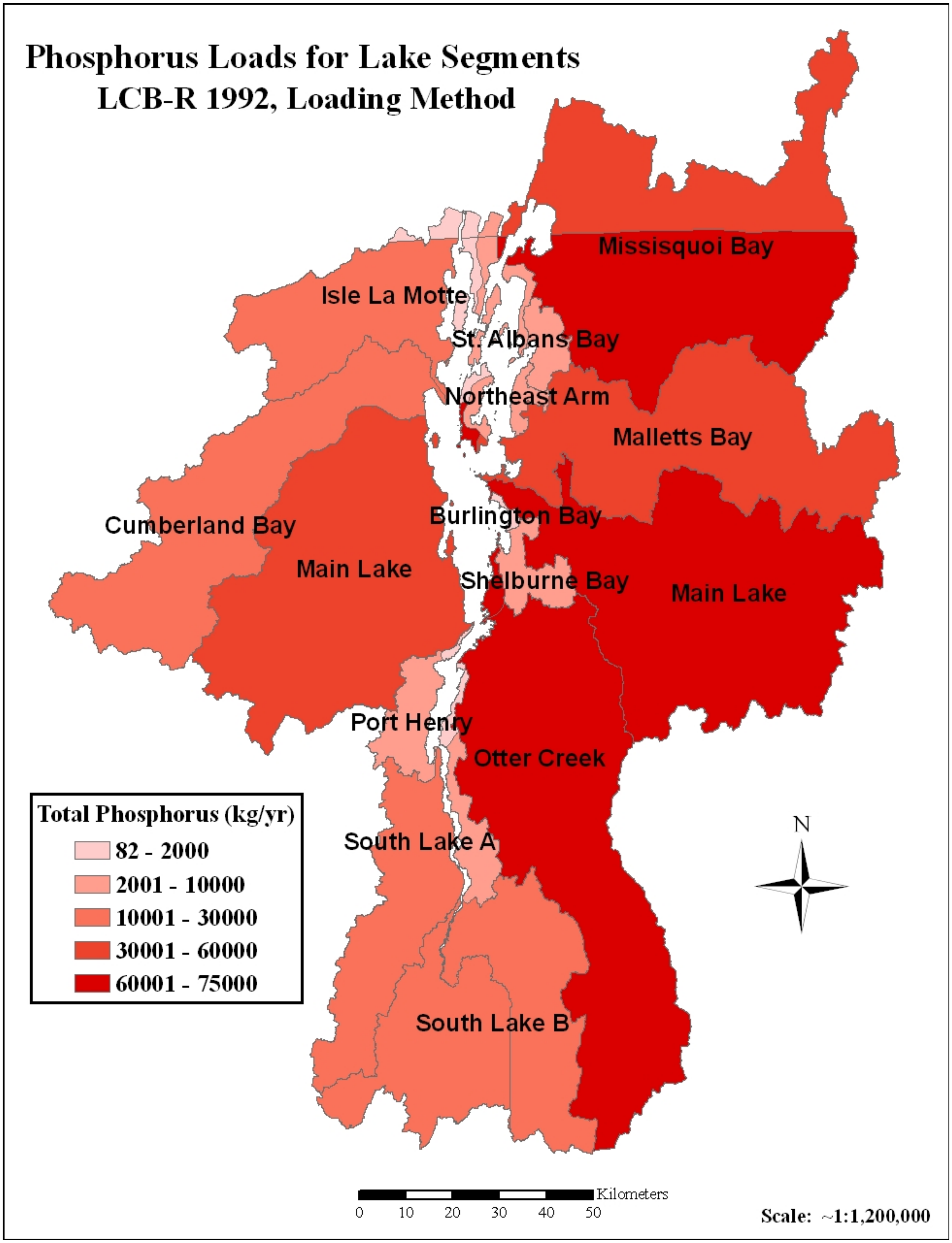

Figure 2-5. Phosphorus loads for Lake Champlain segments using LCB-R 1992 – loading method.

For LCB 2001, the total loading-method estimate of 561,449 kg was predictably much higher than the LCB-R 1992 total; the annual mean precipitation value for the corresponding sampling period (2001-2002) was higher (40.7 in) than the 1991 mean (35.8 in), and it was also higher than the long-term precipitation mean (38.5 in) for the Basin. In fact, use of the long-term precipitation averages with LCB 2001 produced a lower total estimate (527,047 kg). Missisquoi Bay-VT, Main Lake-VT, and Otter Creek-VT were again the most important Basin segments, Missisquoi Bay-VT was the largest AG source, and the URB category was the largest contributor to phosphorus loading Basin-wide, accounting for more than 46% of total (Table 2-13 and Figure 2-6).

The increase in urban land uses from 1992 and 2001 also contributed to the larger estimate, but this contribution is difficult to determine exactly. This is the one drawback of the loading method; it provides a refined assessment of conditions affecting runoff in a given year but incorporates too many variables to isolate specific causal factors for each lake segment.

Table 2-13. Phosphorus load estimate by lake segment using LCB 2001 – loading method.

LCB 2001 – Loading Method		Pollution Load (year)				Source of Load			Land Use			Area Load
Lake Segment	Area (ha)	URB (kg)	AG (kg)	FOR (kg)	Total (kg)	URB (%)	AG (%)	FOR (%)	URB (%)	AG (%)	FOR (%)	kg/ha
Burlington Bay	1,419	1,683	8	10	1,702	98.9	0.5	0.6	83.6	1.6	13.5	1.2
Cumberland Bay	174,186	15,884	4,106	8,031	28,020	56.7	14.7	28.7	6.1	6	78.5	0.16
Isle La Motte-NY	97,332	8,908	9,043	3,255	21,206	42	42.6	15.4	6.9	26.3	62.5	0.22
Isle La Motte-QUE	6,022	708	1,348	87	2,142	33	62.9	4	8	57.6	26.3	0.36
Isle La Motte-VT	6,889	1,091	1,361	103	2,554	42.7	53.3	4	11.8	54.8	29.3	0.37
Main Lake-NY	257,944	19,450	5,915	11,443	36,808	52.8	16.1	31.1	5.6	6.5	85.3	0.14
Main Lake-VT	281,542	55,098	13,302	14,249	82,649	66.7	16.1	17.2	11.8	10.8	75.4	0.29
Malletts Bay	201,022	34,501	14,416	11,344	60,260	57.3	23.9	18.8	9.2	14.3	74.1	0.3
Missisquoi Bay-QUE	131,645	14,148	26,259	6,248	46,654	30.3	56.3	13.4	6	24.3	67.9	0.35
Missisquoi Bay-VT	180,900	23,162	71,421	8,391	102,974	22.5	69.4	8.1	7	25.1	64.8	0.57
Northeast Arm	23,350	3,717	3,689	498	7,904	47	46.7	6.3	11	40.6	38.3	0.34
Otter Creek-NY	1,071	42	8	55	105	40.2	7.8	51.9	2.8	2	93.8	0.1
Otter Creek-VT	286,559	35,214	30,798	10,199	76,211	46.2	40.4	13.4	8.2	27.7	60.5	0.27
Port Henry-NY	23,857	2,417	955	954	4,325	55.9	22.1	22.1	7.6	11.2	79.4	0.18
Port Henry-VT	3,166	793	738	28	1,560	50.9	47.3	1.8	18.1	63.1	17.1	0.49
Shelburne Bay	17,940	6,249	2,909	380	9,538	65.5	30.5	4	23.5	39.2	35.2	0.53
South Lake A-NY	96,487	8,015	2,214	3,845	14,075	56.9	15.7	27.3	5.8	6.1	73.6	0.15
South Lake A-VT	17,394	1,688	4,052	248	5,987	28.2	67.7	4.1	7	63.1	26.6	0.34
South Lake B-NY	98,565	12,636	10,968	3,185	26,788	47.2	40.9	11.9	8.7	28.9	58.5	0.27
South Lake B-VT	100,314	11,192	8,043	3,980	23,215	48.2	34.6	17.1	7.4	20	68.3	0.23
St. Albans Bay	13,056	3,529	3,011	231	6,771	52.1	44.5	3.4	16.4	53.3	28.4	0.52
Total	**2,020,660**	**260,124**	**214,563**	**86,762**	**561,449**	**46.3**	**38.2**	**15.5**	**8.1**	**18.3**	**69.5**	**0.28**

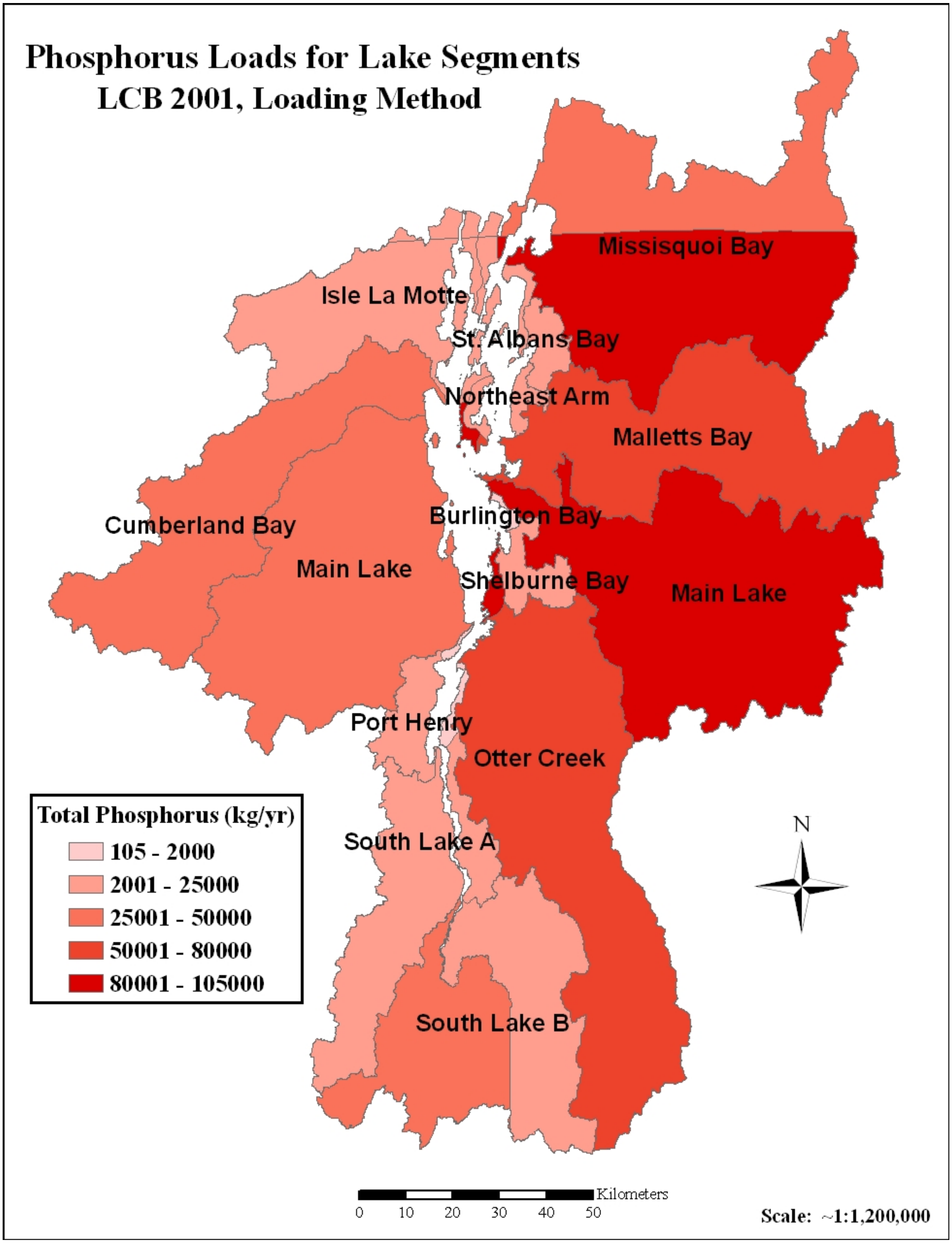

Figure 2-6. Phosphorus loads for Lake Champlain segments using LCB 2001 – loading method.

Comparison of 1992 and 2001 Estimates

A direct comparison of the lake-segment results for LCB-R 1992 and LCB 2001 better illustrates temporal and spatial patterns and differences between the phosphorus estimation methods (Table 2-14, Figure 2-7, and Figure 2-8). The export-method estimates were much higher than the loading-method results, reflecting the wide annual variation in precipitation that they encompass; on average, the Basin receives a non-point phosphorus load of about 750,000 kg or more. The difference between the two export estimates was smaller, however, and more meaningful; it identified a specific 10-year increase of 26,096 kg/yr in total phosphorus load that is almost certainly a function of land-use change. With all variables constant except for LULC, the estimated export load increased in 19 of 21 lake segments regardless of size and geographic location. This trend mirrored a similar Basin-wide increase in the Urban LULC class. Furthermore, the largest increases in phosphorus export were observed in lake segments with the largest LULC increases (by area) in the URB category, particularly the Main Lake, Otter, and Malletts Bay segments. As more land is converted from agriculture and forests to developed land uses, with a greater volume of impervious surfaces, transport of phosphorus to the lake is more rapid and concentrated.

The loading method provides a more precise estimate of the phosphorus load in a given sampling period; in this case, the estimates for both LCB-R 1992 and LCB 2001 were well below the average conditions suggested by the export estimates. The large difference between the total loading estimates further illustrates the direct influence of precipitation on runoff and, ultimately, non-point pollution; the 2001-2002 sampling period was wetter than 1991, helping to produce a loading estimate 17% larger than the earlier one. Land-use change also was an important contributor to this observed pattern, but its contribution to the overall trend cannot be directly isolated from the year-specific loading estimates. However, using the difference in export estimates as a rough indicator (26,096 kg export vs. 82,212 kg loading), about one-third of the loading increase was perhaps attributable to conversion of agricultural lands and forests to urbanized landscapes.

Note that the difference between the loading-method result would have been larger if the original, negative value of the FOR coefficient had been used in final phosphorus estimates. This observation demonstrates a potential disadvantage to the use of substitute coefficient values. Although it is important to show the real and important contribution of Forest land-use classes to phosphorus loading, our use of a substitute value to adjust the regression-derived total P outputs to the lake, reduces our ability to more accurately interpret land use changes.

Also note the large, negative difference in the loading results for the Missisquoi Bay-QUE lake segment (-12,382 kg/yr), which was attributable to an observed decrease in phosphorus measurements in the Pike watershed between 1991 and 2001-2002. The Pike watershed comprises the western third of the Missisquoi Bay-QUE segment and Agriculture is the dominant land use. In contrast to most of the watersheds in the Basin, however, about 40% less phosphorus was measured in the Pike watershed in 2001-2002 compared to 1991 (Appendix K), despite the higher Basin-wide precipitation totals in the latter sampling period. Consequently, the adjusted AG coefficient (loading method) for the Pike during the 2001-2002 period was only a third of the value for 1991 (0.11 vs. 0.29), resulting in a large decline in estimated phosphorus between the two sampling period. The adjusted AG coefficient for the Pike using the export method was also comparatively low for the 2001-2002 period (Table 2-4), but this value was obscured in the average adjusted coefficient subsequently used in final phosphorus calculations. These observations reinforce the primary distinction between the export and loading methods; the export method provides an assessment of average conditions in the Basin while the loading method focuses on specific conditions in an individual year.

Table 2-14. Comparison of export and loading results for LCB-R 1992 and LCB 2001 using coefficients derived in this study.

	Export Method			Loading Method		
Lake Segment	**LCB-R 1992 (kg/yr)**	**LCB 2001 (kg/yr)**	**Difference (kg/yr)**	**LCB-R 1992 (kg/yr)**	**LCB 2001 (kg/yr)**	**Difference (kg/yr)**
Burlington Bay	3,002	3,007	5	1,953	1,702	-251
Cumberland Bay	38,402	38,882	480	21,190	28,020	6,831
Isle La Motte-NY	33,788	35,183	1,395	14,760	21,206	6,446
Isle La Motte-QUE	3,401	3,406	6	1,636	2,142	506
Isle La Motte-VT	4,179	4,439	260	1,913	2,554	640
Main Lake-NY	55,267	56,117	851	30,670	36,808	6,138
Main Lake-VT	105,504	111,612	6,108	70,292	82,649	12,357
Malletts Bay	66,670	70,629	3,958	42,184	60,260	18,076
Missisquoi Bay-QUE	73,437	73,365	-71	59,036	46,654	-12,382
Missisquoi Bay-VT	112,995	114,353	1,358	73,907	102,974	29,067
Northeast Arm	12,138	12,649	511	6,270	7,904	1,635
Otter Creek-NY	132	132	0	82	105	23
Otter Creek-VT	109,130	115,094	5,964	70,367	76,211	5,844
Port Henry-NY	6,857	7,024	168	4,428	4,325	-103
Port Henry-VT	2,348	2,690	342	1,422	1,560	138
Shelburne Bay	14,217	15,170	954	8,558	9,538	980
South Lake A-NY	20,253	20,806	553	13,445	14,075	629
South Lake A-VT	9,573	9,981	408	5,671	5,987	317
South Lake B-NY	40,441	41,588	1,147	24,640	26,788	2,148
South Lake B-VT	32,622	33,928	1,306	21,543	23,215	1,672
St. Albans Bay	9,426	9,821	394	5,271	6,771	1,500
Total	**753,781**	**779,877**	**26,096**	**479,238**	**561,449**	**82,212**

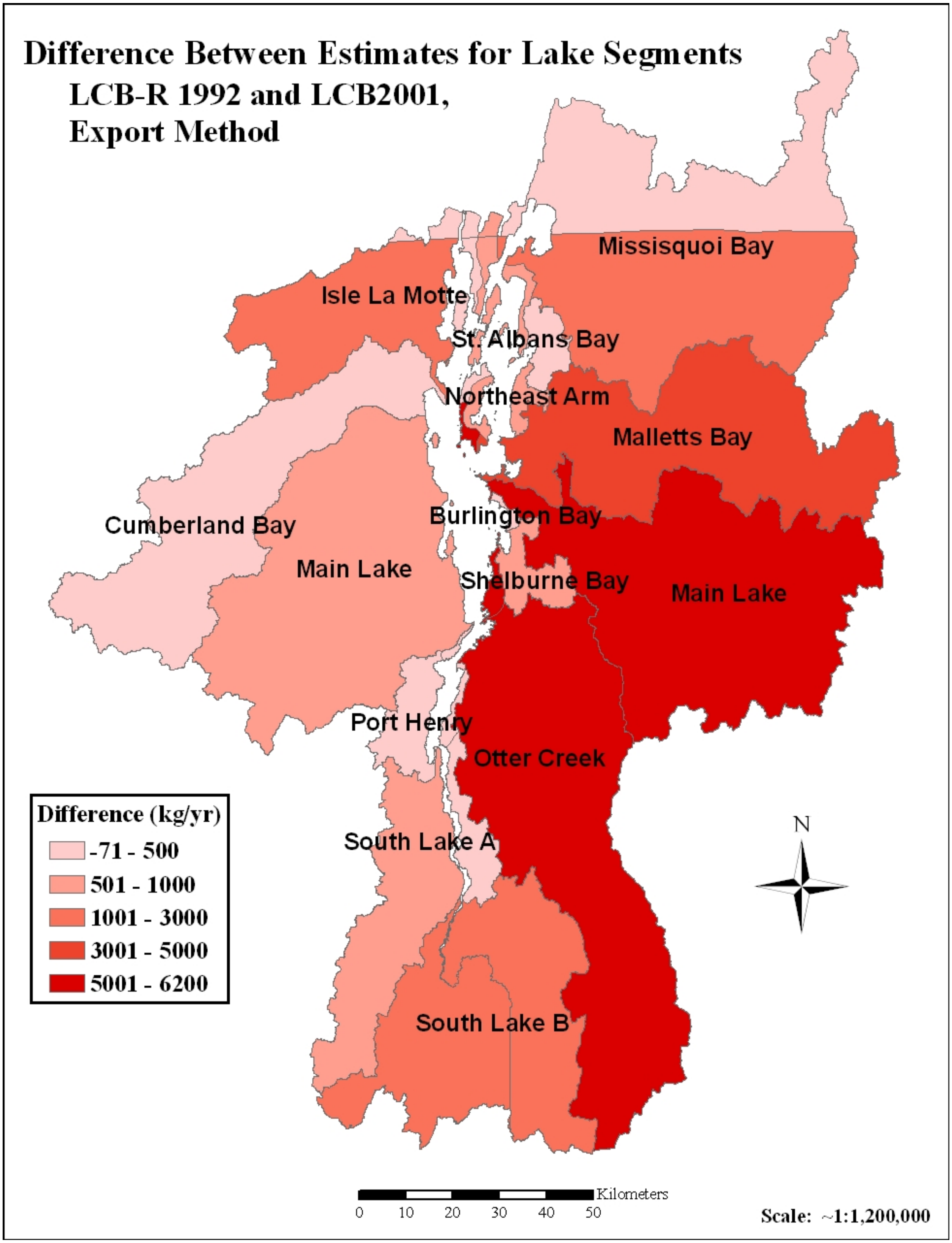

Figure 2-7. Difference (kg) between estimates for LCB-R 1992 and LCB 2001 – export method.

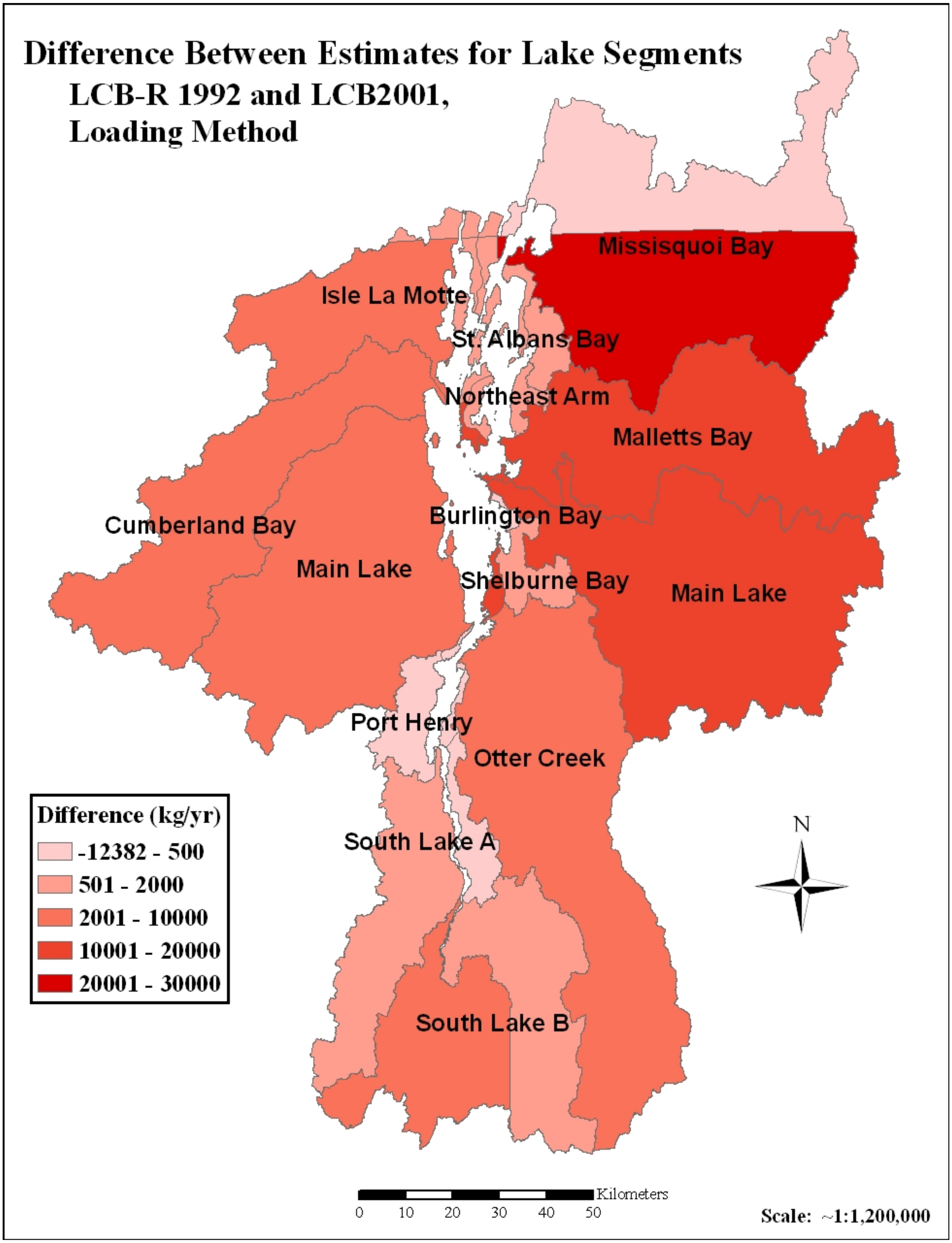

Figure 2-8. Difference (kg) between estimates for LCB-R 1992 and LCB 2001 – loading method.

To further assess the influence of LULC change on Basin-wide phosphorus loading patterns, it is informative to consider estimates derived for LCB-R 1992 and LCB 2001 using the export and loading coefficients previously reported by Hegman et al. (Table 2-15). The same patterns among lake segments were evident, with the Main Lake-VT, Otter Creek-VT, and Mallets Bay segments showing the largest increases between 1992 and 2001, but the magnitude of change in total phosphorus estimates was less than half of that observed with the new export coefficients (13,631 kg vs. 26,096 kg). It is also interesting to note that the observed difference between loading estimates was quite similar to that for export estimates (12,628 kg vs. 13,631 kg) when the same long-term precipitation data were used with both LULC datasets. Clearly, phosphorus estimates are affected by the magnitude of the coefficients used to produce them, and observed differences between estimates will increase as coefficients increase. Consequently, it is important to reiterate that our estimate of LULC-induced phosphorus change (26,096 kg) was based on average conditions in the Basin; in years with below-average precipitation, the difference would be lower while in years with above-average precipitation, the difference would be higher. Nonetheless, we believe that average export coefficients produce the best estimate of LULC-induced change because: 1) these coefficients better reflect actual LULC patterns in the Basin than those developed by Hegman et al., especially the relationship between URB and AG; 2) they reflect annual variation in phosphorus measurements; and 3) they permit comparison of temporally-distinct LULC maps in which LULC change is isolated as the primary variable of interest.

Table 2-15. Comparison of export and loading results for LCB-R 1992 and LCB 2001 using coefficients derived from Hegman et al. (1999).

	Export Method			Loading Method		
Lake Segment	LCB-R 1992 (kg/yr)	LCB 2001 (kg/yr)	Difference (kg/yr)	LCB-R 1992 (kg/yr)	LCB 2001 (kg/yr)	Difference (kg/yr)
Burlington Bay	1,794	1,797	3	1,671	1,673	2
Cumberland Bay	25,497	25,746	249	22,387	22,531	144
Isle La Motte-NY	22,483	23,266	783	20,694	21,313	619
Isle La Motte-QUE	2,241	2,244	3	2,371	2,374	3
Isle La Motte-VT	2,735	2,882	148	2,722	2,845	123
Main Lake-NY	37,120	37,590	470	31,461	31,825	364
Main Lake-VT	67,828	71,311	3,483	69,371	72,708	3,337
Malletts Bay	43,597	45,854	2,257	47,903	50,189	2,286
Missisquoi Bay-QUE	65,042	64,967	-75	70,455	70,369	-86
Missisquoi Bay-VT	101,330	100,960	-371	105,404	105,153	-251
Northeast Arm	7,902	8,191	290	7,865	8,108	243
Otter Creek-NY	94	94	0	75	75	0
Otter Creek-VT	72,111	75,504	3,393	75,042	78,144	3,103
Port Henry-NY	4,516	4,611	96	4,171	4,254	84
Port Henry-VT	1,527	1,721	194	1,598	1,766	169
Shelburne Bay	8,980	9,522	541	9,201	9,685	484
South Lake A-NY	13,453	13,766	314	12,357	12,625	267
South Lake A-VT	6,388	6,620	232	6,610	6,807	197
South Lake B-NY	26,543	27,199	656	28,733	29,358	625
South Lake B-VT	21,581	22,326	744	23,163	23,891	728
St. Albans Bay	6,071	6,292	221	6,152	6,338	186
Total	**538,832**	**552,463**	**13,631**	**549,404**	**562,033**	**12,628**

Summary and Conclusions

Use of the export and loading methods has often been determined by data availability; when specific precipitation and streamflow data are lacking, the export method provides a simple way of estimating phosphorus load from aggregated LULC data (Hegman et al. 1999). Its estimates represent average conditions in a drainage basin at any one time. In contrast, the loading method requires more data but provides a more precise estimate of non-point phosphorus pollution in a particular sampling period.

In this study, we used both methods to examine phosphorus loading patterns in the Lake Champlain Basin, taking advantage of new LULC maps that permit analysis of recent and past landscape conditions. We also had the flexibility of using phosphorus measurements collected throughout the Basin at regular sampling intervals, which helped improve modeling by encompassing wide variability in non-point pollution loads and streamflow. We used this information to better gauge the range of precipitation-induced annual fluctuations in phosphorus export.

In conjunction with the new LULC datasets, which were spaced approximately 10 years apart, the loading method produced an estimated phosphorus load of 479,238 kg for LCB-R 1992 (precipitation data for calendar year 1991) and a load of 561,449 kg for LCB 2001 (precipitation data for hydrological year 2001-2002). These figures represent the best possible estimates of actual phosphorus loading in those years; precipitation totals for the closest matching phosphorus sampling periods were used to calibrate them. Accordingly, they can be used as benchmarks in future studies examining annual fluctuations in phosphorus patterns.

The average conditions represented by the export estimates make an analysis of land use-driven phosphorus change possible. By calculating average export coefficients and applying them both to the LCB-R 1992 and LCB 2001 LULC datasets, we estimated a 10-year increase in phosphorus levels of 26,096 kg. These results showed that Urban land types play a larger role in phosphorus transfer from land to water than previously demonstrated in the Basin, and presumably this trend is attributable to conversion of agricultural lands and forest to developed uses. The new LULC maps better represent Urban features, especially Urban Open Space and roads, and regression equations produced for both the export and loading methods consistently identified larger coefficients for an aggregated Urban category. These larger coefficients in turn produced larger phosphorus estimates, and our results indicated that the Urban category was the most important source of phosphorus in most lake segments. Agriculture remains an important contributor to phosphorus loading, however, especially in lake segments where animal densities traditionally have been high. For example, the AG category was responsible for 65-70% of the load from Missisquoi Bay, which was the largest single contributor of phosphorus to Lake Champlain.

More research is needed to identify the specific contribution of Urban Open Space to phosphorus export. This LULC category is increasing throughout the Basin and could add further to the phosphorus concentrations emanating from developed areas. Although lawns are not as impervious as pavement, structures, and industrial zones, they do not slow runoff as effectively as natural vegetation cover and may contribute directly to phosphorus pollution when fertilizers are excessively applied or poorly timed.

Previously, Urban Open Space was most likely lumped with agricultural classes in LULC mapping, and more work is needed to improve discrimination of these land uses. Better classification will likely increase the already high contribution of the Urban category in regression modeling while reducing the phosphorus load erroneously assigned to Agriculture.

Animal-unit data should be used to update phosphorus estimates if they become available for the entire Basin. In their earlier study of the Basin, Hegman et al. (1999) used the number of animal units in each watershed to adjust the phosphorus contribution from the AG category. If a watershed contained more animal units than expected from a linear relationship between AG area and the number of animals, its phosphorus estimate was adjusted upwards; if a watershed contained fewer animals than expected, its estimate was adjusted downwards. Because complete, Basin-wide animal-unit data were unavailable for 2001, we adjusted only the Missisquoi and Pike watersheds, which occur in the Missisquoi Bay lake segments. Consequently, we likely underestimated the phosphorus contribution from other watersheds where high-intensity agriculture is practiced (e.g., Rock). Furthermore, strategies to reduce phosphorus emissions due to livestock and row-crop agriculture are different, meaning that isolation of these processes from a single, lumped AG coefficient can benefit land managers as they plan for various phosphorus-reduction strategies.

We believe that the export and loading methods are both useful in describing the direction and magnitude of phosphorus trends in the Lake Champlain Basin, and they are most useful when their results are interpreted together. Although these methods differ in their applicability and precision, both are improved by more and better source data, and it is our hope that phosphorus measurements continue to be collected throughout the Basin. Multiple years of sampling data are essential for developing more precise estimates and tracking long-term trends. Animal-unit data may help phosphorus modeling if they become available for the entire Basin, and additional research may also help clarify which analytical approaches best represent annual variability in phosphorus pollution.

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Glossary

CLU: USDA common land unit boundaries; individual polygons correspond to la distinct piece of land with a common owner, manager, and with a single land cover type. Only farmland that participates in a USDA program is included.

Error matrix: A table used to display LULC mapping accuracy information.

Export method: A means of examining the general relationship between phosphorus measurements and land-cover patterns; predictive equations vary greatly depending on the precipitation received in a given sampling period, which is not factored into the analysis.

Image Objects: Pixels that are grouped together based on spectral and spatial properties.

Landsat: A series of remote sensing satellites that gather data in the visible and infrared portions of the electromagnetic spectrum at a resolution of approximately 30 meters.

Loading method: A means of examining the general relationship between phosphorus measurements and land-cover patterns calibrated according to the volume of precipitation in an individual sampling period.

Overall accuracy: An LULC accuracy measurement that estimates the percent of the pixels classified correctly.

Pixels: In raster geospatial data the discrete elements that comprise the two dimensional array, often called a grid cell.

Producer's accuracy: An LULC accuracy measurement a measure of omission; the chance that a pixel in a given LULC class depicted is assigned to the correct class.

Reference points: Data gathered from the ground or from high resolution imagery used to compare the mapped LULC category with the actual LULC class.

Tasseled cap: A method of transforming multispectral satellite imagery into coefficients of greenness, wetness, and brightness; often useful for performing change detection across two or more time periods.

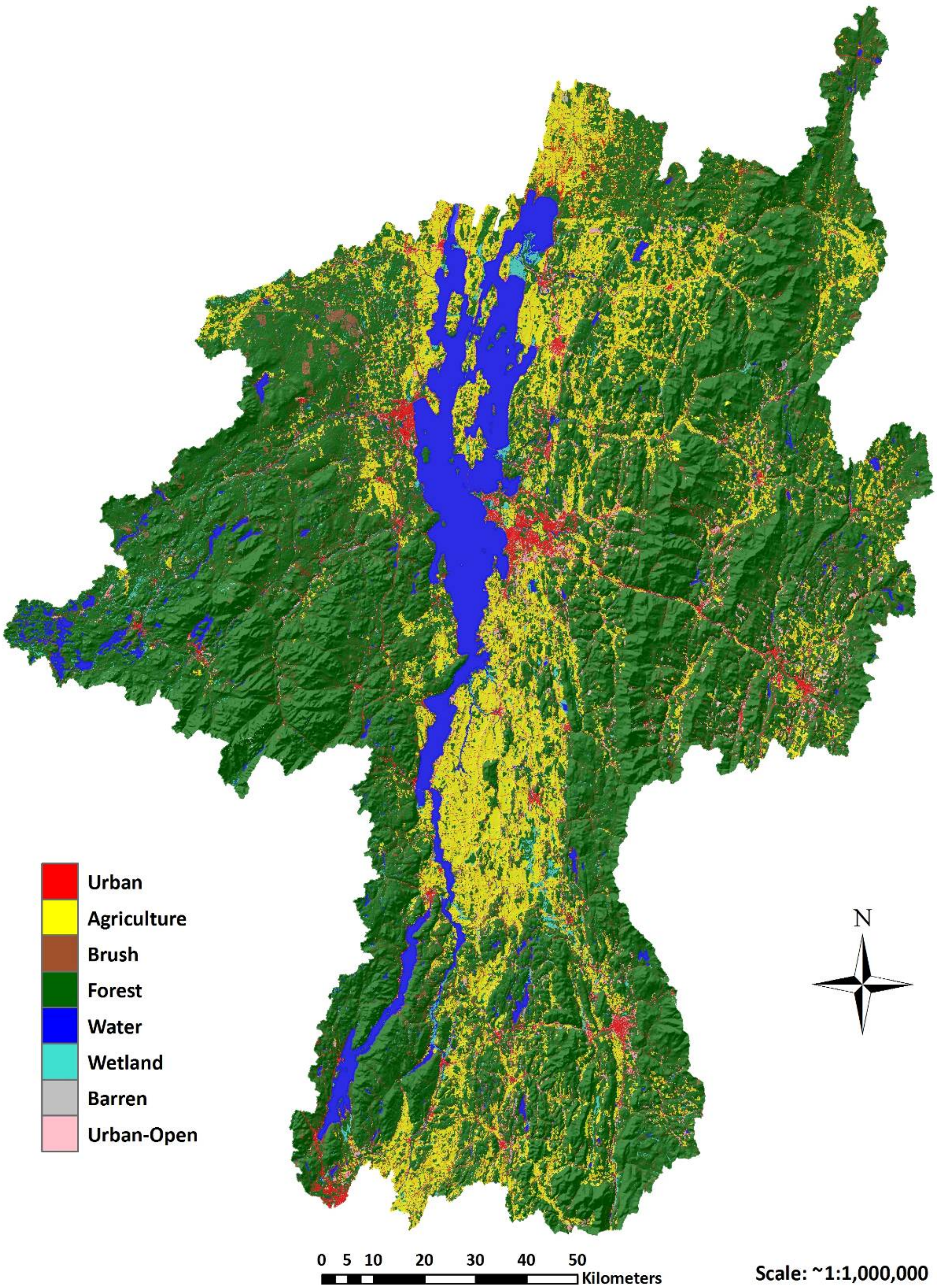
Tie points: Points generated to geo-rectify one satellite scene to another; these points occupy a common location on both scenes.

Urban fields: Large open areas with low-lying vegetation and no impervious surfaces that are "urban" with respect to land use; includes playing fields and large lawns.

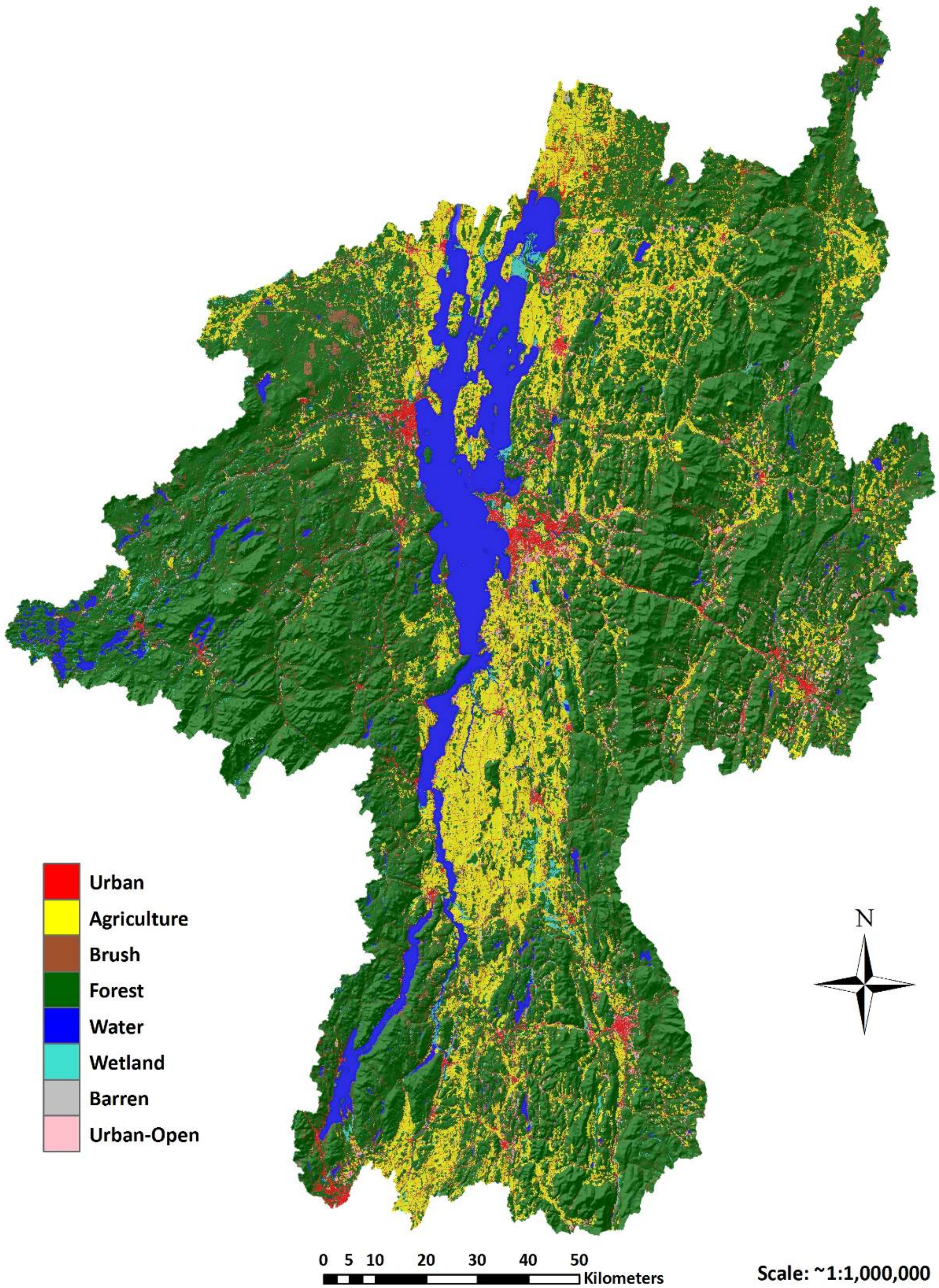
Urban-open: Areas with low-lying vegetation and little impervious surfaces that are functionally urban; often spectrally appear similar to agricultural fields.

User's accuracy: An LULC accuracy measurement a measure of commission; the likelihood of assigning a pixel in a given LULC class to the correct class.

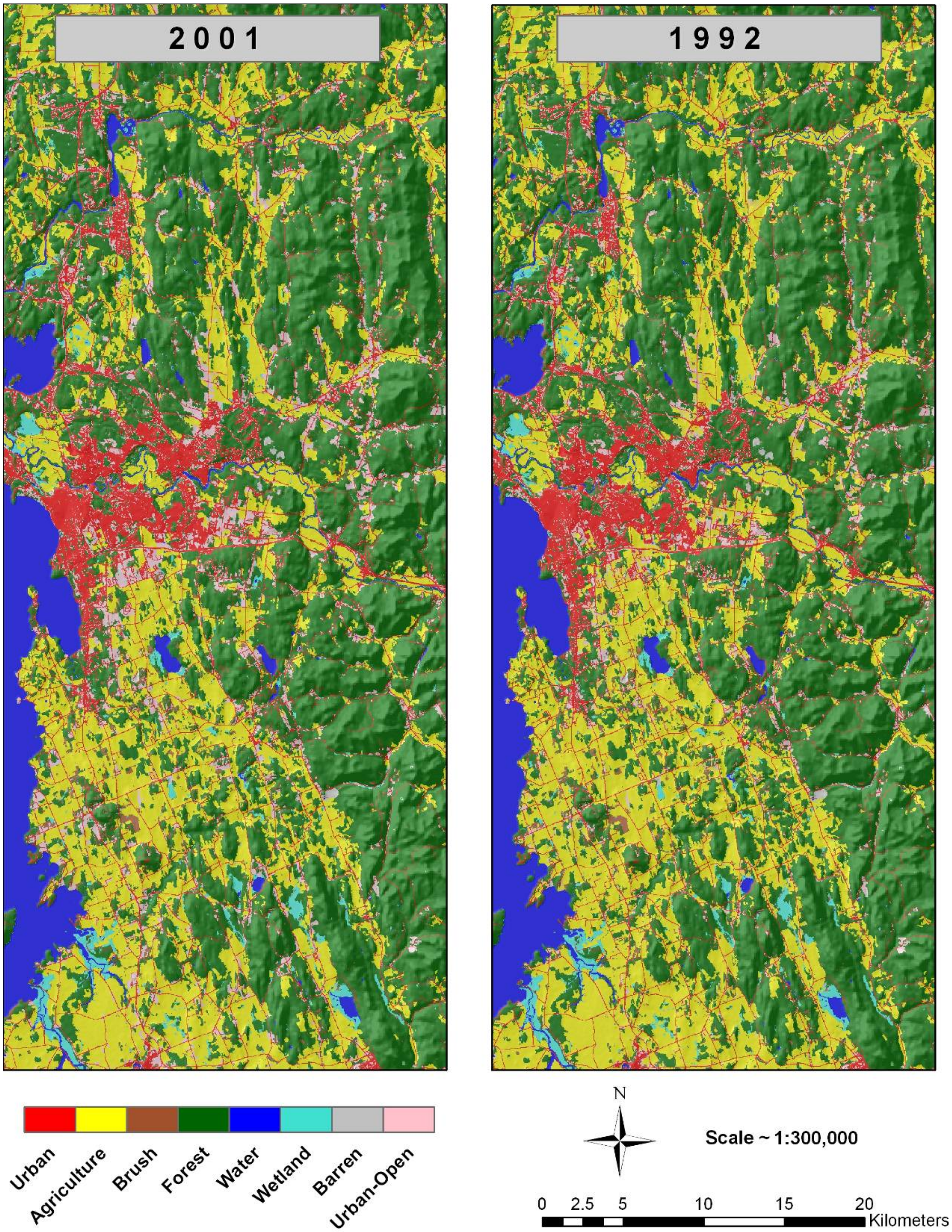
Appendix A. Circa 2001 LULC (LCB 2001).



Appendix B. Circa 1992 LULC (LCB-R 1992).



Appendix C. Circa 2001 (LCB 2001) and circa 1992 (LCB-R 1992) LULC comparison for the greater Burlington area.



Appendix D. Area (hectares) summary and change by LULC class for Vermont HUC 12 watersheds.

The Vermont HUC12 watershed layer from VCGI includes select watersheds in Quebec and New York.

HUC 12	Urban	Agriculture	Brush	Forest	Water	Wetland	Barren	Urban Open
1992								
020100070201	1272	357	417	15125	451	3	1	0
020100081007	634	6173	300	4187	11	1	200	0
020100081008	521	5749	78	1201	52	372	21	0
020100081006	655	3774	93	2536	13	1	15	0
020100081004	291	536	282	4779	4	0	5	0
020100070202	522	578	372	8676	50	3	1	0
020100081005	679	2680	371	7026	10	66	33	96
020100081103	505	3168	87	1411	16	305	5	28
020100070301	117	130	86	4291	23	0	0	0
020100070303	960	1414	575	13790	26	19	6	4
020100081003	692	990	418	9264	131	2	6	0
020100070302	348	264	285	8678	14	44	3	3
020100070104	597	4307	501	9121	10	144	11	87
020100081101	828	6399	297	6532	49	320	11	215
020100081105	10	2	1	18	173	41	0	0
020100081102	213	303	28	814	4	169	1	44
020100081607	1061	6057	189	2502	38	437	23	214
020100081608	19	2	6	60	251	22	1	4
020100081203	158	1723	33	1519	23	410	2	22
020100081002	431	2585	254	4676	5	111	6	215
020100070304	640	2489	264	10296	47	68	14	208
020100081500	3066	13810	3815	53151	1114	1791	25	763
020100070105	658	2524	363	9742	15	223	10	136
020100081001	156	875	56	1174	573	36	2	23
020100070703	764	1688	126	1977	442	1078	86	361
020100081104	75	378	7	119	84	732	1	3
020100081208	106	728	26	350	13	202	1	29
020100081210	8	2	2	13	8	6	0	1
020100081205	334	1944	38	647	28	882	1	79
020100070502	664	5886	311	5602	120	55	30	112
020100070701	404	1576	212	3845	200	98	6	133
020100070402	283	752	116	5634	6	15	1	46
020100070401	407	577	150	13511	4	24	4	113

020100070103	308	1047	266	6998	1	55	3	64
020100070702	303	2688	142	1796	1	50	1	75
020100081602	699	3001	1354	7974	77	406	8	222
020100070501	599	2618	185	11385	15	46	3	165
020100081606	1735	4580	344	3772	172	543	12	540
020100070603	477	4071	203	5524	7	38	3	126
020100081202	745	3660	77	1123	11	131	2	246
020100070602	265	1165	174	4056	204	238	3	132
020100070102	205	689	85	4805	10	35	3	33
020100070601	565	2514	235	10794	59	126	5	117
020100081204	590	1982	201	3896	56	220	4	262
020100080903	4	9	0	7	5	11	0	1
020100081300	1126	3041	806	13708	47	235	0	336
020100050104	482	797	229	9212	45	74	14	212
020100030401	819	524	438	11362	23	61	13	568
020100020201	429	599	187	11206	10	114	4	242
020100070101	276	405	211	7199	20	36	160	90
020100081601	1165	3279	419	5476	36	574	8	237
020100081201	555	2824	118	2254	25	46	3	158
020100050302	362	468	127	14450	46	222	7	83
020100050301	768	1242	384	13524	165	155	66	470
020100050306	1125	3086	400	7300	527	487	25	565
020100050305	483	2264	168	5589	23	50	8	204
020100050103	412	882	219	8363	31	89	3	152
020100050303	600	1863	208	11625	44	71	21	154
020100050105	70	44	164	4369	255	87	1	12
020100081400	1108	1376	655	13601	101	276	2	409
020100050304	654	1729	299	10183	52	56	7	296
020100050202	732	2424	306	9693	17	102	24	644
020100080901	1812	2178	493	7680	133	270	24	959
020100050101	721	1371	597	11742	425	99	19	201
020100050107	598	1575	235	8118	25	72	23	254
020100050106	975	2406	300	8350	155	173	27	446
020100050102	821	2140	479	11013	234	136	29	202
020100030704	3427	2917	354	4025	278	566	33	1157
020100050201	571	909	245	7761	11	27	5	441
020100081605	1035	12	26	198	8	56	3	231
020100030602	892	960	475	11156	12	46	34	458
020100081604	821	1378	349	9565	216	210	0	242
020100030702	987	1961	377	11004	113	89	80	582
020100030301	214	76	130	8071	38	67	4	93

020100030603	615	351	368	12876	217	65	16	475
020100030203	910	740	450	10449	334	239	25	586
020100030703	726	1914	174	2077	201	137	5	275
020100080802	1404	987	125	885	4	23	21	603
020100030201	639	1126	460	9717	357	57	11	263
020100080804	0	0	0	2	2	0	0	0
020100030604	457	177	181	12360	58	30	12	89
020100081603	338	2003	194	831	23	45	0	165
020100080803	29	45	4	104	11	1	0	12
020100080700	2743	4000	534	62370	698	427	141	473
020100030302	589	268	245	9789	76	56	12	419
020100030601	735	647	306	8135	34	42	15	506
020100030202	871	1054	501	13228	80	144	12	687
020100080801	1105	5700	651	5364	143	170	2	588
020100030701	584	1158	165	14972	14	37	3	305
020100030403	615	244	175	7016	35	22	10	376
020100030204	811	2170	341	5051	29	121	15	455
020100080502	584	3840	267	5017	196	551	12	181
020100080501	408	1432	118	7741	8	89	56	189
020100080603	208	1251	85	585	5	14	0	95
020100030504	694	1104	170	10366	17	24	5	317
020100030503	140	47	27	4140	0	5	0	104
020100080604	2	3	2	30	71	24	0	2
020100080602	1019	1679	336	14574	176	82	2	225
020100080401	574	5523	272	4932	11	156	29	212
020100030402	588	472	437	8334	5	50	30	318
020100080601	319	1607	86	611	26	64	1	155
020100030103	1405	1049	455	4653	115	56	19	607
020100080402	351	4631	164	1387	107	316	0	112
020100030502	539	559	161	8170	7	15	106	306
020100020502	581	5353	141	2052	179	341	1	192
020100030102	868	940	481	9475	62	97	67	426
020100020202	189	369	69	3895	6	74	1	93
020100030101	860	1834	364	5365	26	59	146	351
020100020501	714	12035	377	1650	532	97	4	128
020100020203	583	3535	212	7982	20	93	8	209
020100030501	423	292	68	9196	19	13	3	233
020100020308	930	6569	410	4018	140	1013	24	276
020100080303	418	6513	328	1057	43	95	4	74
020100020402	548	7670	358	2976	11	407	5	193
020100080305	510	1300	116	5540	58	109	7	140

020100020306	628	1822	376	12987	13	200	9	212
020100080306	2	1	1	13	43	17	0	2
020100080302	542	532	113	13956	396	286	50	136
020100010303	618	1093	379	9721	12	331	10	227
020100020109	1368	1867	275	5690	36	123	9	620
020100080304	353	1763	107	2390	51	113	0	71
020100020305	384	1002	315	6820	550	547	2	113
020100020401	489	6742	844	2957	81	80	2	126
020100080301	372	4096	528	2797	66	341	2	109
020100020303	328	439	171	4144	4	48	4	93
020100080202	478	457	75	5943	39	89	5	122
020100020304	308	1650	388	2992	41	816	18	122
020100080201	2662	450	734	43584	11990	616	8	386
020100080105	466	795	660	6544	293	253	36	139
020100080107	0	0	0	3	50	41	0	0
020100020302	459	1517	446	6076	70	273	18	192
020100080106	215	1510	401	3158	64	95	0	32
020100020301	500	926	277	9338	17	111	7	283
020100010306	474	3227	732	6261	458	239	5	99
020100020107	1095	693	180	12690	365	208	41	553
020100010304	915	823	511	9023	1189	348	10	507
020100080104	136	331	183	2248	15	46	0	38
020100010307	662	3240	1021	5309	197	349	0	205
020100010305	236	646	263	2601	102	91	5	96
020100020106	299	119	104	8754	8	30	2	155
020100080102	158	139	110	4253	124	86	3	29
020100020108	529	1677	280	9140	39	357	2	242
020100010302	603	1998	662	6181	35	167	3	255
020100080101	107	1	120	6021	143	45	0	13
020100010301	397	1106	253	7639	8	39	0	210
020100010205	885	3461	1114	8949	188	261	8	351
020100020105	642	1189	344	8787	41	186	0	425
020100010100	4078	15138	3051	26979	676	781	14	758
020100010203	724	2048	482	9311	463	193	0	328
020100020103	600	1499	229	10157	32	217	20	315
020100020104	245	213	100	5848	66	118	0	203
020100010202	198	1018	88	3501	1	37	0	48
020100010204	501	2754	670	5332	28	151	8	141
020100020102	95	0	177	6360	17	80	0	1
020100020101	322	789	58	7222	45	208	3	142
020100010201	347	1514	160	9089	2	42	1	153

2001								
020100070201	1272	357	417	15125	451	3	1	0
020100081007	634	6173	300	4187	11	1	200	0
020100081008	521	5749	78	1201	52	372	21	0
020100081006	655	3774	93	2536	13	1	15	0
020100081004	291	536	282	4779	4	0	5	0
020100070202	522	578	372	8676	50	3	1	0
020100081005	685	2638	370	7027	10	66	33	133
020100081103	508	3145	87	1411	16	305	5	49
020100070301	117	130	86	4291	23	0	0	0
020100070303	967	1407	575	13789	26	19	6	6
020100081003	692	990	418	9264	131	2	6	0
020100070302	348	264	164	8798	14	44	3	3
020100070104	617	4260	525	9067	10	144	11	144
020100081101	857	6221	297	6532	49	320	11	364
020100081105	10	2	1	18	173	41	0	0
020100081102	216	293	28	814	4	169	1	51
020100081607	1121	5935	191	2493	38	437	23	283
020100081608	20	2	3	61	251	22	1	5
020100081203	163	1710	33	1519	23	410	2	31
020100081002	450	2439	258	4666	5	111	6	347
020100070304	655	2460	252	10260	47	68	14	270
020100081500	3181	12414	4601	53291	1114	1791	25	1119
020100070105	671	2484	367	9731	15	223	10	171
020100081001	160	863	54	1176	573	36	2	30
020100070703	808	1538	118	1981	442	1078	86	471
020100081104	77	377	7	119	84	732	1	3
020100081208	117	711	26	350	13	202	1	35
020100081210	8	2	2	13	8	6	0	1
020100081205	342	1908	38	646	28	882	1	107
020100070502	694	5832	248	5607	120	55	30	194
020100070701	422	1526	213	3803	200	98	6	205
020100070402	290	714	93	5651	6	15	1	85
020100070401	416	540	151	13497	4	24	4	154
020100070103	317	1041	282	6961	1	55	3	82
020100070702	324	2625	112	1820	1	48	1	126
020100081602	710	2644	1602	7988	77	406	8	307
020100070501	618	2531	183	11354	15	46	3	266
020100081606	1774	4371	369	3787	172	544	12	670
020100070603	494	3999	185	5520	7	38	3	204
020100081202	789	3553	70	1130	11	131	2	309

020100070602	273	1090	172	4058	204	238	3	199
020100070102	210	670	90	4799	10	35	3	49
020100070601	580	2458	222	10806	59	126	5	161
020100081204	604	1899	181	3913	56	220	4	333
020100080903	4	9	0	7	5	11	0	1
020100081300	1145	2781	952	13760	47	235	0	379
020100050104	492	721	220	9217	45	74	14	282
020100030401	829	412	517	11281	23	61	13	670
020100020201	429	513	188	11204	10	114	4	327
020100070101	280	395	129	7278	20	36	160	99
020100081601	1192	3116	449	5487	36	575	8	329
020100081201	589	2728	95	2276	25	46	3	222
020100050302	372	431	129	14445	46	222	7	113
020100050301	789	1092	407	13494	165	155	66	605
020100050306	1161	2901	388	7306	527	487	25	720
020100050305	509	2140	172	5580	23	50	8	306
020100050103	421	840	226	8351	31	89	3	190
020100050303	618	1806	216	11602	44	71	21	208
020100050105	71	24	202	4349	255	87	1	13
020100081400	1119	1133	801	13629	101	276	2	465
020100050304	671	1607	278	10197	52	56	7	410
020100050202	746	2191	300	9694	17	102	24	867
020100080901	1899	1899	481	7668	133	270	24	1175
020100050101	740	1302	639	11674	425	99	19	278
020100050107	621	1447	234	8107	25	72	23	371
020100050106	1004	2204	302	8347	155	173	27	620
020100050102	836	2047	475	11005	234	136	29	292
020100030704	3532	2583	348	3996	278	566	33	1420
020100050201	577	849	246	7752	11	27	5	502
020100081605	1038	10	26	198	8	56	3	231
020100030602	904	855	485	11146	12	46	34	551
020100081604	842	1225	392	9581	216	210	0	316
020100030702	1002	1796	371	11004	113	89	80	737
020100030301	215	65	139	8066	38	67	4	99
020100030603	622	268	367	12877	217	65	16	553
020100030203	920	657	470	10427	334	239	25	662
020100030703	746	1720	181	2069	201	137	5	450
020100080802	1422	759	125	879	4	23	21	818
020100030201	662	1030	461	9709	357	57	11	345
020100080804	0	0	0	2	2	0	0	0
020100030604	459	170	181	12359	58	30	12	94

020100081603	340	1875	193	831	23	45	0	292
020100080803	29	41	4	104	11	1	0	16
020100080700	2760	3900	540	62374	698	427	141	545
020100030302	595	190	255	9778	76	56	12	492
020100030601	757	460	297	8140	34	42	15	674
020100030202	891	874	502	13219	80	144	12	854
020100080801	1107	5439	651	5364	143	170	2	848
020100030701	584	1116	160	14975	14	37	3	347
020100030403	618	236	177	7012	35	22	10	381
020100030204	844	1952	345	5042	29	121	15	645
020100080502	596	3558	268	5015	196	551	12	451
020100080501	408	1393	128	7731	8	89	56	228
020100080603	210	1149	85	585	5	14	0	195
020100030504	696	966	241	10294	17	24	5	454
020100030503	140	46	55	4111	0	5	0	106
020100080604	2	3	2	30	71	24	0	2
020100080602	1034	1624	338	14571	176	82	2	267
020100080401	580	5239	271	4932	11	156	29	492
020100030402	597	436	398	8337	5	50	30	381
020100080601	322	1418	86	611	26	64	1	342
020100030103	1454	833	423	4665	115	56	19	793
020100080402	357	4407	164	1387	107	316	0	330
020100030502	540	503	161	8170	7	15	106	362
020100020502	588	5114	141	2052	179	341	1	424
020100030102	901	789	487	9460	62	97	67	552
020100020202	189	344	69	3895	6	74	1	118
020100030101	889	1653	359	5353	26	59	146	519
020100020501	724	11874	377	1650	532	97	4	280
020100020203	592	3335	213	7980	20	93	8	400
020100030501	424	211	68	9196	19	13	3	314
020100020308	952	6324	410	4009	140	1013	24	507
020100080303	425	6404	327	1058	43	95	4	177
020100020402	556	7426	361	2970	11	407	5	432
020100080305	525	1233	116	5538	58	109	7	194
020100020306	636	1755	400	12959	13	200	9	275
020100080306	2	1	1	13	43	17	0	2
020100080302	543	498	113	13956	396	286	50	169
020100010303	621	1039	380	9718	12	331	10	279
020100020109	1389	1755	277	5688	36	123	9	711
020100080304	405	1676	109	2393	51	113	0	101
020100020305	389	942	319	6816	550	547	2	169

020100020401	492	6626	851	2948	81	80	2	241
020100080301	376	3980	531	2791	66	341	2	225
020100020303	330	413	180	4132	4	48	4	121
020100080202	486	423	75	5943	39	89	5	148
020100020304	312	1606	387	2990	41	816	18	165
020100080201	2671	384	734	43584	11990	616	8	443
020100080105	470	781	660	6543	293	253	36	149
020100080107	0	0	0	3	50	41	0	0
020100020302	468	1423	453	6065	70	272	18	282
020100080106	215	1489	401	3158	64	95	0	54
020100020301	504	817	285	9326	17	111	7	391
020100010306	475	3169	735	6257	458	239	5	156
020100020107	1103	655	180	12690	365	208	41	582
020100010304	918	762	516	9018	1189	348	10	566
020100080104	138	310	183	2248	15	46	0	57
020100010307	665	3140	1021	5309	197	349	0	302
020100010305	238	600	264	2600	102	91	5	140
020100020106	301	100	152	8706	8	30	2	172
020100080102	159	137	139	4224	124	86	3	31
020100020108	534	1610	279	9140	39	357	2	305
020100010302	612	1923	665	6174	35	167	3	325
020100080101	107	1	120	6021	143	45	0	13
020100010301	399	1027	252	7638	8	39	0	288
020100010205	895	3362	1131	8929	188	261	8	441
020100020105	643	1156	343	8789	41	186	0	457
020100010100	4167	14714	3075	26938	676	781	14	1111
020100010203	729	1953	485	9306	463	193	0	421
020100020103	616	1383	229	10158	32	217	20	416
020100020104	245	202	100	5848	66	118	0	215
020100010202	198	998	89	3501	1	37	0	67
020100010204	506	2755	670	5305	28	151	8	163
020100020102	95	0	177	6360	17	80	0	1
020100020101	323	768	57	7222	45	208	3	163
020100010201	348	1450	160	9089	2	42	1	216
Change								
020100070201	0	0	0	0	0	0	0	0
020100081007	0	0	0	0	0	0	0	0
020100081008	0	0	0	0	0	0	0	0
020100081006	0	0	0	0	0	0	0	0
020100081004	0	0	0	0	0	0	0	0
020100070202	0	0	0	0	0	0	0	0

020100081005	6	-42	-1	1	0	0	0	37
020100081103	3	-23	0	0	0	0	0	21
020100070301	0	0	0	0	0	0	0	0
020100070303	7	-7	0	-1	0	0	0	2
020100081003	0	0	0	0	0	0	0	0
020100070302	0	0	-121	120	0	0	0	0
020100070104	20	-47	24	-54	0	0	0	57
020100081101	29	-178	0	0	0	0	0	149
020100081105	0	0	0	0	0	0	0	0
020100081102	3	-10	0	0	0	0	0	7
020100081607	60	-122	2	-9	0	0	0	69
020100081608	1	0	-3	1	0	0	0	1
020100081203	5	-13	0	0	0	0	0	9
020100081002	19	-146	4	-10	0	0	0	132
020100070304	15	-29	-12	-36	0	0	0	62
020100081500	115	-1396	786	140	0	0	0	356
020100070105	13	-40	4	-11	0	0	0	35
020100081001	4	-12	-2	2	0	0	0	7
020100070703	44	-150	-8	4	0	0	0	110
020100081104	2	-1	0	0	0	0	0	0
020100081208	11	-17	0	0	0	0	0	6
020100081210	0	0	0	0	0	0	0	0
020100081205	8	-36	0	-1	0	0	0	28
020100070502	30	-54	-63	5	0	0	0	82
020100070701	18	-50	1	-42	0	0	0	72
020100070402	7	-38	-23	17	0	0	0	39
020100070401	9	-37	1	-14	0	0	0	41
020100070103	9	-6	16	-37	0	0	0	18
020100070702	21	-63	-30	24	0	-2	0	51
020100081602	11	-357	248	14	0	0	0	85
020100070501	19	-87	-2	-31	0	0	0	101
020100081606	39	-209	25	15	0	1	0	130
020100070603	17	-72	-18	-4	0	0	0	78
020100081202	44	-107	-7	7	0	0	0	63
020100070602	8	-75	-2	2	0	0	0	67
020100070102	5	-19	5	-6	0	0	0	16
020100070601	15	-56	-13	12	0	0	0	44
020100081204	14	-83	-20	17	0	0	0	71
020100080903	0	0	0	0	0	0	0	0
020100081300	19	-260	146	52	0	0	0	43
020100050104	10	-76	-9	5	0	0	0	70

020100030401	10	-112	79	-81	0	0	0	102
020100020201	0	-86	1	-2	0	0	0	85
020100070101	4	-10	-82	79	0	0	0	9
020100081601	27	-163	30	11	0	1	0	92
020100081201	34	-96	-23	22	0	0	0	64
020100050302	10	-37	2	-5	0	0	0	30
020100050301	21	-150	23	-30	0	0	0	135
020100050306	36	-185	-12	6	0	0	0	155
020100050305	26	-124	4	-9	0	0	0	102
020100050103	9	-42	7	-12	0	0	0	38
020100050303	18	-57	8	-23	0	0	0	54
020100050105	1	-20	38	-20	0	0	0	1
020100081400	11	-243	146	28	0	0	0	56
020100050304	17	-122	-21	14	0	0	0	114
020100050202	14	-233	-6	1	0	0	0	223
020100080901	87	-279	-12	-12	0	0	0	216
020100050101	19	-69	42	-68	0	0	0	77
020100050107	23	-128	-1	-11	0	0	0	117
020100050106	29	-202	2	-3	0	0	0	174
020100050102	15	-93	-4	-8	0	0	0	90
020100030704	105	-334	-6	-29	0	0	0	263
020100050201	6	-60	1	-9	0	0	0	61
020100081605	3	-2	0	0	0	0	0	0
020100030602	12	-105	10	-10	0	0	0	93
020100081604	21	-153	43	16	0	0	0	74
020100030702	15	-165	-6	0	0	0	0	155
020100030301	1	-11	9	-5	0	0	0	6
020100030603	7	-83	-1	1	0	0	0	78
020100030203	10	-83	20	-22	0	0	0	76
020100030703	20	-194	7	-8	0	0	0	175
020100080802	18	-228	0	-6	0	0	0	215
020100030201	23	-96	1	-8	0	0	0	82
020100080804	0	0	0	0	0	0	0	0
020100030604	2	-7	0	-1	0	0	0	5
020100081603	2	-128	-1	0	0	0	0	127
020100080803	0	-4	0	0	0	0	0	4
020100080700	17	-100	6	4	0	0	0	72
020100030302	6	-78	10	-11	0	0	0	73
020100030601	22	-187	-9	5	0	0	0	168
020100030202	20	-180	1	-9	0	0	0	167
020100080801	2	-261	0	0	0	0	0	260

020100030701	0	-42	-5	3	0	0	0	42
020100030403	3	-8	2	-4	0	0	0	5
020100030204	33	-218	4	-9	0	0	0	190
020100080502	12	-282	1	-2	0	0	0	270
020100080501	0	-39	10	-10	0	0	0	39
020100080603	2	-102	0	0	0	0	0	100
020100030504	2	-138	71	-72	0	0	0	137
020100030503	0	-1	28	-29	0	0	0	2
020100080604	0	0	0	0	0	0	0	0
020100080602	15	-55	2	-3	0	0	0	42
020100080401	6	-284	-1	0	0	0	0	280
020100030402	9	-36	-39	3	0	0	0	63
020100080601	3	-189	0	0	0	0	0	187
020100030103	49	-216	-32	12	0	0	0	186
020100080402	6	-224	0	0	0	0	0	218
020100030502	1	-56	0	0	0	0	0	56
020100020502	7	-239	0	0	0	0	0	232
020100030102	33	-151	6	-15	0	0	0	126
020100020202	0	-25	0	0	0	0	0	25
020100030101	29	-181	-5	-12	0	0	0	168
020100020501	10	-161	0	0	0	0	0	152
020100020203	9	-200	1	-2	0	0	0	191
020100030501	1	-81	0	0	0	0	0	81
020100020308	22	-245	0	-9	0	0	0	231
020100080303	7	-109	-1	1	0	0	0	103
020100020402	8	-244	3	-6	0	0	0	239
020100080305	15	-67	0	-2	0	0	0	54
020100020306	8	-67	24	-28	0	0	0	63
020100080306	0	0	0	0	0	0	0	0
020100080302	1	-34	0	0	0	0	0	33
020100010303	3	-54	1	-3	0	0	0	52
020100020109	21	-112	2	-2	0	0	0	91
020100080304	52	-87	2	3	0	0	0	30
020100020305	5	-60	4	-4	0	0	0	56
020100020401	3	-116	7	-9	0	0	0	115
020100080301	4	-116	3	-6	0	0	0	116
020100020303	2	-26	9	-12	0	0	0	28
020100080202	8	-34	0	0	0	0	0	26
020100020304	4	-44	-1	-2	0	0	0	43
020100080201	9	-66	0	0	0	0	0	57
020100080105	4	-14	0	-1	0	0	0	10

020100080107	0	0	0	0	0	0	0	0
020100020302	9	-94	7	-11	0	-1	0	90
020100080106	0	-21	0	0	0	0	0	22
020100020301	4	-109	8	-12	0	0	0	108
020100010306	1	-58	3	-4	0	0	0	57
020100020107	8	-38	0	0	0	0	0	29
020100010304	3	-61	5	-5	0	0	0	59
020100080104	2	-21	0	0	0	0	0	19
020100010307	3	-100	0	0	0	0	0	97
020100010305	2	-46	1	-1	0	0	0	44
020100020106	2	-19	48	-48	0	0	0	17
020100080102	1	-2	29	-29	0	0	0	2
020100020108	5	-67	-1	0	0	0	0	63
020100010302	9	-75	3	-7	0	0	0	70
020100080101	0	0	0	0	0	0	0	0
020100010301	2	-79	-1	-1	0	0	0	78
020100010205	10	-99	17	-20	0	0	0	90
020100020105	1	-33	-1	2	0	0	0	32
020100010100	89	-424	24	-41	0	0	0	353
020100010203	5	-95	3	-5	0	0	0	93
020100020103	16	-116	0	1	0	0	0	101
020100020104	0	-11	0	0	0	0	0	12
020100010202	0	-20	1	0	0	0	0	19
020100010204	5	1	0	-27	0	0	0	22
020100020102	0	0	0	0	0	0	0	0
020100020101	1	-21	-1	0	0	0	0	21
020100010201	1	-64	0	0	0	0	0	63

Appendix E. Area (hectares) summary and change by LULC class for New York HUC 11 watersheds.

The New York HUC 11 watersheds layer includes select watersheds in Quebec. Those watersheds where a HUC 11 designator was not available are listed as" N/A."

HUC 11	Urban	Agriculture	Brush	Forest	Water	Wetland	Barren	Urban Open
1992								
02010006110	296	1839	80	503	380	51	19	1
02010006090	14	346	22	617	0	12	0	0
02010006090	4	17	0	1	0	0	0	2
02010006100	370	1018	49	525	14	249	3	127
02010006090	944	4633	415	6641	54	571	2	233
01410065407	0	1	1	13	0	1	0	0
N/A	552	2608	586	7353	44	377	8	215
02010006080	1551	6172	2793	38423	1016	827	14	313
02010006130	24	338	3	13	2	12	0	0
02010006070	696	3004	1351	8052	77	409	8	222
02010006140	206	1484	73	830	27	72	9	52
02010006060	182	1397	48	833	1	113	0	24
02010006050	1347	3255	421	5465	40	574	8	240
02010006040	1478	471	372	4889	166	127	7	519
02010006030	1369	1519	965	20919	260	289	1	680
02010004110	586	5	10	266	15	12	0	173
02010004090	1097	1367	653	13629	101	276	2	409
02010006020	786	422	1050	28740	1083	946	8	180
02010004100	200	625	112	895	11	30	0	114
02010004080	1093	2976	793	13441	46	213	0	317
02010006010	2444	1135	904	74117	9047	3685	20	665
02010004120	53	69	18	414	60	107	0	25
02010004070	1445	1795	786	15882	445	387	0	340
02010004060	1926	481	627	54426	1899	674	17	525
02010004040	601	414	292	8245	292	158	0	190
02010004050	1321	678	310	47985	321	231	119	292
02010004020	1003	852	201	23218	127	140	92	168
02010004030	1704	3146	303	38373	486	280	49	308
02010004010	245	965	76	1852	23	58	0	50
02010001260	603	1563	177	8321	52	33	1	139
02010001250	420	116	160	6262	141	52	1	87
02010001240	232	222	24	2385	12	15	7	89
02010001230	181	699	69	3012	34	83	1	28
02010001220	542	532	113	13957	396	284	50	136
02010001210	353	1763	107	2394	53	116	0	71
02010001200	460	457	75	5932	59	91	5	119
02010001180	236	642	193	2812	96	48	0	54
02010001170	136	334	184	2242	14	30	0	38
02010001160	230	150	465	3736	178	199	36	85
02010001070	49	162	127	587	6	14	0	18

02010001080	111	829	198	1105	58	97	0	22
02010001150	261	140	232	10285	235	144	3	42
02010001130	200	986	244	1172	5	68	0	67
02010001100	158	581	192	2130	15	83	0	64
02010001140	4250	15218	3091	27600	729	828	14	813
02010001120	1214	4686	1325	10345	197	333	1	343
02010001110	64	261	117	602	2	16	0	22
02010001120	0	7	0	51	0	0	0	0
N/A	2583	450	726	37872	529	507	6	382
01410065407	34	0	4	260	11354	48	1	7
N/A	63	0	2	5460	108	62	0	0
N/A	0	0	0	0	0	0	0	0
2001								
02010006110	297	1839	82	499	380	51	19	1
02010006090	14	331	35	620	0	12	0	0
02010006090	4	17	0	1	0	0	0	2
02010006100	418	930	48	526	14	249	3	168
02010006090	1014	4357	488	6660	54	571	2	346
01410065407	0	1	1	13	0	1	0	0
N/A	566	2284	731	7377	44	377	8	357
02010006080	1581	5393	3346	38517	1016	827	14	414
02010006130	24	339	4	11	2	12	0	0
02010006070	706	2647	1601	8066	77	409	8	306
02010006140	220	1444	81	831	27	72	9	71
02010006060	191	1362	59	839	1	113	0	34
02010006050	1374	3096	451	5477	40	575	8	331
02010006040	1497	316	460	4907	166	127	7	551
02010006030	1390	1163	1127	20976	260	289	1	796
02010004110	588	0	12	267	15	12	0	173
02010004090	1109	1125	799	13657	101	276	2	465
02010006020	799	44	1277	28877	1083	946	8	180
02010004100	204	595	116	897	11	30	0	135
02010004080	1111	2717	940	13492	46	213	0	360
02010006010	2482	618	1178	74312	9047	3685	20	675
02010004120	55	63	18	416	60	107	0	28
02010004070	1469	1521	940	15937	445	387	0	383
02010004060	1943	300	711	54474	1899	674	17	558
02010004040	617	319	335	8261	292	158	0	211
02010004050	1330	573	344	48002	321	231	119	336
02010004020	1005	830	207	23222	127	140	92	177
02010004030	1717	3071	303	38373	486	280	49	370
02010004010	251	905	76	1852	23	58	0	103
02010001260	617	1514	178	8318	52	33	1	175
02010001250	422	110	160	6260	141	52	1	92
02010001240	236	204	23	2383	12	15	7	104
02010001230	186	687	69	3012	34	83	1	34
02010001220	543	498	113	13956	396	284	50	169
02010001210	405	1676	109	2396	53	116	0	101

02010001200	468	423	75	5932	59	91	5	145
02010001180	239	630	193	2811	96	48	0	63
02010001170	138	313	184	2242	14	30	0	56
02010001160	231	148	465	3736	178	199	36	86
02010001070	49	154	127	587	6	14	0	26
02010001080	111	826	198	1105	58	97	0	25
02010001150	262	137	261	10256	235	144	3	44
02010001130	203	971	244	1172	5	68	0	79
02010001100	160	571	192	2130	15	83	0	72
02010001140	4339	14795	3115	27559	729	828	14	1165
02010001120	1227	4599	1341	10324	197	333	1	422
02010001110	66	257	113	605	2	16	0	25
02010001120	0	7	0	51	0	0	0	0
N/A	2592	384	726	37872	529	507	6	439
01410065407	34	0	4	260	11354	48	1	7
N/A	63	0	2	5460	108	62	0	0
N/A	0	0	0	0	0	0	0	0
Change								
02010006110	1	0	2	-4	0	0	0	0
02010006090	0	-15	13	3	0	0	0	0
02010006090	0	0	0	0	0	0	0	0
02010006100	48	-88	-1	1	0	0	0	41
02010006090	70	-276	73	19	0	0	0	113
01410065407	0	0	0	0	0	0	0	0
N/A	14	-324	145	24	0	0	0	142
02010006080	30	-779	553	94	0	0	0	101
02010006130	0	1	1	-2	0	0	0	0
02010006070	10	-357	250	14	0	0	0	84
02010006140	14	-40	8	1	0	0	0	19
02010006060	9	-35	11	6	0	0	0	10
02010006050	27	-159	30	12	0	1	0	91
02010006040	19	-155	88	18	0	0	0	32
02010006030	21	-356	162	57	0	0	0	116
02010004110	2	-5	2	1	0	0	0	0
02010004090	12	-242	146	28	0	0	0	56
02010006020	13	-378	227	137	0	0	0	0
02010004100	4	-30	4	2	0	0	0	21
02010004080	18	-259	147	51	0	0	0	43
02010006010	38	-517	274	195	0	0	0	10
02010004120	2	-6	0	2	0	0	0	3
02010004070	24	-274	154	55	0	0	0	43
02010004060	17	-181	84	48	0	0	0	33
02010004040	16	-95	43	16	0	0	0	21
02010004050	9	-105	34	17	0	0	0	44
02010004020	2	-22	6	4	0	0	0	9
02010004030	13	-75	0	0	0	0	0	62
02010004010	6	-60	0	0	0	0	0	53
02010001260	14	-49	1	-3	0	0	0	36

02010001250	2	-6	0	-2	0	0	0	5
02010001240	4	-18	-1	-2	0	0	0	15
02010001230	5	-12	0	0	0	0	0	6
02010001220	1	-34	0	-1	0	0	0	33
02010001210	52	-87	2	2	0	0	0	30
02010001200	8	-34	0	0	0	0	0	26
02010001180	3	-12	0	-1	0	0	0	9
02010001170	2	-21	0	0	0	0	0	18
02010001160	1	-2	0	0	0	0	0	1
02010001070	0	-8	0	0	0	0	0	8
02010001080	0	-3	0	0	0	0	0	3
02010001150	1	-3	29	-29	0	0	0	2
02010001130	3	-15	0	0	0	0	0	12
02010001100	2	-10	0	0	0	0	0	8
02010001140	89	-423	24	-41	0	0	0	352
02010001120	13	-87	16	-21	0	0	0	79
02010001110	2	-4	-4	3	0	0	0	3
02010001120	0	0	0	0	0	0	0	0
N/A	9	-66	0	0	0	0	0	57
01410065407	0	0	0	0	0	0	0	0
N/A	0	0	0	0	0	0	0	0
N/A	0	0	0	0	0	0	0	0

Appendix F. Area (hectares) summary and change by LULC class for Basin-wide HUC 8 watersheds.

HUC 8 Watershed	Urban	Agriculture	Brush	Forest	Water	Wetland	Barren	Urban Open
1992								
Boquet-Ausable	11047	13294	4124	218787	3717	2529	277	2868
Lamoille-Grand Isle	14849	45680	5624	162501	2527	4966	299	6420
Missisquoi	16172	70490	7481	205604	2631	3707	675	2617
Otter-Lewis	14214	74184	7172	172570	2669	6924	277	5834
Poultney-Metowee-South Basin	18319	58585	13236	221072	17077	5426	199	5010
Saranac-Chazy	12589	30463	9177	197244	11903	8409	111	3637
Winooski	23271	32614	8344	217866	2350	2365	704	11570
2001								
Boquet-Ausable	11167	11952	4736	219008	3717	2529	277	3257
Lamoille-Grand Isle	15346	43237	5633	162355	2527	4966	299	8504
Missisquoi	16502	69250	7154	205621	2631	3704	675	3839
Otter-Lewis	14383	71206	7295	172411	2669	6923	277	8681
Poultney-Metowee-South Basin	18572	56622	13328	220918	17077	5426	199	6782
Saranac-Chazy	12910	26899	11007	197818	11903	8411	111	4473
Winooski	23711	29136	8491	217561	2350	2365	704	14765
Change								
Boquet-Ausable	120	-1342	612	221	0	0	0	389
Lamoille-Grand Isle	497	-2443	9	-146	0	0	0	2084
Missisquoi	330	-1240	-327	17	0	-3	0	1222
Otter-Lewis	169	-2978	123	-159	0	-1	0	2847
Poultney-Metowee-South Basin	253	-1963	92	-154	0	0	0	1772
Saranac-Chazy	321	-3564	1830	574	0	2	0	836
Winooski	440	-3478	147	-305	0	0	0	3195

Appendix G. Area (hectares) summary and change by LULC class for lake segments.

Segment	Urban	Agriculture	Brush	Forest	Water	Wetland	Barren	Urban Open
1992								
Burlington Bay	977	11	13	191	8	10	2	207
Cumberland Bay	7862	7167	4000	136303	10626	5764	45	2375
Isle la Motte	5656	28500	5392	64309	1800	3035	72	1445
Lake Champlain	154	32	42	400	111359	498	5	40
Main Lake	31095	39030	11798	432386	6051	4820	956	13116
Malletts Bay	11237	25637	4864	149113	2210	2218	301	5311
Missisquoi Bay	16352	71385	7552	206586	2759	4321	661	2625
Northeast Arm	1715	9160	588	8928	233	2114	16	583
Otter Creek	14466	75188	7244	174599	2703	6945	283	5940
Port Henry	1675	4468	473	19484	243	215	10	451
Shelburne Bay	2508	6745	779	6320	169	194	23	1203
South Lake A	5325	15044	2364	75653	12794	1618	67	1011
South Lake B	11284	39271	10413	126244	4381	3552	120	3526
St. Albans Bay	1466	6994	224	3677	44	186	6	458
2001								
Burlington Bay	980	9	13	191	8	10	2	207
Cumberland Bay	7982	5563	4802	136725	10626	5765	45	2634
Isle la Motte	5883	26405	6422	64456	1800	3036	72	2135
Lake Champlain	161	30	37	401	111359	498	5	40
Main Lake	31642	34707	12561	432312	6051	4820	956	16203
Malletts Bay	11583	23738	4925	148928	2210	2218	301	6989
Missisquoi Bay	16682	70134	7229	206600	2759	4319	661	3858
Northeast Arm	1771	8895	575	8935	233	2114	16	798
Otter Creek	14637	72139	7367	174440	2703	6944	283	8855
Port Henry	1706	4207	474	19478	243	215	10	686
Shelburne Bay	2529	6252	779	6313	169	194	23	1682
South Lake A	5412	14540	2369	75649	12794	1618	67	1427
South Lake B	11418	38083	10499	126100	4381	3552	120	4638
St. Albans Bay	1545	6778	187	3712	44	186	6	596
Change								
Burlington	3	-2	0	0	0	0	0	0

Bay								
Cumberland Bay	120	-1604	802	422	0	1	0	259
Isle la Motte	227	-2095	1030	147	0	1	0	690
Lake Champlain	7	-2	-5	1	0	0	0	0
Main Lake	547	-4323	763	-74	0	0	0	3087
Malletts Bay	346	-1899	61	-185	0	0	0	1678
Missisquoi Bay	330	-1251	-323	14	0	-2	0	1233
Northeast Arm	56	-265	-13	7	0	0	0	215
Otter Creek	171	-3049	123	-159	0	-1	0	2915
Port Henry	31	-261	1	-6	0	0	0	235
Shelburne Bay	21	-493	0	-7	0	0	0	479
South Lake A	87	-504	5	-4	0	0	0	416
South Lake B	134	-1188	86	-144	0	0	0	1112
St. Albans Bay	79	-216	-37	35	0	0	0	138

Appendix H. Area (hectares) summary and change by LULC class for monitored tributaries.

Monitored Tributary	Urban	Agriculture	Brush	Forest	Water	Wetland	Barren	Urban Open
1992								
Ausable	4692	2953	1724	118294	2664	1293	136	1157
Bouquet	2707	3999	504	61591	613	420	141	475
East	371	4081	528	2787	66	339	2	108
Great Chazy	3064	13776	3817	53034	1114	1787	25	763
Highland Furgeh	106	21	133	2520	202	14	0	8
Hosington	140	290	22	2319	1	6	0	54
Indian Brook	636	368	138	1559	22	38	7	289
LaChute	3106	907	804	49264	696	660	11	500
LaPlatte	1105	5700	651	5363	145	170	2	589
Lamoille	9376	23204	4362	141355	2080	2059	276	4337
Lewis	1013	5302	394	12952	225	658	68	390
Little Ausable	1093	2976	793	13441	46	213	0	317
Little Chazy	696	3004	1351	8052	77	409	8	222
Little Otter	939	10273	439	6245	128	519	29	330
Mallets Creek	610	1637	240	4440	89	114	9	415
Mettawee/Barge Canal	7101	26971	5834	64909	1415	1579	31	1903
Mill	564	2816	118	2262	25	46	3	159
Mill (Port Henry)	420	116	160	6262	141	52	1	87
Mill (Putnam Station)	136	334	184	2242	14	30	0	38
Missisquoi - Quebec	3432	3319	2066	54933	576	141	15	1
Missisquoi - VT	7289	34614	3228	108368	1161	2278	342	2025
Mt. Hope	73	1	81	3319	100	23	0	8
Non-D_F Watershed	13996	50001	4551	67513	2195	6100	171	3949
Otter	12279	58475	6320	153772	2324	5742	184	5132
Pike - Quebec	3584	19853	1630	30344	224	600	279	3
Pike - VT	536	3598	230	4744	578	150	7	331
Poultney	3539	11095	3553	44989	1975	1440	33	1475
Putnam	542	532	113	13957	396	284	50	136
Rock - Quebec	331	2130	119	2785	20	31	4	28
Rock - VT	496	4269	178	3748	29	289	7	187
Salmon	1097	1367	653	13629	101	276	2	409
Saranac	6077	3547	3290	128665	10557	5046	37	2044
Stevens	765	3736	81	1134	16	134	2	249
Stonebridge	262	762	104	1763	5	39	2	174
Winooski	19406	22574	7302	210972	2151	2098	675	9957
2001								
Ausable	4742	2394	1994	118413	2664	1293	136	1277
Bouquet	2722	3901	511	61595	613	420	141	547

East	374	3966	530	2782	66	339	2	223
Great Chazy	3179	12381	4601	53174	1114	1787	25	1119
Highland Furgeh	107	0	151	2522	202	14	0	8
Hosington	140	287	22	2319	1	6	0	56
Indian Brook	684	246	134	1546	22	38	7	379
LaChute	3123	807	804	49264	696	660	11	584
LaPlatte	1107	5439	651	5363	145	170	2	848
Lamoille	9633	21606	4435	141183	2080	2059	276	5778
Lewis	1026	4975	405	12940	225	658	68	705
Little Ausable	1111	2717	940	13492	46	213	0	360
Little Chazy	706	2647	1601	8066	77	409	8	306
Little Otter	951	9761	439	6245	128	519	29	831
Mallets Creek	640	1495	232	4444	89	114	9	529
Mettawee/Barge Canal	7214	26256	5878	64815	1415	1579	31	2554
Mill	598	2720	95	2284	25	46	3	223
Mill (Port Henry)	422	110	160	6260	141	52	1	92
Mill (Putnam Station)	138	313	184	2242	14	30	0	56
Missisquoi - Quebec	3432	3319	2020	54979	576	141	15	1
Missisquoi - VT	7554	33763	2950	108344	1161	2276	342	2914
Mt. Hope	73	1	81	3319	100	23	0	8
Non-D_F Watershed	14343	48006	4646	67507	2195	6102	171	5507
Otter	12423	56336	6432	153625	2324	5741	184	7163
Pike - Quebec	3585	19850	1630	30344	224	600	279	4
Pike - VT	565	3400	231	4737	578	150	7	506
Poultney	3559	10639	3566	44968	1975	1440	33	1920
Putnam	543	498	113	13956	396	284	50	169
Rock - Quebec	333	2125	119	2784	20	31	4	30
Rock - VT	525	4095	178	3748	29	289	7	334
Salmon	1109	1125	799	13657	101	276	2	465
Saranac	6167	2141	4042	129073	10557	5046	37	2201
Stevens	810	3628	74	1140	16	134	2	313
Stonebridge	271	693	100	1767	5	39	2	233
Winooski	19822	19811	7450	210672	2151	2098	675	12457
Change								
Ausable	50	-559	270	119	0	0	0	120
Bouquet	15	-98	7	4	0	0	0	72
East	3	-115	2	-5	0	0	0	115
Great Chazy	115	-1395	784	140	0	0	0	356
Highland Furgeh	1	-21	18	2	0	0	0	0
Hosington	0	-3	0	0	0	0	0	2
Indian Brook	48	-122	-4	-13	0	0	0	90
LaChute	17	-100	0	0	0	0	0	84
LaPlatte	2	-261	0	0	0	0	0	259
Lamoille	257	-1598	73	-172	0	0	0	1441
Lewis	13	-327	11	-12	0	0	0	315

Little Ausable	18	-259	147	51	0	0	0	43
Little Chazy	10	-357	250	14	0	0	0	84
Little Otter	12	-512	0	0	0	0	0	501
Mallets Creek	30	-142	-8	4	0	0	0	114
Mettawee/Barge Canal	113	-715	44	-94	0	0	0	651
Mill	34	-96	-23	22	0	0	0	64
Mill (Port Henry)	2	-6	0	-2	0	0	0	5
Mill (Putnam Station)	2	-21	0	0	0	0	0	18
Missisquoi - Quebec	0	0	-46	46	0	0	0	0
Missisquoi - VT	265	-851	-278	-24	0	-2	0	889
Mt. Hope	0	0	0	0	0	0	0	0
Non-D_F Watershed	347	-1995	95	-6	0	2	0	1558
Otter	144	-2139	112	-147	0	-1	0	2031
Pike - Quebec	1	-3	0	0	0	0	0	1
Pike - VT	29	-198	1	-7	0	0	0	175
Poultney	20	-456	13	-21	0	0	0	445
Putnam	1	-34	0	-1	0	0	0	33
Rock - Quebec	2	-5	0	-1	0	0	0	2
Rock - VT	29	-174	0	0	0	0	0	147
Salmon	12	-242	146	28	0	0	0	56
Saranac	90	-1406	752	408	0	0	0	157
Stevens	45	-108	-7	6	0	0	0	64
Stonebridge	9	-69	-4	4	0	0	0	59
Winooski	416	-2763	148	-300	0	0	0	2500

Appendix I. Area (hectares) summary and change by LULC class for states/ provinces.

State	Urban	Agriculture	Brush	Forest	Water	Wetland	Barren	Urban Open
1992								
NY	35982	72079	21141	565018	30194	14048	493	9169
QC	8403	32186	4040	91775	6160	1198	324	47
VT	67022	224122	30408	745976	13322	19389	1735	28933
2001								
NY	36643	66236	23647	565725	30194	14049	493	11137
QC	8407	32160	4008	91821	6160	1198	324	56
VT	68500	212860	30433	745264	13322	19384	1735	39414
Change								
NY	661	-5843	2506	707	0	1	0	1968
QC	4	-26	-32	46	0	0	0	9
VT	1478	-11262	25	-712	0	-5	0	10481

Appendix J. Area (hectares) summary and change by LULC class for towns.

Town	Urban	Agriculture	Brush	Forest	Water	Wetland	Barren	Urban Open
1992								
Lacolle	0	2	0	0	0	0	0	0
Notre-Dame-du-Mont-Carmel	289	1775	58	416	363	46	18	1
Saint-Bernard-de-Lacolle	25	421	44	699	0	17	1	3
Abercorn	153	365	111	2086	2	14	4	0
Frelighsburg	573	1445	420	9891	14	81	7	4
Bedford	446	1388	54	1681	10	1	29	0
Stanbridge East	316	603	195	3820	2	1	5	0
Saint-Armand	549	2773	221	4461	2416	272	6	35
Saint-Pierre-de-Véronne-à-Pike-River	314	3014	47	383	44	325	14	0
Stanbridge Station	194	1177	16	469	3	0	1	0
Venise-en-Québec	205	263	40	225	699	217	2	0
Saint-Georges-de-Clarenceville	258	1483	44	1470	1501	82	4	1
Noyan	174	1413	13	512	383	10	0	2
Sainte-Brigide-d'Iberville	15	245	5	29	0	0	0	0
Notre-Dame-de-Stanbridge	274	3286	23	833	6	1	3	0
Sainte-Sabine	302	2843	140	1470	0	0	181	0
Saint-Sébastien	98	1839	26	334	4	20	6	0
Saint-Alexandre	43	1277	16	211	10	1	0	0
Dunham	525	822	441	9201	132	2	0	0
Cowansville	37	6	15	216	3	0	0	0
Saint-Ignace-de-Stanbridge	374	2462	224	3605	1	0	24	0
Farnham	99	576	33	688	0	0	7	0
Bonsecours	6	1	9	308	1	0	0	0
Eastman	228	24	32	975	111	1	0	0
Bolton-Est	340	102	128	4964	119	1	1	0
Saint-Étienne-de-Bolton	221	115	103	3236	71	1	0	0
Stukely-Sud	63	31	13	410	1	0	0	0
Stukely	388	79	122	4441	107	0	1	0
Bolton-Ouest	43	13	15	1514	18	0	0	0
Austin	18	2	2	283	40	0	0	0
Orford	0	0	2	166	0	0	0	0
Potton	925	1529	936	17536	68	81	7	0
Sutton	908	812	492	15242	31	24	3	1
Brookfield	14	38	15	221	0	0	0	3
Groton	0	0	4	368	0	0	0	0

Plymouth	6	0	42	177	0	0	0	0
Randolph	29	56	20	731	13	5	0	13
West Topsham	5	3	3	278	0	0	0	0
Londonderry	0	0	2	1073	6	10	0	0
Weston	4	0	0	81	0	0	0	0
Dorset	208	423	51	5387	12	36	1	140
East Dorset	62	69	10	1002	4	58	0	35
Burlington	1427	271	52	403	100	139	5	343
South Burlington	1622	1225	109	770	29	29	4	532
Winooski	254	2	16	59	14	4	2	45
Burlington	48	0	0	0	0	0	0	2
Alburg	468	3838	93	2281	234	703	3	158
Bakersfield	174	393	31	5036	3	10	1	42
Belvidere Center	140	65	44	5211	5	154	3	27
Bristol	1254	3986	450	21753	154	578	20	551
Cambridge	410	1493	148	3624	17	30	6	138
Charlotte	744	5733	609	3026	57	122	0	344
Colchester	1712	1690	362	4357	332	624	24	740
East Berkshire	40	273	6	77	6	3	0	3
East Fairfield	447	2306	177	7777	17	54	4	90
Enosburg Falls	1685	11585	711	19180	142	170	38	525
Essex Junction	1680	2155	294	5716	78	91	66	760
Fairfax	796	4027	339	7907	260	144	24	312
Fairfield	318	2127	189	3965	37	200	3	98
Ferrisburg	380	3813	140	1446	133	430	0	125
Franklin	523	3774	260	5476	576	168	6	271
Grand Isle	349	2348	150	1175	114	59	3	87
Highgate Center	419	3446	103	2274	144	44	1	98
Hinesburg	632	2873	325	5923	93	137	52	357
Huntington	343	794	102	7657	2	19	2	217
Isle la Motte	148	908	57	729	59	87	2	45
Jeffersonville	607	1975	236	12842	75	122	17	137
Jericho	723	1157	274	9440	18	57	23	848
Milton	1552	3788	491	9796	388	555	15	842
Montgomery Center	388	488	169	13117	6	26	4	96
New Haven	511	6699	286	3988	3	104	47	189
North Ferrisburg	292	1768	100	1753	78	177	1	108
North Hero	295	1328	96	1013	254	206	4	107
Richford	703	2899	237	10751	44	47	13	215
Richmond	732	1121	284	9787	70	40	11	249
Saint Albans	1701	7253	367	6269	135	370	7	511
Shelburne	820	2773	265	1796	314	145	20	398
Sheldon	315	1862	138	2711	224	43	3	89
South Hero	344	1764	115	1235	141	116	3	92
Starksboro	380	844	94	8704	7	59	6	172
Swanton	1436	6382	280	4841	734	2839	96	567
Underhill	640	789	396	13173	9	46	6	448
Vergennes	1426	16287	579	3851	781	335	3	458

Waterville	186	405	78	4366	3	29	4	60
Westford	323	1469	158	4881	24	63	3	144
Williston	1387	2290	266	4116	121	86	38	666
Montpelier	1895	1294	642	16968	215	147	33	1069
Adamant	72	67	37	806	20	23	2	104
Barre	1908	1937	659	10316	65	109	78	957
Cabot	394	805	275	5110	51	24	8	180
Calais	101	36	39	1471	34	30	2	67
East Barre	107	65	41	650	0	17	2	26
East Calais	396	117	196	3939	177	92	15	292
East Montpelier	352	1421	142	2316	13	59	9	140
Eden	274	308	162	9699	65	117	64	189
Eden Mills	195	39	231	7727	158	58	50	112
Graniteville	161	103	71	885	12	8	133	56
Hyde Park	633	1530	274	6570	277	137	26	330
Johnson	547	1140	198	9887	29	61	30	243
Marshfield	529	575	340	7002	212	110	11	409
Moretown	522	532	134	9193	15	12	4	276
Morrisville	978	2486	327	9352	66	163	13	386
Northfield	908	561	732	12931	8	72	34	730
North Montpelier	20	45	19	154	2	4	0	15
Plainfield	689	1248	441	10096	49	123	7	490
Roxbury	103	12	52	2406	2	10	2	45
Stowe	1196	1109	561	14469	25	56	41	761
Waitsfield	671	1004	155	13343	6	22	30	288
Warren	567	426	121	8787	22	15	83	353
Washington	173	269	119	1949	1	6	3	98
Waterbury	1056	693	433	21389	256	98	21	441
Waterbury Center	256	288	163	2852	28	16	4	288
Williamstown	684	1584	287	5194	13	41	12	215
Wolcott	802	1219	391	16437	183	185	16	278
Woodbury	281	16	106	6326	238	50	6	51
Worcester	385	171	228	11763	29	65	9	256
Rutland	1766	1059	196	7746	24	100	16	751
Belmont	103	71	37	1533	24	36	0	138
Bomoseen	189	134	53	992	308	49	0	99
Brandon	1300	3817	1178	18521	547	1199	32	423
Bridport	477	8155	193	1173	50	60	6	66
Castleton	549	1281	404	8157	15	173	3	274
Center Rutland	81	134	18	670	0	13	0	23
Chittenden	95	21	25	2710	124	20	2	45
Cuttingsville	474	635	197	11764	16	62	1	214
Danby	437	1245	309	13067	42	329	3	159
East Wallingford	275	314	104	4748	7	55	0	211
Fair Haven	1257	5629	1711	14377	1294	715	34	425
Florence	184	563	251	4265	17	116	11	56
Granville	33	0	6	2523	1	1	1	2
Hancock	8	0	31	1443	2	1	0	6

Killington	32	0	5	1405	0	5	25	15
Middlebury	1447	11425	510	8730	142	692	12	516
Middletown Springs	374	1178	200	6957	5	38	0	168
Mount Holly	189	374	107	2285	4	98	0	118
North Clarendon	463	1310	200	4040	31	87	6	358
Orwell	654	6288	1161	6332	316	336	2	184
Pawlet	389	2345	222	8234	3	52	0	79
Pittsfield	71	6	72	4826	212	31	0	69
Pittsford	578	1276	292	7781	37	191	7	337
Poultney	647	1771	690	7313	253	153	8	430
Proctor	193	291	41	1509	27	45	2	61
Ripton	296	67	124	8796	13	95	3	72
Rochester	0	0	0	1	0	0	0	0
Salisbury	377	2522	414	4459	323	700	5	107
Shoreham	444	6298	550	1544	71	498	2	97
Wallingford	593	1523	199	11987	106	432	19	246
Wells	301	383	214	3807	240	131	1	180
West Pawlet	200	1204	307	2410	9	43	8	112
West Rupert	152	1000	112	3881	2	27	0	21
West Rutland	563	1005	300	7769	1	218	10	261
Whiting	247	4090	242	1552	22	362	4	55
Craftsbury	124	469	72	2772	2	31	1	35
East Hardwick	283	1006	199	2976	13	25	10	101
Glover	0	5	5	725	0	0	0	0
Greensboro	349	947	262	4749	378	46	5	89
Greensboro Bend	171	163	165	2372	2	15	5	41
Hardwick	573	1441	317	6513	58	104	22	213
Irasburg	10	10	2	170	0	1	0	0
Lowell	431	919	291	10650	17	72	102	105
Lyndonville	66	5	53	2519	44	33	0	10
Newport	0	0	0	17	0	0	0	0
Newport Center	386	3015	296	4846	2	92	9	97
North Troy	725	3154	422	12470	13	238	9	140
Peacham	73	17	32	1744	143	15	0	0
Sheffield	11	2	12	209	0	1	2	0
Troy	43	143	27	806	0	9	1	15
West Danville	115	253	87	1661	19	9	2	21
Westfield	267	1004	92	7913	2	32	2	46
Glens Falls	312	0	6	13	0	0	0	22
Queensbury	1734	854	299	5129	142	374	12	289
Argyle	58	474	79	340	2	33	0	8
Bolton Landing	501	11	173	10040	3173	109	2	89
Brant Lake	6	0	2	1103	58	34	0	0
Clemons	227	83	283	8466	122	83	10	68
Comstock	89	385	138	1351	2	17	0	21
Diamond Point	252	0	22	2231	2160	47	0	11
Fort Ann	1154	8061	1578	19005	431	290	1	265
Fort Edward	87	1383	147	241	3	80	0	9

Granville	1065	4073	1232	8702	125	290	1	274
Hague	471	21	89	12507	3967	69	0	82
Hampton	200	779	215	1919	19	58	0	79
Hartford	88	446	89	674	1	8	0	6
Hudson Falls	208	2162	398	938	8	71	1	43
Kattskill Bay	51	0	5	196	2	2	0	9
Lake George	1182	106	182	8364	2342	109	5	113
Lake Luzerne	4	0	0	92	0	4	0	0
Middle Granville	62	115	43	322	3	5	0	11
Newcomb	0	0	0	134	0	0	0	0
North Granville	25	264	16	403	1	5	0	1
North Hudson	0	0	0	3418	49	77	5	0
Putnam Station	384	923	392	5391	176	91	0	88
Salem	0	3	0	1	0	0	0	0
Ticonderoga	1037	2397	272	14696	638	329	16	246
Warrensburg	0	0	0	215	0	0	0	0
Whitehall	1244	4046	1613	17463	350	582	29	399
Plattsburgh	3877	4455	555	7929	301	884	15	1048
Altona	531	1208	1362	10958	81	254	12	193
Keeseville	1382	1156	878	22652	690	366	0	314
Au Sable Forks	990	394	479	19745	1702	394	0	200
Bloomingdale	354	184	123	16249	516	865	18	148
Cadyville	477	864	727	8158	127	146	1	150
Champlain	786	4629	230	4106	86	414	4	163
Chazy	636	3701	185	3213	61	355	9	142
Churubusco	13	76	14	213	2	18	0	0
Crown Point	708	1589	199	10787	190	265	39	191
Elizabethtown	511	29	96	14503	23	47	33	129
Ellenburg Center	470	2861	667	11895	66	413	0	31
Ellenburg Depot	435	1349	536	11489	864	209	3	85
Essex	45	593	20	269	0	29	0	6
Jay	492	407	157	7889	63	50	4	78
Keene	449	42	37	14757	50	31	1	71
Keene Valley	300	6	38	23340	163	50	147	47
Lake Clear	129	28	47	3171	556	232	0	65
Lake Placid	980	321	111	31852	1199	585	11	329
Lewis	542	101	53	12573	72	96	66	78
Malone	0	0	0	8	0	0	0	0
Lyon Mountain	30	190	25	526	2	11	0	0
Mineville	235	44	30	2694	44	22	0	44
Mooers	377	1791	284	4724	18	261	8	162
Mooers Forks	230	965	177	2187	7	57	0	67
Moriah	177	255	26	3864	59	19	0	58
Moriah Center	71	43	97	1667	13	17	0	13
Morrisonville	678	975	568	7900	124	174	6	447
New Russia	320	0	17	7139	350	50	1	14
Owls Head	0	1	26	779	0	6	0	0
Paul Smiths	8	1	6	592	3	32	0	10

Peru	1358	3725	940	16756	164	304	0	431
Port Henry	282	149	50	2168	22	12	8	78
Redford	58	15	22	771	0	17	0	45
Rouses Point	279	449	15	134	3	94	1	106
Saranac	1066	814	867	24451	215	486	0	463
Saranac Lake	1153	416	240	19611	5630	1245	2	276
Schuyler Falls	508	382	450	14585	125	262	0	183
Tupper Lake	189	30	49	11447	1185	464	0	9
Upper Jay	52	1	11	1628	12	7	0	24
Vermontville	768	601	965	26000	1032	1003	8	165
West Chazy	968	4554	1749	11655	85	613	6	312
Westport	1346	3730	358	17223	171	116	1	281
Willsboro	800	2257	158	8434	257	150	1	219
Wilmington	481	112	224	18973	87	156	6	161
2001								
Lacolle	0	2	0	0	0	0	0	0
Notre-Dame-du-Mont-Carmel	290	1776	61	412	363	46	18	1
Saint-Bernard-de-Lacolle	25	405	56	702	0	17	1	3
Abercorn	153	365	111	2086	2	14	4	0
Frelighsburg	573	1442	420	9891	14	81	7	7
Bedford	446	1388	54	1681	10	1	29	0
Stanbridge East	316	603	195	3820	2	1	5	0
Saint-Armand	551	2767	221	4461	2416	272	6	40
Saint-Pierre-de-Véronne-à-Pike-River	314	3014	47	383	44	325	14	0
Stanbridge Station	194	1177	16	469	3	0	1	0
Venise-en-Québec	205	263	40	225	699	217	2	0
Saint-Georges-de-Clarenceville	258	1482	44	1470	1501	82	4	1
Noyan	175	1412	13	513	383	10	0	3
Sainte-Brigide-d'Iberville	15	245	5	29	0	0	0	0
Notre-Dame-de-Stanbridge	274	3286	23	833	6	1	3	0
Sainte-Sabine	302	2843	140	1470	0	0	181	0
Saint-Sébastien	98	1839	26	334	4	20	6	0
Saint-Alexandre	43	1277	16	211	10	1	0	0
Dunham	525	822	441	9201	132	2	0	0
Cowansville	37	6	15	216	3	0	0	0
Saint-Ignace-de-Stanbridge	374	2462	224	3605	1	0	24	0
Farnham	99	576	33	688	0	0	7	0
Bonsecours	6	1	9	308	1	0	0	0
Eastman	228	24	32	975	111	1	0	0
Bolton-Est	340	102	128	4964	119	1	1	0
Saint-Étienne-de-	221	115	103	3236	71	1	0	0

Bolton							
Stukely-Sud	63	31	13	410	1	0	0	0
Stukely	388	79	122	4441	107	0	1	0
Bolton-Ouest	43	13	15	1514	18	0	0	0
Austin	18	2	2	283	40	0	0	0
Orford	0	0	2	166	0	0	0	0
Potton	925	1530	887	17584	68	81	7	0
Sutton	908	811	494	15240	31	24	3	1
Brookfield	15	35	16	221	0	0	0	4
Groton	0	0	4	368	0	0	0	0
Plymouth	6	0	42	177	0	0	0	0
Randolph	29	44	21	731	13	5	0	24
West Topsham	5	3	3	278	0	0	0	0
Londonderry	0	0	2	1073	6	10	0	0
Weston	4	0	0	81	0	0	0	0
Dorset	208	365	51	5387	12	36	1	197
East Dorset	63	60	9	1002	4	58	0	44
Burlington	1437	260	51	399	100	139	5	348
South Burlington	1655	975	109	756	29	29	4	762
Winooski	254	2	15	58	14	4	2	45
Burlington	48	0	0	0	0	0	0	2
Alburg	497	3751	93	2278	234	703	3	219
Bakersfield	178	370	32	5033	3	10	1	63
Belvidere Center	142	62	44	5210	5	154	3	30
Bristol	1263	3664	454	21749	154	578	20	864
Cambridge	421	1447	146	3617	17	30	6	181
Charlotte	748	5435	609	3026	57	122	0	637
Colchester	1754	1592	355	4352	332	624	24	807
East Berkshire	41	271	7	77	6	3	0	4
East Fairfield	461	2253	165	7785	17	54	4	132
Enosburg Falls	1752	11324	622	19153	142	170	38	835
Essex Junction	1749	1862	289	5701	78	91	66	1005
Fairfax	838	3809	333	7913	260	144	24	489
Fairfield	329	2058	177	3973	37	200	3	161
Ferrisburg	385	3593	140	1446	133	430	0	340
Franklin	553	3547	262	5473	576	168	6	469
Grand Isle	362	2261	147	1176	114	59	3	164
Highgate Center	443	3372	103	2269	144	44	1	152
Hinesburg	633	2717	326	5922	93	137	52	513
Huntington	343	772	102	7657	2	19	2	238
Isle la Motte	152	878	55	723	59	87	2	79
Jeffersonville	625	1911	244	12819	75	122	17	197
Jericho	728	955	277	9435	18	57	23	1048
Milton	1607	3552	472	9806	388	555	15	1033
Montgomery Center	398	462	166	13105	6	26	4	128
New Haven	524	6397	286	3988	3	104	47	481
North Ferrisburg	296	1632	100	1753	78	177	1	239
North Hero	302	1269	96	1012	254	206	4	161

Richford	724	2828	227	10713	44	47	13	313
Richmond	741	1080	274	9793	70	40	11	284
Saint Albans	1786	7001	307	6325	135	367	7	687
Shelburne	822	2626	264	1796	314	145	20	543
Sheldon	329	1830	132	2678	224	43	3	146
South Hero	357	1697	114	1233	141	116	3	149
Starksboro	381	824	103	8695	7	59	6	191
Swanton	1509	6160	268	4846	734	2839	96	723
Underhill	650	696	382	13177	9	46	6	542
Vergennes	1447	15678	580	3851	781	335	3	1046
Waterville	193	369	79	4364	3	29	4	90
Westford	333	1333	150	4886	24	63	3	274
Williston	1453	1953	269	4095	121	86	38	953
Montpelier	1928	1139	616	16985	215	147	33	1201
Adamant	73	45	38	805	20	23	2	125
Barre	1982	1565	636	10316	65	109	78	1278
Cabot	407	749	276	5106	51	24	8	228
Calais	101	24	38	1472	34	30	2	78
East Barre	110	59	46	644	0	17	2	29
East Calais	401	106	197	3935	177	92	15	300
East Montpelier	368	1332	148	2306	13	59	9	217
Eden	281	262	184	9673	65	117	64	232
Eden Mills	197	20	266	7708	158	58	50	112
Graniteville	169	62	72	876	12	8	133	97
Hyde Park	659	1375	273	6567	277	137	26	463
Johnson	558	1044	192	9886	29	61	30	334
Marshfield	543	478	332	7003	212	110	11	500
Moretown	524	480	150	9176	15	12	4	326
Morrisville	1009	2282	337	9338	66	163	13	564
Northfield	917	463	760	12870	8	72	34	851
North Montpelier	22	35	19	154	2	4	0	24
Plainfield	708	1043	465	10065	49	123	7	681
Roxbury	104	3	55	2403	2	10	2	52
Stowe	1213	938	571	14458	25	56	41	917
Waitsfield	672	892	241	13257	6	22	30	399
Warren	568	313	135	8773	22	15	83	465
Washington	178	244	107	1957	1	6	3	122
Waterbury	1075	545	439	21375	256	98	21	576
Waterbury Center	262	232	161	2858	28	16	4	334
Williamstown	700	1471	294	5180	13	41	12	320
Wolcott	814	1105	383	16442	183	185	16	381
Woodbury	283	14	94	6338	238	50	6	51
Worcester	389	137	238	11757	29	65	9	283
Rutland	1782	993	196	7746	24	100	16	801
Belmont	103	67	37	1533	24	36	0	142
Bomoseen	190	125	53	992	308	49	0	108
Brandon	1316	3649	1209	18479	547	1197	32	587
Bridport	482	8065	193	1171	50	60	6	152

Castleton	553	1211	405	8154	15	173	3	343
Center Rutland	82	127	18	670	0	13	0	29
Chittenden	95	18	25	2710	124	20	2	48
Cuttingsville	474	620	248	11713	16	62	1	229
Danby	443	1187	309	13067	42	329	3	211
East Wallingford	275	292	104	4748	7	55	0	233
Fair Haven	1261	5436	1717	14371	1294	715	34	615
Florence	184	549	251	4265	17	116	11	70
Granville	33	0	6	2523	1	1	1	2
Hancock	8	0	31	1443	2	1	0	6
Killington	32	0	5	1405	0	5	25	15
Middlebury	1478	10906	515	8723	142	692	12	1006
Middletown Springs	376	1089	202	6953	5	38	0	257
Mount Holly	189	372	104	2287	4	98	0	121
North Clarendon	478	1184	201	4040	31	87	6	470
Orwell	659	6093	1163	6326	316	336	2	377
Pawlet	390	2311	222	8233	3	52	0	112
Pittsfield	71	5	72	4826	212	31	0	71
Pittsford	584	1144	301	7767	37	191	7	467
Poultney	656	1642	698	7301	253	153	8	556
Proctor	193	289	41	1509	27	45	2	64
Ripton	296	66	128	8793	13	95	3	74
Rochester	0	0	0	1	0	0	0	0
Salisbury	383	2470	426	4441	323	700	5	159
Shoreham	448	6196	550	1544	71	498	2	196
Wallingford	603	1466	198	11989	106	432	19	293
Wells	301	363	217	3803	240	131	1	201
West Pawlet	204	1162	306	2408	9	43	8	152
West Rupert	153	1018	114	3855	2	27	0	27
West Rutland	567	964	299	7769	1	218	10	299
Whiting	249	4043	245	1542	22	362	4	107
Craftsbury	128	461	78	2761	2	31	1	44
East Hardwick	293	934	206	2960	13	25	10	170
Glover	0	5	5	725	0	0	0	0
Greensboro	358	934	271	4706	378	46	5	126
Greensboro Bend	176	145	192	2354	2	15	5	46
Hardwick	582	1385	320	6503	58	104	22	267
Irasburg	10	10	2	169	0	1	0	0
Lowell	439	899	222	10711	17	72	102	125
Lyndonville	66	4	50	2521	44	33	0	11
Newport	0	0	0	17	0	0	0	0
Newport Center	405	2953	307	4832	2	92	9	143
North Troy	744	3127	380	12472	13	238	9	188
Peacham	73	17	36	1741	143	15	0	0
Sheffield	11	0	18	205	0	1	2	0
Troy	43	140	26	801	0	9	1	24
West Danville	119	238	90	1656	19	9	2	35
Westfield	274	994	84	7913	2	32	2	59

Glens Falls	312	0	6	13	0	0	0	22
Queensbury	1756	591	299	5129	142	374	12	530
Argyle	61	469	80	338	2	33	0	13
Bolton Landing	501	11	173	10040	3173	109	2	89
Brant Lake	6	0	2	1103	58	34	0	0
Clemons	227	82	312	8437	122	83	10	69
Comstock	100	365	140	1349	2	17	0	31
Diamond Point	252	0	22	2231	2160	47	0	11
Fort Ann	1194	7941	1590	18983	431	290	1	356
Fort Edward	88	1381	151	237	3	80	0	11
Granville	1079	4003	1256	8670	125	290	1	339
Hague	471	21	89	12507	3967	69	0	82
Hampton	203	755	210	1922	19	58	0	102
Hartford	89	443	89	673	1	8	0	7
Hudson Falls	209	2140	398	937	8	71	1	63
Kattskill Bay	51	0	5	196	2	2	0	9
Lake George	1184	102	183	8363	2342	109	5	114
Lake Luzerne	4	0	0	92	0	4	0	0
Middle Granville	63	113	39	327	3	5	0	12
Newcomb	0	0	0	134	0	0	0	0
North Granville	25	264	16	403	1	5	0	1
North Hudson	0	0	0	3418	49	77	5	0
Putnam Station	388	894	392	5390	176	91	0	112
Salem	0	3	0	1	0	0	0	0
Ticonderoga	1106	2268	270	14698	638	329	16	307
Warrensburg	0	0	0	215	0	0	0	0
Whitehall	1254	3979	1613	17462	350	582	29	456
Plattsburgh	3934	4146	605	7955	301	885	15	1223
Altona	540	919	1584	10974	81	254	12	235
Keeseville	1404	897	1030	22706	690	366	0	347
Au Sable Forks	1009	208	578	19799	1702	394	0	214
Bloomingdale	363	34	202	16312	516	865	18	148
Cadyville	486	705	819	8170	127	146	1	196
Champlain	856	4421	256	4118	86	414	4	264
Chazy	670	3577	209	3220	61	355	9	201
Churubusco	13	74	16	214	2	18	0	0
Crown Point	718	1497	204	10786	190	265	39	269
Elizabethtown	511	28	96	14503	23	47	33	130
Ellenburg Center	481	2636	821	11943	66	413	0	43
Ellenburg Depot	444	1188	633	11512	864	209	3	117
Essex	46	586	20	269	0	29	0	12
Jay	498	345	172	7899	63	50	4	108
Keene	449	42	37	14757	50	31	1	71
Keene Valley	300	6	38	23340	163	50	147	47
Lake Clear	130	9	55	3181	556	232	0	65
Lake Placid	990	254	130	31871	1199	585	11	347
Lewis	542	99	53	12573	72	96	66	80
Malone	0	0	0	8	0	0	0	0

Lyon Mountain	30	169	41	530	2	11	0	0
Mineville	235	39	30	2694	44	22	0	50
Mooers	387	1537	393	4741	18	261	8	279
Mooers Forks	235	874	218	2193	7	57	0	106
Moriah	177	241	26	3864	59	19	0	71
Moriah Center	71	43	97	1667	13	17	0	13
Morrisonville	691	757	706	7926	124	174	6	488
New Russia	320	0	17	7139	350	50	1	14
Owls Head	0	0	26	779	0	6	0	0
Paul Smiths	8	0	6	592	3	32	0	10
Peru	1379	3413	1112	16813	164	304	0	493
Port Henry	290	142	51	2162	22	12	8	81
Redford	59	0	35	773	0	17	0	45
Rouses Point	313	393	15	135	3	94	1	128
Saranac	1081	463	1040	24547	215	486	0	531
Saranac Lake	1172	291	288	19660	5630	1245	2	285
Schuyler Falls	512	232	556	14614	125	262	0	194
Tupper Lake	192	0	57	11466	1185	464	0	9
Upper Jay	52	1	11	1628	12	7	0	24
Vermontville	779	249	1205	26101	1032	1003	8	165
West Chazy	983	4073	2053	11677	85	613	6	450
Westport	1369	3624	358	17223	171	116	1	365
Willsboro	818	2142	165	8437	257	150	1	307
Wilmington	483	57	248	18986	87	156	6	176
Change								
Lacolle	0	0	0	0	0	0	0	0
Notre-Dame-du-Mont-Carmel	1	1	3	-4	0	0	0	0
Saint-Bernard-de-Lacolle	0	-16	12	3	0	0	0	0
Abercorn	0	0	0	0	0	0	0	0
Frelighsburg	0	-3	0	0	0	0	0	3
Bedford	0	0	0	0	0	0	0	0
Stanbridge East	0	0	0	0	0	0	0	0
Saint-Armand	2	-6	0	0	0	0	0	5
Saint-Pierre-de-Véronne-à-Pike-River	0	0	0	0	0	0	0	0
Stanbridge Station	0	0	0	0	0	0	0	0
Venise-en-Québec	0	0	0	0	0	0	0	0
Saint-Georges-de-Clarenceville	0	-1	0	0	0	0	0	0
Noyan	1	-1	0	1	0	0	0	1
Sainte-Brigide-d'Iberville	0	0	0	0	0	0	0	0
Notre-Dame-de-Stanbridge	0	0	0	0	0	0	0	0
Sainte-Sabine	0	0	0	0	0	0	0	0
Saint-Sébastien	0	0	0	0	0	0	0	0

Saint-Alexandre	0	0	0	0	0	0	0	0
Dunham	0	0	0	0	0	0	0	0
Cowansville	0	0	0	0	0	0	0	0
Saint-Ignace-de-Stanbridge	0	0	0	0	0	0	0	0
Farnham	0	0	0	0	0	0	0	0
Bonsecours	0	0	0	0	0	0	0	0
Eastman	0	0	0	0	0	0	0	0
Bolton-Est	0	0	0	0	0	0	0	0
Saint-Étienne-de-Bolton	0	0	0	0	0	0	0	0
Stukely-Sud	0	0	0	0	0	0	0	0
Stukely	0	0	0	0	0	0	0	0
Bolton-Ouest	0	0	0	0	0	0	0	0
Austin	0	0	0	0	0	0	0	0
Orford	0	0	0	0	0	0	0	0
Potton	0	1	-49	48	0	0	0	0
Sutton	0	-1	2	-2	0	0	0	0
Brookfield	1	-3	1	0	0	0	0	1
Groton	0	0	0	0	0	0	0	0
Plymouth	0	0	0	0	0	0	0	0
Randolph	0	-12	1	0	0	0	0	11
West Topsham	0	0	0	0	0	0	0	0
Londonderry	0	0	0	0	0	0	0	0
Weston	0	0	0	0	0	0	0	0
Dorset	0	-58	0	0	0	0	0	57
East Dorset	1	-9	-1	0	0	0	0	9
Burlington	10	-11	-1	-4	0	0	0	5
South Burlington	33	-250	0	-14	0	0	0	230
Winooski	0	0	-1	-1	0	0	0	0
Burlington	0	0	0	0	0	0	0	0
Alburg	29	-87	0	-3	0	0	0	61
Bakersfield	4	-23	1	-3	0	0	0	21
Belvidere Center	2	-3	0	-1	0	0	0	3
Bristol	9	-322	4	-4	0	0	0	313
Cambridge	11	-46	-2	-7	0	0	0	43
Charlotte	4	-298	0	0	0	0	0	293
Colchester	42	-98	-7	-5	0	0	0	67
East Berkshire	1	-2	1	0	0	0	0	1
East Fairfield	14	-53	-12	8	0	0	0	42
Enosburg Falls	67	-261	-89	-27	0	0	0	310
Essex Junction	69	-293	-5	-15	0	0	0	245
Fairfax	42	-218	-6	6	0	0	0	177
Fairfield	11	-69	-12	8	0	0	0	63
Ferrisburg	5	-220	0	0	0	0	0	215
Franklin	30	-227	2	-3	0	0	0	198
Grand Isle	13	-87	-3	1	0	0	0	77
Highgate Center	24	-74	0	-5	0	0	0	54
Hinesburg	1	-156	1	-1	0	0	0	156

Huntington	0	-22	0	0	0	0	0	21
Isle la Motte	4	-30	-2	-6	0	0	0	34
Jeffersonville	18	-64	8	-23	0	0	0	60
Jericho	5	-202	3	-5	0	0	0	200
Milton	55	-236	-19	10	0	0	0	191
Montgomery Center	10	-26	-3	-12	0	0	0	32
New Haven	13	-302	0	0	0	0	0	292
North Ferrisburg	4	-136	0	0	0	0	0	131
North Hero	7	-59	0	-1	0	0	0	54
Richford	21	-71	-10	-38	0	0	0	98
Richmond	9	-41	-10	6	0	0	0	35
Saint Albans	85	-252	-60	56	0	-3	0	176
Shelburne	2	-147	-1	0	0	0	0	145
Sheldon	14	-32	-6	-33	0	0	0	57
South Hero	13	-67	-1	-2	0	0	0	57
Starksboro	1	-20	9	-9	0	0	0	19
Swanton	73	-222	-12	5	0	0	0	156
Underhill	10	-93	-14	4	0	0	0	94
Vergennes	21	-609	1	0	0	0	0	588
Waterville	7	-36	1	-2	0	0	0	30
Westford	10	-136	-8	5	0	0	0	130
Williston	66	-337	3	-21	0	0	0	287
Montpelier	33	-155	-26	17	0	0	0	132
Adamant	1	-22	1	-1	0	0	0	21
Barre	74	-372	-23	0	0	0	0	321
Cabot	13	-56	1	-4	0	0	0	48
Calais	0	-12	-1	1	0	0	0	11
East Barre	3	-6	5	-6	0	0	0	3
East Calais	5	-11	1	-4	0	0	0	8
East Montpelier	16	-89	6	-10	0	0	0	77
Eden	7	-46	22	-26	0	0	0	43
Eden Mills	2	-19	35	-19	0	0	0	0
Graniteville	8	-41	1	-9	0	0	0	41
Hyde Park	26	-155	-1	-3	0	0	0	133
Johnson	11	-96	-6	-1	0	0	0	91
Marshfield	14	-97	-8	1	0	0	0	91
Moretown	2	-52	16	-17	0	0	0	50
Morrisville	31	-204	10	-14	0	0	0	178
Northfield	9	-98	28	-61	0	0	0	121
North Montpelier	2	-10	0	0	0	0	0	9
Plainfield	19	-205	24	-31	0	0	0	191
Roxbury	1	-9	3	-3	0	0	0	7
Stowe	17	-171	10	-11	0	0	0	156
Waitsfield	1	-112	86	-86	0	0	0	111
Warren	1	-113	14	-14	0	0	0	112
Washington	5	-25	-12	8	0	0	0	24
Waterbury	19	-148	6	-14	0	0	0	135
Waterbury Center	6	-56	-2	6	0	0	0	46

Williamstown	16	-113	7	-14	0	0	0	105
Wolcott	12	-114	-8	5	0	0	0	103
Woodbury	2	-2	-12	12	0	0	0	0
Worcester	4	-34	10	-6	0	0	0	27
Rutland	16	-66	0	0	0	0	0	50
Belmont	0	-4	0	0	0	0	0	4
Bomoseen	1	-9	0	0	0	0	0	9
Brandon	16	-168	31	-42	0	-2	0	164
Bridport	5	-90	0	-2	0	0	0	86
Castleton	4	-70	1	-3	0	0	0	69
Center Rutland	1	-7	0	0	0	0	0	6
Chittenden	0	-3	0	0	0	0	0	3
Cuttingsville	0	-15	51	-51	0	0	0	15
Danby	6	-58	0	0	0	0	0	52
East Wallingford	0	-22	0	0	0	0	0	22
Fair Haven	4	-193	6	-6	0	0	0	190
Florence	0	-14	0	0	0	0	0	14
Granville	0	0	0	0	0	0	0	0
Hancock	0	0	0	0	0	0	0	0
Killington	0	0	0	0	0	0	0	0
Middlebury	31	-519	5	-7	0	0	0	490
Middletown Springs	2	-89	2	-4	0	0	0	89
Mount Holly	0	-2	-3	2	0	0	0	3
North Clarendon	15	-126	1	0	0	0	0	112
Orwell	5	-195	2	-6	0	0	0	193
Pawlet	1	-34	0	-1	0	0	0	33
Pittsfield	0	-1	0	0	0	0	0	2
Pittsford	6	-132	9	-14	0	0	0	130
Poultney	9	-129	8	-12	0	0	0	126
Proctor	0	-2	0	0	0	0	0	3
Ripton	0	-1	4	-3	0	0	0	2
Rochester	0	0	0	0	0	0	0	0
Salisbury	6	-52	12	-18	0	0	0	52
Shoreham	4	-102	0	0	0	0	0	99
Wallingford	10	-57	-1	2	0	0	0	47
Wells	0	-20	3	-4	0	0	0	21
West Pawlet	4	-42	-1	-2	0	0	0	40
West Rupert	1	18	2	-26	0	0	0	6
West Rutland	4	-41	-1	0	0	0	0	38
Whiting	2	-47	3	-10	0	0	0	52
Craftsbury	4	-8	6	-11	0	0	0	9
East Hardwick	10	-72	7	-16	0	0	0	69
Glover	0	0	0	0	0	0	0	0
Greensboro	9	-13	9	-43	0	0	0	37
Greensboro Bend	5	-18	27	-18	0	0	0	5
Hardwick	9	-56	3	-10	0	0	0	54
Irasburg	0	0	0	-1	0	0	0	0
Lowell	8	-20	-69	61	0	0	0	20

Lyndonville	0	-1	-3	2	0	0	0	1
Newport	0	0	0	0	0	0	0	0
Newport Center	19	-62	11	-14	0	0	0	46
North Troy	19	-27	-42	2	0	0	0	48
Peacham	0	0	4	-3	0	0	0	0
Sheffield	0	-2	6	-4	0	0	0	0
Troy	0	-3	-1	-5	0	0	0	9
West Danville	4	-15	3	-5	0	0	0	14
Westfield	7	-10	-8	0	0	0	0	13
Glens Falls	0	0	0	0	0	0	0	0
Queensbury	22	-263	0	0	0	0	0	241
Argyle	3	-5	1	-2	0	0	0	5
Bolton Landing	0	0	0	0	0	0	0	0
Brant Lake	0	0	0	0	0	0	0	0
Clemons	0	-1	29	-29	0	0	0	1
Comstock	11	-20	2	-2	0	0	0	10
Diamond Point	0	0	0	0	0	0	0	0
Fort Ann	40	-120	12	-22	0	0	0	91
Fort Edward	1	-2	4	-4	0	0	0	2
Granville	14	-70	24	-32	0	0	0	65
Hague	0	0	0	0	0	0	0	0
Hampton	3	-24	-5	3	0	0	0	23
Hartford	1	-3	0	-1	0	0	0	1
Hudson Falls	1	-22	0	-1	0	0	0	20
Kattskill Bay	0	0	0	0	0	0	0	0
Lake George	2	-4	1	-1	0	0	0	1
Lake Luzerne	0	0	0	0	0	0	0	0
Middle Granville	1	-2	-4	5	0	0	0	1
Newcomb	0	0	0	0	0	0	0	0
North Granville	0	0	0	0	0	0	0	0
North Hudson	0	0	0	0	0	0	0	0
Putnam Station	4	-29	0	-1	0	0	0	24
Salem	0	0	0	0	0	0	0	0
Ticonderoga	69	-129	-2	2	0	0	0	61
Warrensburg	0	0	0	0	0	0	0	0
Whitehall	10	-67	0	-1	0	0	0	57
Plattsburgh	57	-309	50	26	0	1	0	175
Altona	9	-289	222	16	0	0	0	42
Keeseville	22	-259	152	54	0	0	0	33
Au Sable Forks	19	-186	99	54	0	0	0	14
Bloomingdale	9	-150	79	63	0	0	0	0
Cadyville	9	-159	92	12	0	0	0	46
Champlain	70	-208	26	12	0	0	0	101
Chazy	34	-124	24	7	0	0	0	59
Churubusco	0	-2	2	1	0	0	0	0
Crown Point	10	-92	5	-1	0	0	0	78
Elizabethtown	0	-1	0	0	0	0	0	1
Ellenburg Center	11	-225	154	48	0	0	0	12

Ellenburg Depot	9	-161	97	23	0	0	0	32
Essex	1	-7	0	0	0	0	0	6
Jay	6	-62	15	10	0	0	0	30
Keene	0	0	0	0	0	0	0	0
Keene Valley	0	0	0	0	0	0	0	0
Lake Clear	1	-19	8	10	0	0	0	0
Lake Placid	10	-67	19	19	0	0	0	18
Lewis	0	-2	0	0	0	0	0	2
Malone	0	0	0	0	0	0	0	0
Lyon Mountain	0	-21	16	4	0	0	0	0
Mineville	0	-5	0	0	0	0	0	6
Mooers	10	-254	109	17	0	0	0	117
Mooers Forks	5	-91	41	6	0	0	0	39
Moriah	0	-14	0	0	0	0	0	13
Moriah Center	0	0	0	0	0	0	0	0
Morrisonville	13	-218	138	26	0	0	0	41
New Russia	0	0	0	0	0	0	0	0
Owls Head	0	-1	0	0	0	0	0	0
Paul Smiths	0	-1	0	0	0	0	0	0
Peru	21	-312	172	57	0	0	0	62
Port Henry	8	-7	1	-6	0	0	0	3
Redford	1	-15	13	2	0	0	0	0
Rouses Point	34	-56	0	1	0	0	0	22
Saranac	15	-351	173	96	0	0	0	68
Saranac Lake	19	-125	48	49	0	0	0	9
Schuyler Falls	4	-150	106	29	0	0	0	11
Tupper Lake	3	-30	8	19	0	0	0	0
Upper Jay	0	0	0	0	0	0	0	0
Vermontville	11	-352	240	101	0	0	0	0
West Chazy	15	-481	304	22	0	0	0	138
Westport	23	-106	0	0	0	0	0	84
Willsboro	18	-115	7	3	0	0	0	88
Wilmington	2	-55	24	13	0	0	0	15

Appendix K. Non-point phosphorus measurements (kg/yr) for 30 Lake Champlain Basin watersheds, 1991-2002.

Watershed	1991	1993-1994[a]	1995-1996	1997-1998	1999-2000	2001-2002
Ausable	11,192	29,609	61,983	48,701	41,369	27,197
Bouquet	13,458	27,701	24,346	33,365	23,152	11,700
East	1,200	---[b]	---	---	---	---
Great Chazy	16,721	27,216	30,210	39,579	33,347	18,619
Highland Furgeh	100	---	---	---	---	---
Hosington	500	---	---	---	---	---
Indian Brook	900	---	---	---	---	---
LaChute	1,100	---	---	---	---	---
Lamoille	25,708	30,311	34,148	86,057	52,099	46,222
LaPlatte	7,623	4,634	8,734	8,516	4,990	5,378
Lewis	5,200	4,842	6,556	10,036	11,171	5,885
Little Chazy	3,200	3,846	5,572	7,314	8,447	4,550
Little Otter	5,400	7,068	9,486	15,367	9,062	5,880
Mallets Creek	1,700	---	---	---	---	---
Mettawee/Barge Canal	34,509	61,344	59,196	87,204	54,325	19,077
Mill	3,500	---	---	---	---	---
Mill (Port Henry)	600	---	---	---	---	---
Mill (Putnam)	400	---	---	---	---	---
Missisquoi	71,316	101,822	103,351	202,957	125,735	113,861
Mt. Hope	100	---	---	---	---	---
Otter	45,750	93,813	97,900	152,007	91,899	69,626
Pike	45,660	48,557	55,165	121,579	37,678	27,104
Poultney	14,399	28,892	29,467	34,095	33,337	19,196
Putnam	1,300	1,856	5,088	2,944	1,907	1,795
Rock	28,900	---	---	---	---	---
Salmon	1,700	3,434	2,177	4,117	3,282	2,032
Saranac	7,714	18,922	18,047	24,024	19,599	12,112
Stevens	3,400	---	---	---	---	---
Stonebridge	800	---	---	---	---	---
Winooski	59,559	87,870	119,214	164,617	138,757	82,946

Source: Eric Smeltzer, VTDEC.

[a]Sampling occurred during a hydrological year (October 1 through September 30).

[b]Not available.

Appendix L. Export and loading estimates for Diagnostic Feasibility Study watersheds using LCB-R 1992 and LCB 2001.

		Export Method		Loading Method	
Diagnostic Feasibility Watershed[a]	**Area (ha)**	**LCB-R 1992 (kg/yr)**	**LCB 2001 (kg/yr)**	**LCB-R 1992 (kg/yr)**	**LCB 2001 (kg/yr)**
Ausable	132,864	22,621	22,875	13,265	16,368
Bouquet	70,436	13,388	13,552	7,928	8,843
East	8,277	4,146	4,374	2,486	2,658
Great Chazy	77,361	22,664	23,480	10,094	14,913
Highland Furgeh	3,003	488	489	267	351
Hosington	2,831	777	782	480	469
Indian Brook	3,055	2,701	2,974	1,895	1,848
LaChute	55,927	12,221	12,412	8,239	8,661
Lamoille	187,237	57,412	60,740	36,229	54,012
LaPlatte	13,721	8,380	8,877	4,914	5,960
Lewis	20,999	7,570	8,202	4,748	6,104
Little Ausable[b]	18,869	6,428	6,516	2,892	3,540
Little Chazy	13,814	5,319	5,490	2,156	3,100
Little Otter	18,898	10,023	10,998	5,949	7,408
Mallets Creek	7,553	3,917	4,189	2,409	2,789
Mettawee/Barge	109,832	45,502	47,011	28,496	31,001
Mill	5,992	3,716	3,889	2,047	2,698
Mill (Port Henry)	7,236	1,711	1,727	1,151	1,087
Mill (Putnam	2,976	849	889	541	582
Missisquoi	224,043	119,401	120,124	79,181	113,847
Mt. Hope	3,604	395	395	251	331
Otter	244,458	90,046	94,271	58,791	61,656
Pike	66,748	55,822	56,003	47,286	27,105
Poultney	68,078	23,506	24,403	15,157	16,116
Putnam	16,005	2,696	2,762	1,815	1,947
Rock	14,648	7,010	7,351	4,066	5,656
Salmon	17,525	5,607	5,721	2,719	3,539
Saranac	159,205	30,101	30,340	17,207	22,971
Stevens	6,116	4,946	5,146	2,784	3,546
Stonebridge	3,111	1,702	1,831	958	1,198
Winooski	275,362	101,160	106,881	67,875	79,764
Total[c]	**1,859,785**	**672,224**	**694,692**	**434,277**	**510,068**

[a]See VTDEC/NYSDEC (1997).

[b]Not included in regression analyses in this study or in Hegman et al. (1999).

[c]Note that totals do not match Basin-wide estimates because some watersheds were excluded from the Diagnostic Feasibility Study.

Appendix M. Export and loading estimates for HUC8 watersheds using LCB-R 1992 and LCB 2001.

	Export Method		Loading Method	
HUC8 Watershed	**LCB-R 1992 (kg/yr)**	**LCB 2001 (kg/yr)**	**LCB-R 1992 (kg/yr)**	**LCB 2001 (kg/yr)**
Boquet-Ausable	54,990	55,833	30,507	36,600
Lamoille-Grand Isle	91,898	96,888	55,567	77,231
Missisquoi	184,908	186,174	131,876	148,624
Otter-Lewis	107,612	113,443	69,461	75,111
Poultney-Metowee-South Basin	111,967	115,909	71,080	75,864
Saranac-Chazy	73,462	75,337	36,521	50,047
Winooski	121,990	129,083	80,364	93,516
Total	**746,828**	**772,667**	**475,377**	**556,993**

Appendix N. Export and loading estimates for New York HUC11 watersheds using LCB-R 1992 and LCB 2001.

	Export Method		Loading Method	
HUC11 Watershed	LCB-R 1992 (kg/yr)	LCB 2001 (kg/yr)	LCB-R 1992 (kg/yr)	LCB 2001 (kg/yr)
02010006110	1,944	1,948	935	1,199
02010006090	287	285	121	187
02010006090	26	26	12	15
02010006100	1,927	2,095	930	1,161
02010006090	6,335	6,673	2,681	3,660
01410065407	3	3	1	2
N/A[a]	4,200	4,482	1,909	2,703
02010006080	11,817	12,013	5,372	8,348
02010006130	270	273	97	137
02010006070	5,319	5,490	2,156	3,100
02010006140	1,639	1,700	611	848
02010006060	1,438	1,470	591	810
02010006050	6,479	6,695	3,082	3,940
02010006040	5,750	5,834	2,957	3,461
02010006030	7,568	7,797	3,801	5,827
02010004110	1,929	1,932	1,010	1,035
02010004090	5,607	5,721	2,719	3,539
02010006020	4,555	4,502	2,455	3,617
02010004100	1,281	1,327	605	721
02010004080	6,428	6,516	2,892	3,540
02010006010	12,228	12,207	7,994	10,065
02010004120	267	274	134	152
02010004070	6,749	6,846	3,381	4,009
02010004060	9,165	9,231	5,778	7,208
02010004040	2,775	2,836	1,548	1,835
02010004050	6,706	6,799	4,106	5,151
02010004020	4,580	4,600	2,652	3,080
02010004030	8,808	8,952	5,277	5,763
02010004010	1,458	1,572	826	1,002
02010001260	3,287	3,383	2,035	2,057
02010001250	1,711	1,727	1,151	1,087
02010001240	1,058	1,096	726	664
02010001230	1,123	1,146	708	738
02010001220	2,696	2,762	1,815	1,947
02010001210	2,313	2,468	1,453	1,485
02010001200	2,034	2,100	1,393	1,345
02010001180	1,360	1,385	880	882
02010001170	849	889	541	582
02010001160	1,330	1,333	857	885
02010001070	369	385	226	247
02010001080	1,010	1,015	584	635
02010001150	1,428	1,449	907	1,142
02010001130	1,476	1,504	885	914
02010001100	1,122	1,142	702	748
02010001140	25,121	25,981	15,068	16,519
02010001120	8,039	8,227	5,071	5,340
02010001110	473	480	294	312
02010001120	7	7	4	6
N/A	9,793	9,918	6,593	6,933
01410065407	116	116	80	75
N/A	394	394	253	383
N/A	0	0	0	0
Total	**194,646**	**199,004**	**108,857**	**131,040**

[a]N/A = Watershed polygon does not contain a numeric HUC code.

Appendix O. Export and loading estimates for Vermont HUC12 watersheds[a] using LCB-R 1992 and LCB 2001.

	Export Method		Loading Method	
HUC12 Watershed	LCB-R 1992 (kg/yr)	LCB 2001 (kg/yr)	HUC11 Watershed	LCB-R 1992 (kg/yr)
020100070201	5,282	5,282	4,343	4,579
020100081007	12,802	12,802	11,136	5,358
020100081008	11,288	11,288	9,439	4,710
020100081006	8,344	8,344	7,103	3,788
020100081004	2,330	2,330	2,016	1,385
020100070202	3,449	3,449	2,622	3,283
020100081005	7,445	7,479	6,149	3,953
020100081103	3,404	3,449	1,929	2,468
020100070301	879	879	660	917
020100070303	6,712	6,719	4,918	6,904
020100081003	4,535	4,535	3,796	2,922
020100070302	2,272	2,055	1,687	2,125
020100070104	11,050	11,198	7,836	10,766
020100081101	7,010	7,351	4,066	5,656
020100081105	29	29	20	21
020100081102	557	561	413	356
020100081607	3,857	4,030	1,858	2,352
020100081608	66	69	38	41
020100081607	3,034	3,110	1,451	1,913
020100081203	1,593	1,619	788	1,097
020100081002	6,660	6,800	5,654	3,736
020100070304	7,692	7,808	5,252	7,722
020100081500	22,695	23,511	10,105	14,930
020100070105	7,782	7,835	5,588	7,567
020100081001	2,087	2,094	1,737	1,064
020100070703	6,269	6,363	3,807	5,027
020100081104	441	443	243	305
020100081102	702	707	439	594
020100081208	219	221	116	142
020100081210	25	25	15	15
020100081205	2,286	2,354	1,222	1,560
020100070502	13,713	13,780	8,529	12,913
020100070701	4,837	4,973	2,945	4,406
020100081208	596	627	279	374
020100070402	2,683	2,683	1,782	2,621
020100070401	3,235	3,295	2,235	3,380
020100081607	249	251	89	126
020100070103	3,674	3,760	2,595	3,744
020100070702	6,289	6,298	3,610	5,539
020100081602	5,325	5,499	2,160	3,104
020100070501	7,620	7,757	4,817	7,414
020100081606	5,169	5,422	2,220	2,914
020100070603	9,701	9,770	5,735	9,148
020100081202	4,838	5,038	2,725	3,476
020100070602	3,660	3,704	2,145	3,291
020100070102	2,243	2,269	1,567	2,284
020100070601	7,287	7,304	4,417	7,361
020100081204	667	669	390	454
020100080903	19	19	12	12

020100081300	6,618	6,707	2,985	3,644
020100050104	2,766	2,915	1,830	2,494
020100030401	4,560	4,821	3,296	3,392
020100020201	2,647	2,810	1,936	2,211
020100070101	2,373	2,239	1,652	2,260
020100081601	6,025	6,246	2,837	3,696
020100081201	3,694	3,866	2,031	2,683
020100050302	2,101	2,180	1,349	2,403
020100081204	2,981	3,130	1,638	2,043
020100050301	4,686	5,003	3,154	4,607
020100050306	6,700	7,061	3,882	4,897
020100050305	3,457	3,707	1,973	3,103
020100050103	2,450	2,546	1,633	2,277
020100081606	480	483	256	263
020100050303	3,661	3,811	2,242	4,351
020100050105	520	535	333	590
020100081606	1,918	1,920	1,004	1,029
020100081400	5,638	5,751	2,734	3,554
020100050304	4,068	4,309	2,452	4,706
020100050202	5,546	5,998	3,447	4,943
020100080901	8,934	9,518	5,786	6,054
020100050101	4,025	4,245	2,665	3,546
020100050107	3,597	3,869	2,319	3,484
020100081606	1,240	1,287	585	701
020100050106	5,587	5,976	3,652	4,658
020100050102	4,648	4,852	2,995	3,938
020100030704	13,706	14,424	8,883	8,617
020100081606	95	102	50	57
020100050201	3,582	3,717	2,297	4,007
020100081605	132	133	82	74
020100030602	4,751	4,955	3,174	5,264
020100081604	2,689	2,747	1,501	1,768
020100081605	3,086	3,090	2,004	1,750
020100030702	5,848	6,173	3,725	4,901
020100030301	1,242	1,259	831	1,198
020100030603	3,732	3,894	2,565	3,818
020100030203	4,939	5,114	3,364	3,950
020100030703	3,887	4,263	2,297	2,561
020100080802	5,767	6,215	3,605	3,527
020100030201	3,656	3,861	2,389	3,024
020100080804	1	1	1	1
020100030604	2,120	2,134	1,444	2,128
020100081603	2,647	2,892	1,495	1,831
020100080803	139	147	84	90
020100080700	13,524	13,691	8,004	8,942
020100030302	3,266	3,424	2,228	2,685
020100030601	4,052	4,411	2,840	3,503
020100030202	5,434	5,796	3,637	4,336
020100080801	8,379	8,876	4,914	5,959
020100030701	3,685	3,763	2,506	3,260
020100081604	1,451	1,565	821	999
020100030403	3,047	3,067	2,108	2,272
020100030204	4,938	5,367	3,112	3,667
020100080502	4,655	5,192	2,808	3,679
020100080501	2,781	2,861	1,849	2,319
020100080603	1,605	1,798	935	1,165

020100030504	3,767	4,073	2,700	3,151
020100030503	835	855	633	742
020100080604	13	13	8	9
020100080602	4,986	5,096	3,178	3,137
020100080401	5,740	6,282	3,498	4,326
020100030402	3,191	3,326	2,137	2,328
020100080601	260	283	158	177
020100030103	6,181	6,623	3,993	4,146
020100080402	4,160	4,587	2,386	3,012
020100030502	2,917	3,024	2,292	2,360
020100020502	5,397	5,853	3,222	3,632
020100080601	1,997	2,333	1,240	1,351
020100030102	4,528	4,840	3,007	3,311
020100020202	1,144	1,192	836	971
020100030101	4,621	5,002	3,006	3,243
020100020501	9,792	10,100	5,647	5,978
020100020203	4,628	5,009	3,019	3,286
020100030501	2,264	2,418	1,712	1,911
020100020308	7,480	7,968	4,747	4,608
020100080303	5,473	5,681	3,183	3,343
020100020402	6,909	7,382	4,157	4,208
020100080305	2,737	2,870	1,793	1,761
020100020306	4,014	4,164	2,745	2,768
020100080306	11	11	7	6
020100080302	2,696	2,762	1,815	1,947
020100010303	3,440	3,547	2,289	2,464
020100020109	6,555	6,769	4,384	4,249
020100080304	2,312	2,467	1,452	1,484
020100020305	2,348	2,467	1,601	1,601
020100020401	6,320	6,550	3,752	3,876
020100080301	4,162	4,394	2,496	2,669
020100020303	1,610	1,675	1,146	1,124
020100080202	2,088	2,154	1,433	1,375
020100020304	2,458	2,549	1,594	1,610
020100080201	10,250	10,375	6,887	7,362
020100080105	1,361	1,387	881	883
020100080303	2	2	1	2
020100080107	1	1	1	1
020100020302	3,100	3,295	2,073	2,231
020100080106	1,927	1,969	1,147	1,270
020100020301	3,103	3,324	2,171	2,367
020100010306	4,134	4,246	2,520	2,764
020100020107	5,220	5,292	3,621	3,596
020100010304	4,779	4,900	3,309	3,189
020100080104	846	886	540	581
020100080105	1,331	1,333	857	886
020100010307	5,018	5,209	3,015	3,220
020100010305	1,503	1,590	960	1,024
020100020106	1,650	1,716	1,136	1,314
020100080102	806	827	515	598
020100020108	3,528	3,657	2,318	2,577
020100010302	4,051	4,205	2,583	2,730
020100080101	630	631	398	548
020100010301	2,685	2,838	1,795	2,005
020100010205	6,292	6,495	3,934	4,185
020100020105	3,996	4,059	2,813	2,830

020100010100	24,448	25,311	14,614	16,126
020100010203	4,594	4,783	3,116	3,305
020100020103	3,794	4,015	2,662	2,948
020100020104	1,568	1,590	1,164	1,223
020100010202	1,444	1,482	984	1,103
020100010204	3,936	4,001	2,539	2,742
020100020102	621	621	441	662
020100020101	1,991	2,033	1,506	1,679
020100010201	2,671	2,792	1,988	2,251
Total	**692,674**	**717,761**	**444,667**	**517,065**

[a]Some watersheds in this layer extend into adjacent parts of New York and Quebec.

Appendix P. Export and loading estimates for Lake Champlain Basin towns using LCB-R 1992 and LCB 2001.

		Export Method		Loading Method	
Town	State/Province	LCB-R 1992 (kg/yr)	LCB 2001 (kg/yr)	LCB-R 1992 (kg/yr)	LCB 2001 (kg/yr)
Adamant	Vermont	541	583	373	434
Alburg	Vermont	4,081	4,253	1,975	2,646
Bakersfield	Vermont	1,547	1,570	984	1,591
Barre	Vermont	9,239	9,991	5,997	6,433
Belmont	Vermont	737	744	561	524
Belvidere Center	Vermont	710	720	474	784
Bomoseen	Vermont	883	901	622	564
Brandon	Vermont	8,182	8,549	5,524	5,653
Bridport	Vermont	6,529	6,703	3,827	3,880
Bristol	Vermont	8,185	8,800	5,638	6,607
Brookfield	Vermont	86	90	58	64
Burlington	Vermont	4,794	4,824	3,088	2,745
Cabot	Vermont	2,324	2,441	1,516	1,887
Calais	Vermont	531	552	368	441
Cambridge	Vermont	2,560	2,667	1,504	2,649
Castleton	Vermont	3,451	3,589	2,298	2,435
Center Rutland	Vermont	383	397	250	259
Charlotte	Vermont	6,750	7,317	3,812	4,814
Chittenden	Vermont	494	500	362	398
Colchester	Vermont	7,611	7,822	4,874	4,759
Craftsbury	Vermont	850	880	550	794
Cuttingsville	Vermont	2,740	2,799	1,886	2,103
Danby	Vermont	3,010	3,120	2,161	2,611
Dorset	Vermont	1,390	1,500	1,118	1,244
East Barre	Vermont	426	442	289	297
East Berkshire	Vermont	629	632	405	601
East Calais	Vermont	2,092	2,118	1,455	1,626
East Dorset	Vermont	330	346	268	284
East Fairfield	Vermont	6,015	6,062	3,604	5,887
East Hardwick	Vermont	1,828	1,990	1,163	1,559
East Montpelier	Vermont	2,293	2,477	1,404	1,720
East Wallingford	Vermont	1,681	1,723	1,226	1,257
Eden	Vermont	1,871	1,982	1,273	1,986
Eden Mills	Vermont	1,287	1,294	887	1,329
Enosburg Falls	Vermont	28,915	29,230	19,114	25,492
Essex Junction	Vermont	7,882	8,489	5,296	5,531
Fair Haven	Vermont	9,342	9,712	5,811	6,252
Fairfax	Vermont	6,137	6,529	3,445	5,185
Fairfield	Vermont	5,521	5,556	3,216	5,103
Ferrisburg	Vermont	3,754	4,173	2,170	2,718
Florence	Vermont	1,285	1,312	837	950
Franklin	Vermont	8,075	8,388	5,787	5,916
Glover	Vermont	37	37	23	55
Grand Isle	Vermont	2,679	2,848	1,302	1,647
Graniteville	Vermont	693	791	465	511
Granville	Vermont	7,187	7,355	4,569	4,891
Greensboro	Vermont	2,043	2,155	1,344	1,789

Greensboro Bend	Vermont	835	864	558	709
Groton	Vermont	17	17	10	23
Hancock	Vermont	115	115	78	115
Hardwick	Vermont	3,333	3,457	2,173	2,766
Highgate Center	Vermont	4,477	4,591	2,586	3,702
Hinesburg	Vermont	4,701	4,999	2,873	3,591
Huntington	Vermont	2,283	2,324	1,556	1,959
Hyde Park	Vermont	3,808	4,111	2,494	3,477
Irasburg	Vermont	54	56	39	55
Isle la Motte	Vermont	1,107	1,183	463	633
Jeffersonville	Vermont	4,405	4,541	2,647	5,272
Jericho	Vermont	5,233	5,625	3,413	4,870
Johnson	Vermont	3,227	3,423	2,096	3,389
Killington	Vermont	180	180	128	155
Londonderry	Vermont	47	47	33	74
Lowell	Vermont	4,051	3,961	2,828	3,991
Lyndonville	Vermont	333	334	228	331
Marshfield	Vermont	3,220	3,418	2,172	2,596
Middlebury	Vermont	12,622	13,618	7,991	7,902
Middletown Springs	Vermont	2,505	2,679	1,667	1,895
Milton	Vermont	9,063	9,524	5,280	6,273
Montgomery Center	Vermont	2,998	3,048	2,063	3,145
Montpelier	Vermont	9,366	9,670	6,283	6,871
Moretown	Vermont	2,807	2,916	2,015	2,300
Morrisville	Vermont	5,553	5,959	3,602	4,846
Mount Holly	Vermont	1,163	1,167	832	814
New Haven	Vermont	6,212	6,790	3,736	4,484
Newport	Vermont	1	1	0	1
Newport Center	Vermont	7,575	7,644	5,324	7,326
North Clarendon	Vermont	3,164	3,405	2,093	2,212
North Ferrisburg	Vermont	2,223	2,481	1,336	1,689
North Hero	Vermont	1,928	2,044	953	1,211
North Montpelier	Vermont	135	155	87	107
North Troy	Vermont	9,357	9,397	6,697	9,132
Northfield	Vermont	5,463	5,746	3,841	3,990
Orwell	Vermont	6,940	7,322	4,197	4,523
Pawlet	Vermont	3,101	3,165	2,093	2,395
Peacham	Vermont	284	286	189	252
Pittsfield	Vermont	606	609	433	536
Pittsford	Vermont	3,594	3,860	2,506	2,653
Plainfield	Vermont	4,429	4,847	2,902	3,569
Plymouth	Vermont	49	49	31	37
Poultney	Vermont	4,530	4,792	2,977	3,133
Proctor	Vermont	907	911	616	603
Randolph	Vermont	182	204	125	152
Richford	Vermont	8,598	8,745	5,855	8,608
Richmond	Vermont	3,746	3,825	2,410	3,154
Ripton	Vermont	1,417	1,422	1,032	1,101
Rochester	Vermont	0	0	0	0
Roxbury	Vermont	510	529	371	418
Rutland	Vermont	7,431	7,557	5,074	4,737
Saint Albans	Vermont	13,676	14,022	7,841	10,762
Salisbury	Vermont	3,206	3,328	2,046	2,011
Sheffield	Vermont	46	48	32	43
Shelburne	Vermont	5,000	5,281	2,924	3,283
Sheldon	Vermont	4,850	4,956	2,893	4,465

Shoreham	Vermont	5,623	5,818	3,303	3,394
South Burlington	Vermont	6,269	6,777	3,892	3,773
South Hero	Vermont	2,302	2,435	1,177	1,306
Starksboro	Vermont	2,333	2,377	1,625	2,021
Stowe	Vermont	6,564	6,898	4,446	7,057
Swanton	Vermont	11,728	11,957	6,822	9,002
Troy	Vermont	497	511	353	496
Underhill	Vermont	4,025	4,220	2,554	5,108
Vergennes	Vermont	15,237	16,398	8,950	9,946
Waitsfield	Vermont	3,690	3,952	2,809	3,190
Wallingford	Vermont	3,676	3,785	2,535	2,829
Warren	Vermont	3,024	3,246	2,325	2,471
Washington	Vermont	1,000	1,051	670	709
Waterbury	Vermont	5,367	5,669	3,721	5,046
Waterbury Center	Vermont	1,765	1,862	1,229	1,521
Waterville	Vermont	1,106	1,176	691	1,199
Wells	Vermont	1,738	1,781	1,214	1,218
West Danville	Vermont	619	656	396	516
West Pawlet	Vermont	1,813	1,897	1,187	1,299
West Rupert	Vermont	1,280	1,307	887	1,029
West Rutland	Vermont	3,205	3,284	2,127	2,249
West Topsham	Vermont	28	28	18	27
Westfield	Vermont	3,164	3,177	2,226	3,237
Westford	Vermont	2,381	2,645	1,393	2,163
Weston	Vermont	14	14	11	12
Whiting	Vermont	3,480	3,587	2,048	2,101
Williamstown	Vermont	3,627	3,864	2,425	2,564
Williston	Vermont	6,905	7,589	4,283	4,671
Winooski	Vermont	764	765	508	434
Wolcott	Vermont	4,402	4,620	2,916	4,045
Woodbury	Vermont	1,181	1,176	805	1,071
Worcester	Vermont	2,359	2,421	1,598	2,142
	Total-Vermont	**487,448**	**509,150**	**313,038**	**385,095**
Altona	New York	3,863	3,950	1,768	2,618
Argyle	New York	520	534	295	335
Au Sable Forks	New York	4,370	4,401	2,380	2,974
Bloomingdale	New York	2,146	2,126	1,384	1,805
Bolton Landing	New York	2,026	2,026	1,361	1,470
Brant Lake	New York	62	62	38	68
Cadyville	New York	2,900	2,997	1,382	2,272
Champlain	New York	5,540	5,857	2,382	3,248
Chazy	New York	4,474	4,646	1,662	2,297
Churubusco	New York	99	98	44	65
Clemons	New York	1,328	1,346	852	1,025
Comstock	New York	655	697	393	457
Crown Point	New York	3,817	3,984	2,516	2,557
Diamond Point	New York	769	769	526	519
Elizabethtown	New York	2,305	2,307	1,456	1,475
Ellenburg Center	New York	3,927	3,944	1,737	2,692
Ellenburg Depot	New York	2,953	3,018	1,360	2,171
Essex	New York	514	528	273	327
Fort Ann	New York	10,285	10,548	5,889	6,921
Fort Edward	New York	1,188	1,195	633	742
Glens Falls	New York	843	843	566	499
Hague	New York	1,990	1,990	1,361	1,482
Hampton	New York	1,393	1,440	879	930

Hartford	New York	592	598	355	384
Hudson Falls	New York	2,238	2,280	1,184	1,396
Jay	New York	2,115	2,178	1,209	1,404
Kattskill Bay	New York	161	161	111	100
Keene	New York	1,985	1,985	1,297	1,535
Keene Valley	New York	1,895	1,895	1,212	1,722
Keeseville	New York	6,479	6,552	3,346	4,124
Lake Clear	New York	670	666	457	528
Lake George	New York	3,790	3,798	2,560	2,572
Lake Luzerne	New York	15	15	10	12
Lake Placid	New York	4,915	4,959	3,445	4,228
Lewis	New York	2,191	2,194	1,297	1,484
Lyon Mountain	New York	231	228	104	155
Malone	New York	0	0	0	0
Middle Granville	New York	294	297	193	189
Mineville	New York	863	873	585	532
Mooers	New York	2,830	3,060	1,306	1,845
Mooers Forks	New York	1,540	1,620	726	995
Moriah	New York	926	951	616	626
Moriah Center	New York	369	369	237	244
Morrisonville	New York	4,113	4,201	2,017	2,740
New Russia	New York	1,155	1,155	748	749
Newcomb	New York	6	6	4	8
North Granville	New York	255	256	144	166
North Hudson	New York	146	146	85	179
Owls Head	New York	49	49	22	55
Paul Smiths	New York	73	73	46	64
Peru	New York	8,073	8,198	3,663	4,492
Plattsburgh	New York	15,798	16,222	7,884	9,093
Port Henry	New York	1,119	1,144	778	683
Putnam Station	New York	2,223	2,278	1,434	1,476
Queensbury	New York	6,012	6,512	3,976	4,124
Redford	New York	315	314	167	214
Rouses Point	New York	1,260	1,366	641	756
Salem	New York	2	2	1	1
Saranac	New York	5,919	6,021	3,019	4,677
Saranac Lake	New York	4,832	4,859	3,353	3,766
Schuyler Falls	New York	2,871	2,880	1,431	2,036
Ticonderoga	New York	5,489	5,735	3,616	3,666
Tupper Lake	New York	1,033	1,029	670	1,081
Upper Jay	New York	268	268	169	198
Vermontville	New York	4,416	4,378	2,511	3,473
Warrensburg	New York	9	9	5	13
West Chazy	New York	7,576	7,856	3,227	4,633
Westport	New York	7,332	7,535	4,374	4,552
Whitehall	New York	8,345	8,473	5,134	5,476
Willsboro	New York	4,403	4,603	2,485	2,955
Wilmington	New York	2,628	2,655	1,579	2,082
	Total-New York	**187,783**	**192,206**	**104,573**	**126,432**
Abercorn	Quebec	1,360	1,360	963	1,432
Austin	Quebec	64	64	53	55
Bedford	Quebec	3,650	3,650	3,000	1,843
Bolton-Est	Quebec	1,496	1,496	1,198	1,342
Bolton-Ouest	Quebec	226	226	177	233
Bonsecours	Quebec	48	48	40	49

Cowansville	Quebec	137	137	114	93
Dunham	Quebec	3,886	3,886	3,285	2,670
Eastman	Quebec	718	718	611	552
Farnham	Quebec	1,315	1,315	1,156	581
Frelighsburg	Quebec	5,084	5,086	4,166	3,401
Lacolle	Quebec	2	2	1	1
Notre-Dame-de-Stanbridge	Quebec	6,361	6,361	5,420	2,608
Notre-Dame-du-Mont-Carmel	Quebec	1,870	1,874	902	1,152
Noyan	Quebec	1,339	1,340	660	870
Orford	Quebec	12	12	9	15
Potton	Quebec	7,659	7,571	5,712	7,329
Saint-Etienne-de-Bolton	Quebec	1,098	1,098	874	987
Saint-Alexandre	Quebec	2,320	2,320	1,990	888
Saint-Armand	Quebec	4,406	4,418	3,054	2,912
Saint-Bernard-de-Lacolle	Quebec	383	382	165	247
Sainte-Brigide-d'Iberville	Quebec	464	464	402	179
Sainte-Sabine	Quebec	5,904	5,904	5,133	2,451
Saint-Georges-de-Clarenceville	Quebec	1,650	1,651	918	1,193
Saint-Ignace-de-Stanbridge	Quebec	5,671	5,671	4,987	2,588
Saint-Pierre-de-Veronne-a-Pike-River	Quebec	5,883	5,883	4,868	2,525
Saint-Sebastien	Quebec	1,898	1,898	1,266	1,110
Stanbridge East	Quebec	2,317	2,317	1,913	1,349
Stanbridge Station	Quebec	2,444	2,444	2,004	1,129
Stukely	Quebec	1,538	1,538	1,305	1,314
Stukely-Sud	Quebec	257	257	213	213
Sutton	Quebec	5,361	5,365	4,024	5,479
Venise-en-Quebec	Quebec	712	712	457	505
	Total-Quebec	**77,533**	**77,469**	**61,037**	**49,296**