Technical Report No. 31

Estimation of Lake Champlain Basin-Wide Phosphorus Export

September 1999

Prepared by
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(B) *Report on Institutional Arrangements for Watershed Management of the Lake Champlain Basin.* Yellow Wood Associates, Inc. January 1995.

(C) *Report on Institutional Arrangements for Watershed Management of the Lake Champlain Basin. Appendices.* Yellow Wood Associates, Inc. January 1995.

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(B) *Preliminary Economic Analysis of the Draft Plan for the Lake Champlain Basin Program.* Holmes & Associates and Anthony Artuso. March 1995

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    (B) Lake Champlain Sediment Toxics Assessment Program. An Assessment of Sediment - Associated Contaminants in Lake Champlain - Phase 11. Alan McIntosh, Mary Watzin and Erik Brown, UVM School of Natural Resources. October 1997

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26. *Long-Term Water Quality and Biological Monitoring project for Lake Champlain.* Cumulative Report for Project Years 1992- 1996. VT Dept of Environmental Conservation and NYS Dept of Environmental Conservation. March 1998.

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28. *Lake Champlain Underwater Cultural Resources Survey. Volume 1: Lake Survey Background and 1996 Results*. Scott A. McLaughlin and Anne W. Lessman, under the direction of Arthur B. Cohn, Lake Champlain Maritime Museum. December 1998.

29. *Evaluation of Soil Factors Controlling Phosphorus Concentration in Runoff from Agricultural Soils in the Lake Champlain Basin*. Frederick R. Magdoff, William E. Jokela, and Robert P. Durieux, UVM Department of Plant and Soil Sciences. June 1997.

30. *Lower Trophic Level Interactions in the Pelagic Foodweb of Lake Champlain*. Dr. Suzanne N. Levine, Dr. Mark Borchardt, Dr. Moshe Braner, Angela Shambaugh, and Susan Spencer of UVM School of Natural Resources and Marshfield Medical Research Foundation. July 1997.

31. Estimation of Lake Champlain Basinwide Nonpoint Source Phosphorus Export, William Hegman, Associates in Rural Development, Inc., Deane Wang and Catherine Borer, UVM Water Resources & Lake Study Center, September 1999.

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Estimation of Lake Champlain Basinwide Nonpoint Source Phosphorus Export

Final Report

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For:

Lake Champlain Basin Program

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APPENDICES

Acronyms

AGR	Agriculture
ARD	Associates in Rural Development, Inc.
AU	Animal unit
D/F	Diagnostic/feasibility
DEC	Department of Environmental Conservation
ESRI	Environmental Systems Research Institute
FOR	Forest
GIRAS	Geographic Information Retrieval and Analysis System
GIS	Geographic Information System
HU	Hydrologic unit
IDW	Inverse distance weighted
MAPAQ	Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec
NOAA	National Oceanic and Atmospheric Administration
NPS	Nonpoint source
NWI	National Wetland Inventory
NYS	New York State
P	Phosphorus
Q	Mean annual stream volume
TP	Total phosphorus
TSS	Total suspended solids
URB	Urban
US	United States
USGS	U.S. Geological Survey
USLE	Universal Soil Loss Equation
UTM	Universal Transverse Mercator
UVM	University of Vermont
VCGI	Vermont Center for Geographic Information
VT	Vermont

Executive Summary

Introduction

Implementation of the bi-state Lake Champlain phosphorus reduction process requires an accurate assessment of nonpoint phosphorus loads to Lake Champlain. The initial assessment, carried out by Budd and Meals in 1994, provided an important estimate of the allocation of nonpoint sources of phosphorus among land cover categories and subwatersheds or hydrologic units. The initial study established the importance of agricultural nonpoint sources in contributing phosphorus to the Lake and highlighted the disproportionate role of urban land uses in polluting the Lake. Continued progress in managing nonpoint sources of phosphorus in the Basin depends on refinement of existing approaches to relate the effects of phosphorus loading to causes.

This study presents updates and refinements of the original Basin-wide nonpoint phosphorus assessment. The availability of recent digital land cover data and a more detailed delineation of the subwatersheds that comprise the Basin provide an opportunity to develop a more accurate phosphorus load estimation procedure. In addition, recent research conducted within the Lake Champlain Basin on landscape structure and phosphorus loading to surface waters provides more relevant information describing cause and effect relationships than was available at the time of the previous study. Additional animal density data is also available for the Basin.

Geographic information system (GIS) technology is used in this study as the primary tool for modeling and summarizing the phosphorus loads. GIS and phosphorus modeling capabilities have grown more sophisticated in the last several years allowing the researchers greater flexibility and analytical possibilities than were employed in the previous Basin-wide assessment.

Literature Review and Updating Coefficients

To update phosphorus export coefficients and loading values, literature published subsequent to the 1994 Lake Champlain Nonpoint Source Pollution Assessment was reviewed. To avoid duplication of efforts from the original report, the literature was examined for items dated 1993 or later.

Means and ranges of recent literature phosphorus export values for single land use categories were calculated and found to be within the original broad ranges reported by Budd and Meals. No clear rationale emerged from the literature search by which to alter phosphorus export estimates from those used in the Budd and Meals study.

The wide variation in published values for export and loading coefficients between the older and the more recent literature suggests that there is great variation in the processes that deposit and move both anthropogenic and natural sources of phosphorus from land to surface waters. In addition, landscapes and regions are likely to differ widely due to a wide range of physical, biological, geological, and climatological factors. Choosing values out of this diversity can provide a rough estimate of phosphorus loading potential, but more accurate predictions need to be based on regionally-obtained data.

Estimating Export and Loading Coefficients Using the Diagnostic Feasibility Study

Using the estimates for phosphorus export from the 1997 Diagnostic Feasibility Study for 30 sampled rivers and streams in the Lake Champlain Basin permitted the development of regionally specific phosphorus loading coefficients that appear to reflect local conditions of the Basin. These coefficients were developed using regression techniques.

Two different kinds of coefficients were developed. The first are export coefficients which are the average or representative values for the mass of pollutant exported per unit area per year (e.g. kg/ha/yr). The export coefficients selected in this study are either the same (URB) or lower than those selected in the Budd and Meals study, reflecting the result that when the Budd and Meals coefficients were used to estimate the P output from the Diagnostic Feasibility Study watersheds, an overestimate was obtained.

The second set of coefficients are loading coefficients. The loading coefficients are a function of pollutant runoff concentrations and runoff volume. The regionally specific loading coefficients fall somewhat below the general tendency of values reported by Budd and Meals. This may reflect sampling bias in concentration studies where the volume-weighted average concentration may be difficult to estimate without continuous gauging of the watersheds.

There were clearly three outlying sub-basins in the development of the land use data to phosphorus flux relationships. The Rock, Pike, and Missisquoi River watersheds were high outliers in the regression, reflecting the higher than typical phosphorus loads reported from the rivers. To bring these three watersheds into line required the development of an adjusted set of coefficients. The adjustments are assumed to be only necessary for the agricultural land use categories. Given the small sample size, these coefficients can only be considered to be provisional, awaiting further empirical research into the phosphorus fluxes emitted from the landscape in this region of the Basin.

Perhaps a more reasonable approach is to use the animal unit data to "explain" major outlying watersheds in the Basin. Correcting for the "excess" animals in a watershed (deviations from the average animal density) allowed a much better model fit for the Missisquoi, Pike and Rock watersheds and an overall similarly close fitting model (r-square of 0.95) for the Lake Champlain Basin as a whole. However, the improvement in the Missisquoi Bay watersheds is traded off since there are large deviations in the model prediction for several other Basin watersheds. Thus, neither the loading model alone nor the animal unit correction provides an ideal approach for watershed-level predictions across the whole of the Lake Champlain Basin.

The final export and loading coefficients developed and used for the whole Basin are as follows.

Export and Loading Coefficients

Area of Basin	Export Coeffecient kg/ha/yr			Loading Coeffecient mg/l		
	Forest	Ag	Urban	Forest	Ag	Urban
Basin-Wide Coefficients	0.04	0.42	1.50	0.005	0.070	0.160

In this study, animal unit corrections were applied as part of the modeling process. The development of the animal unit coefficients followed a similar process to that of the export and loading coefficients using regression analysis to develop a "best fit". Animal unit data was available for each of the 30 Diagnostic Feasibility Study watersheds; thus, each watershed had a unique animal unit coefficient. Animal unit corrections are only applied to agricultural land use categories since this is where most if not all the animals occur.

Applying Coefficients to Estimate Phosphorus Loading

After the development of the export, loading, and animal unit coefficients, the GIS was used to develop summaries of predicted phosphorus export.

All GIS analysis was carried out in the raster environment meaning that each data layer is made up individual "cells". Each cell is processed separately in the GIS. The final analysis can then be summarized by 14-digit hydrologic unit, lake segment, or any other unit requested.

Export coefficients were applied to each forested, agricultural and urban land use category in the GIS land use data layer. After the GIS calculation was complete, each cell in the GIS land use data layer contained a value in kg/yr. Animal unit corrections are then applied to each cell in the agricultural land use category.

Loading coefficients were also applied to each forested, agricultural, and urban land use category in the GIS land use data layer. Additional information on precipitation runoff was required for the model. This was gathered from long-term precipitation data available for the Basin. Animal unit corrections are then applied to each cell in the agricultural land use category.

The export method and loading method results using best-fit coefficients and animal unit corrections can be expressed in several different ways. For the purposes of this study, results were summarized by Diagnostic-Feasibility Study watersheds, lake segment, and 14-digit hydrologic unit.

The total nonpoint phosphorus load for the Basin for the export method is estimated at 472,000 kg/yr.

The total nonpoint phosphorus load for the Basin for the loading method is estimated at 473,000 kg/yr. This estimate is slightly higher than that reported for the export method. This difference is most likely due to the influence of the precipitation, since the long-term average precipitation used in the loading estimate was higher that the precipitation for the 1991 calibration year.

Figure 1 shows the phosphorus contributions by lake segment for the loading method. Overall, the Missisquoi Bay segment exports 143,300 kg/yr and is by far the largest contributor of phosphorus to the lake. On a per unit basis, it is the second largest contributor (.46 kg/ha/yr) behind Burlington Bay (1.4 kg/ha/yr). Missisquoi Bay segment is approximately 25 percent agriculture, yet 79 percent of the total phosphorus load is attributed to agricultural practices. Burlington Bay is a relatively small contributor of phosphorus to the lake (1989 kg/yr), but because of the high urban land use (93 percent), it is the largest per unit area contributor to the lake.

The loading model shifts 4% of the loading burden from forests to agricultural land. Some of this might be explained by the influence of runoff, which is a variable in the loading model. For both the export and loading models, the contributions of phosphorus from agricultural sources was 10 to 15 percent lower than those reported by Budd and Meals. Urban contributions were consistently higher than those reported by Budd and Meals.

For any specific year, the loading method probably provides a better estimate of the true flux of phosphorus to the Lake primarily because of the introduction of runoff into the model. Given the available data for the Basin, this model can be easily updated and run to investigate the use of different coefficients or hydrologic conditions years. The current export and loading models require the input of animal unit data. If this data is not available, the models can still be run, but variable coefficients may be needed to account for outlier watersheds such as the Missisquoi, Rock, and Pike.

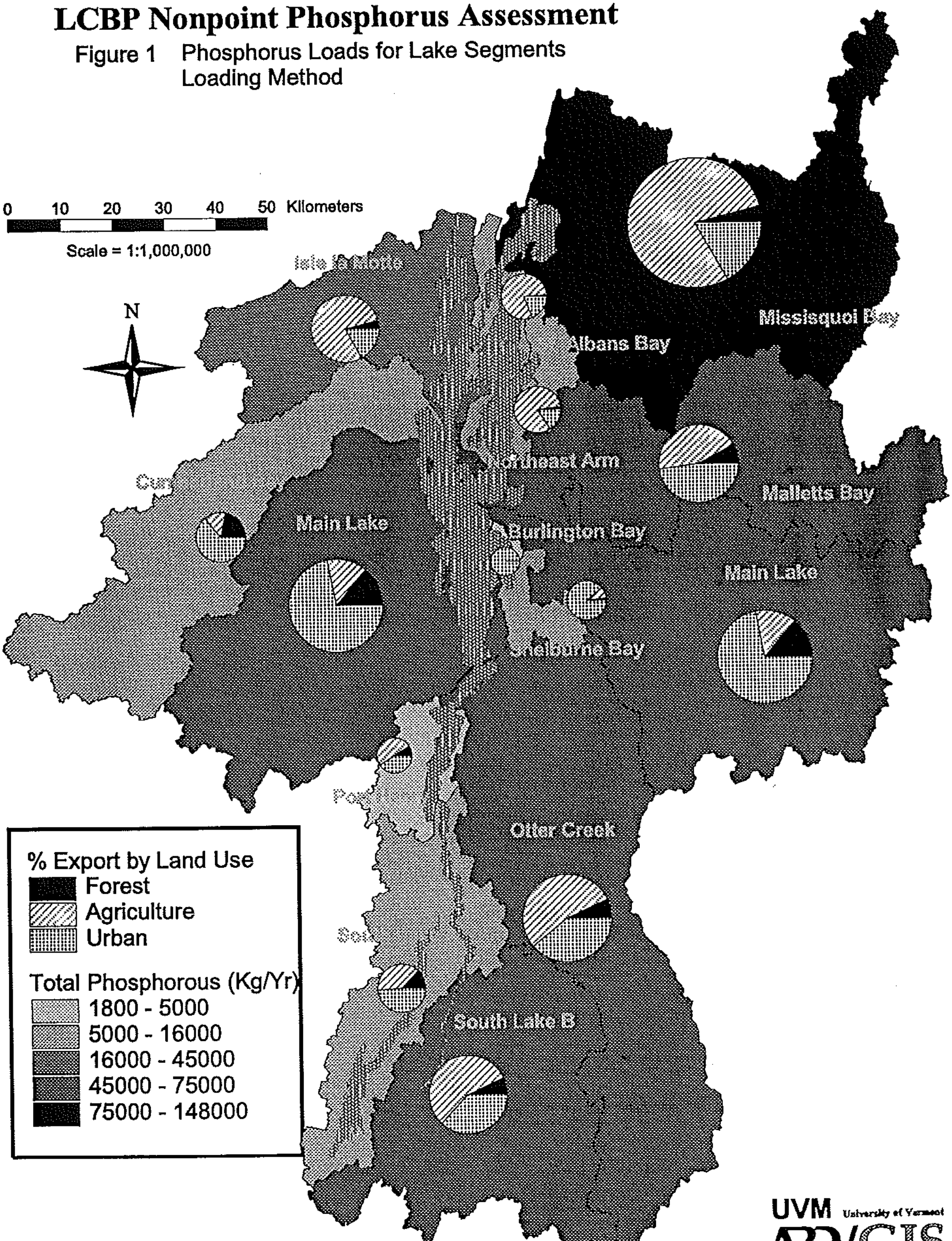
Phosphorus contributions from agricultural sources constitute approximately 55% of the total load to the Basin, thus efforts must be made to reduce this. Phosphorus contributions from urban sources are twice as high as reported by Budd and Meals in their 1994 report. This stems from the fact that the new land use data shows over twice as much urban land (5.5%) as the 1974 land use data (2.5%). The increase in urban contributions of nonpoint phosphorus within the Basin probably warrants more investigation and specific reduction measures since it is likely that urban land uses will continue to increase. In addition, urban land constitutes 5.5% of the land but contributes 37% of the phosphorus.

The application of the coefficients and the use of the 1993 land use data to individual sub-basins are probably not warranted unless the sub-basin is sufficiently large to reflect an average condition of agricultural practice and urban uses. The 1993 land use data is best used on a basin-wide scale and has limitations when applied to small sub-basins because of the inaccuracies in the geographic distribution of the land classification. It cannot be used confidently for proximity analysis.

The raster GIS analysis used in this study proves to be an excellent way to store data, analyze and summarizing the results.

LCBP Nonpoint Phosphorus Assessment

Figure 1 Phosphorus Loads for Lake Segments
Loading Method



Note: Pie chart diameter is proportional
to load contribution

Missisquoi Bay Studies

The comparison of watersheds within the Lake Champlain Basin showed that some watersheds were clearly different from the others in terms of flux and concentration of total phosphorus in surface waters. This difference was reflected in these watersheds being clearly different in the regression analyses. In particular, the Rock, Pike, and Missisquoi watersheds had higher fluxes of total phosphorus than would be expected given the area of the watersheds and their particular land use categories as recorded in the GIS database. All three watersheds drain into Missisquoi Bay.

Animal unit data for the three Missisquoi Bay watersheds were requested from agencies in Vermont and Quebec. Tile drainage information for the three Missisquoi Bay watersheds was also requested from appropriate agencies in Vermont and Quebec. In addition, a synoptic study of stream water quality was conducted on two occasions in the spring and summer of 1998. The objective was to demonstrate the potential for using the existing loading coefficients procedure along with synoptic sampling at high flow to characterize spatial and temporal patterns of phosphorus export at the small watershed scale.

Estimates from the loading model for the Missisquoi Bay watersheds show that approximately 62% of the total nonpoint phosphorus load is coming from Vermont while approximately 38% is from Quebec. Vermont contributes approximately 63% of the agricultural contributions of phosphorus and Quebec 37%.

Estimated phosphorus export from field sampling in the Diagnostic Feasibility Study point out the higher unit area export of phosphorus from the three northern watersheds draining into the Missisquoi Bay. Without looking to extensive new data collection, clues from existing data and short-term synoptic surveys were used to try to understand this difference. Animal unit data suggest that higher than typical animal densities may account for the elevated unit area phosphorus export in this region of the Lake Champlain Basin. Tile drainage data were severely limited and could provide no additional clues to the difference. Two synoptic surveys during high flows in April and August of 1998 suggest that agricultural and forested land use categories dominate the total phosphorus export phenomenon. These data suggest that forest land or forest practice in this region may also be linked to higher than typical unit area phosphorus export rates at certain times of the year. Given the extent of and type of data available for the Missisquoi Bay watershed, we suggest that animal unit data provide the best explanation at this time for the higher than normal phosphorus export from these watersheds.

1. Introduction

Implementation of the bi-state Lake Champlain phosphorus (P) reduction process requires accurate assessment of nonpoint P loads to Lake Champlain. The initial assessment (Budd and Meals 1994) provided an important estimate of the allocation of nonpoint sources of phosphorus among land cover categories and subwatersheds or hydrologic units. The importance of agricultural nonpoint sources in contributing phosphorus to the lake (66 percent of the total annual nonpoint P input) and the disproportionate role of urban land cover in polluting the lake (roughly three times higher than agriculture per unit area) were important results of this study. Continued progress in managing nonpoint sources of phosphorus in the Basin depends on refinement of existing approaches to relate the effects of phosphorus loading to causes.

This study presents updates and refinements of the original Basin-wide nonpoint P assessment. The availability of recent digital land cover data and a more detailed delineation of the subwatersheds that comprise the Basin provide an opportunity to develop a more accurate P load estimation procedure. In addition, recent research (Weller et al. 1996, Braun 1997, Windhausen 1997) conducted within the Lake Champlain Basin on landscape structure and P loading to surface waters provides more relevant information describing cause and effect relationships than was available at the time of the previous study. Furthermore, recent research (Sharpley et al. 1993, Vaithiyanathan and Correll 1992, Dillon et al. 1991, Daniel et al. 1994) on nonpoint source phosphorus provides additional insight into understanding and describing the complex phenomenon of P export and movement.

Incorporating these new insights, along with new data and means of analysis, will improve the information available to managers and policy makers in the Basin. The need for improved information and tools is particularly strong for the Missisquoi Bay Watershed, which has been identified by the Lake Champlain Basin Program as a priority for P load reduction (Lake Champlain Management Conference, 1996). Currently, a special Missisquoi Bay Task Force is studying the problems and developing agreements between Quebec and Vermont for phosphorus reduction. The results of this study will form a basis for agreeing on relative reduction targets.

1.1 Objectives

The objectives for the study were as follows:

1) Estimate nonpoint source P loads from each 14-digit hydrologic unit (HU) to allow comparison to previous and future conditions. Facilitate future comparisons and other uses of the data by (a) aggregating data by major tributary watersheds, lake segments, and the Basin as a whole; and (b) providing and documenting all computer programs and data used to develop P load estimates.

2) Estimate separate nonpoint source P loads for the Quebec and Vermont portions of the 14-digit HUs that comprise the Missisquoi Bay Watershed. If possible with available data, incorporate information on animal density into the load estimates.

3) Summarize in map and tabular form the land cover composition of the 14-digit HUs that comprise the Lake Champlain Basin using the 1993 satellite-based land cover data.

1.2 Background

The 1994 Budd and Meals (Budd/Meals) Basin-wide assessment of the relationship between land cover and nonpoint P loads was based, of necessity, on 20-year-old land cover data. It also relied on the best available delineation of subwatersheds within the Basin, which, at the time, were 11-digit HUs. While the results were useful for determining the relative contributions of major land cover categories (forested, agricultural, and developed land) and of major subwatersheds, there are new data and methodologies that could improve the results.

Most significant are the availability of 1993 Landsat-derived land cover data for the entire Basin that are contemporary with monitored water quality data from the Diagnostic-Feasibility Study (VT DEC, NYS DEC 1997). Based largely on differences in spectral reflection detected by the Landsat Thematic Mapper, the new land cover data set offers 17 land cover classes and a spatial resolution of approximately 0.1 hectare, compared to a minimum mapping unit ranging from 4 to 16 hectares for the previous study. The accuracy of the new land cover layer is estimated at 86 percent while the accuracy of the land cover data used previously is unknown. Calibration of the model is more robust and straightforward because the new land cover data are contemporary with the tributary mouth P load measurements used in the calibration step.

The Vermont and Quebec subwatershed boundaries used for this study are of much higher resolution than previously available. The 11-digit HUs used previously have been subdivided into smaller 14-digit HUs for the Vermont and Quebec portions of the Basin. All HUs were edge-matched resulting in a consistent, seamless data layer for the Basin. Use of this higher-resolution HU data layer in conjunction with the higher-resolution land cover data provides a more detailed understanding of the distribution of sources of nonpoint source P.

Various studies both within and beyond the Basin completed since the Budd/Meals study have provided additional P runoff concentration values and export coefficients. These additional values and coefficients were compared to those found by Budd/Meals. The results of the comparison formed the basis for developing new coefficients used in this study.

Finally, geographic information system (GIS) technology and P modeling capabilities have grown more sophisticated in the last several years. Working in a raster (rather than a vector) GIS environment allows full utilization of the high-resolution land cover data and provides greater flexibility and analytical possibilities than were employed in the previous Basin-wide assessment. For example, using the ArcView Spatial Analyst module, precipitation and runoff volumes can be computed for individual grid cells, and the position of various land cover types relative to a HU's water course can be factored into the P load estimate.

1.3 Study Area

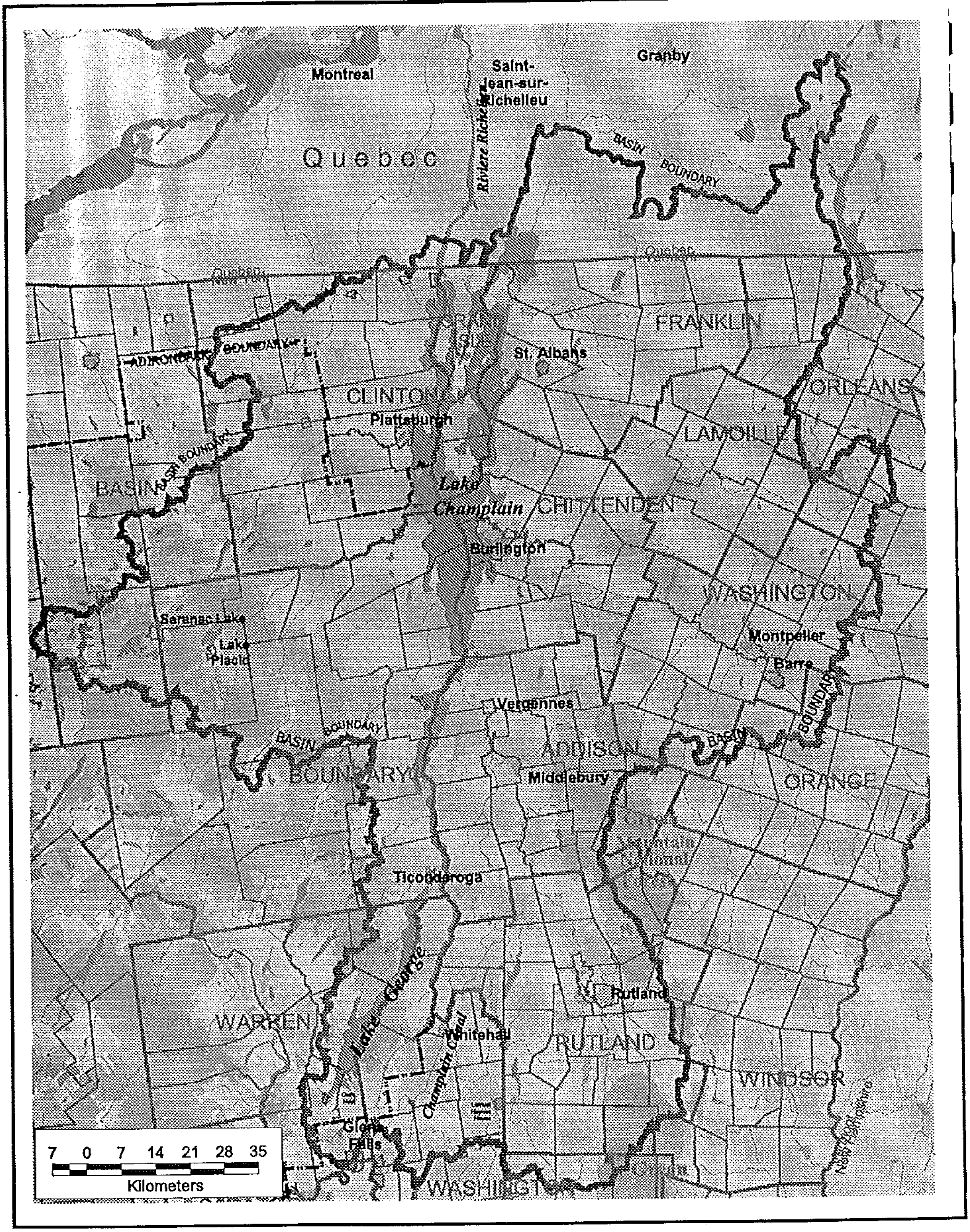
Part of the St. Lawrence River drainage system, the Lake Champlain Basin is a large (21,300 km^2, 8,224 mi^2) region with an estimated population of 607,700 (Holmes and Associates, 1993). Parts of the Basin lie in Quebec, Canada, and the states of New York and Vermont in the USA (Figure 1.1). Topography and land use are quite diverse ranging from the rich agricultural lands in the old glacial lake bottom sediments to the rough granitic Adirondack Mountains and the more calcareous Green Mountains. Burlington, Vermont and Plattsburg, New York are the two largest municipalities in the Basin. They are complemented by many small rural communities throughout the Basin. Much of the drainage area of the Champlain Canal, a significant cultural feature, lies within the Lake Champlain Basin. Lake George, a deep, long, north-south running, New York lake in the southern portion of the Lake Champlain Basin also has cultural significance and served as part of a historical waterway.

Lake Champlain is the sixth largest freshwater lake in the U.S. It has many hydrologic and limnologic similarities to the Great Lakes (Watzin, 1992). Lake Champlain drains an area that is roughly 56 percent in Vermont, 37 percent in New York, and 7 percent in Quebec (Budd and Meals, 1994). Forty-eight (48) percent of Vermont is in the Basin, 6 percent of New York, and 0.1 percent of Quebec (Lake Champlain Basin Study, 1979). The lake's drainage area/surface area ratio of approximately 19:1 is exceptionally large.

1.4 Report Layout

This report is comprised of five major sections. Section 1 introduces the study area and the objectives of the study. Section 2 presents the results of comparing new phosphorus loading values with those found by Budd/Meals in the previous study. It also suggests how this new information should be interpreted and used in the development of phosphorus loading coefficients for this study. Section 3 describes the process used to develop phosphorus-loading coefficients for this study. Section 4 describes the phosphorus models used in this study and presents the results of the models using the new coefficients. Section 5 presents detailed results about Missisquoi Bay. It evaluates the Missisquoi Bay watershed based on other available data with specific reference to animal units, tile drainage, and results of a brief synoptic sampling of small watersheds. Supporting appendices follow Section 5.

Figure 1.1: Lake Champlain Study Area



2. Using Literature Values - Updated Coefficients

2.1. Introduction

An extensive review of the literature by Budd and Meals (1994) allowed a mean and range of phosphorus (P) export and loading coefficients to be estimated (Table 2.1). They then used this subjective appraisal of appropriate values to model phosphorus loading to the Lake Champlain Basin. The table of coefficients based on this review is reprinted in Appendix 7.1 for reference.

A comparison of the Budd/Meals values with values based on recent literature is provided in Table 2.1 below, and the sources and use of the new values are discussed below in Sections 2.2 and 2.3.

Table 2.1: Comparison of previous P export values (kg/ha/yr) from Budd and Meals (1994) and from recent literature reviewed in this study.

Land use	Budd/Meals		This Study's Review	
	best est.	range	mean	range
forest	0.10	(0.01 - 0.9)	0.39	(0.09 - 0.44)
agriculture	0.50	(0.10 - 7.17)	1.26	(0.09 - 2.66)
urban	1.50	(0.05 - 11.6)	0.83	(0.54 - 1.39)

Because no important changes in literature estimates of P export coefficients were discovered in our literature review of research since 1993, the authors agree with the Budd/Meals conclusions about which reasonable central tendencies and ranges in P coefficients to extract from the literature. However, the diversity of published values did prompt reliance on and use of a more regionally-relevant set of P coefficients based on local data obtained through the Diagnostic Feasibility Study and other studies. The development of regionally-based coefficients is discussed in Section 3.

2.2. Recent Estimates

To update phosphorus export coefficients and loading values, literature published subsequent to the original Lake Champlain Nonpoint Source Pollution Assessment (Budd and Meals 1994) was reviewed. To avoid duplication of efforts from the original report, the literature was examined for items dated 1993 or later. Searching was performed using standard computer database techniques. Database searches included AGRICOLA, Environment, the National Agricultural Library, the National Agricultural Statistics Service, the Natural Resources Conservation Service, and the New England Agricultural Statistics Service. Keywords used included: drainage, land use, nonpoint source pollution, nutrient loading, phosphorus, phosphorus loading, phosphorus runoff, runoff, surface water, water pollution, water quality, and watersheds.

Articles, books, conference proceedings, and government documents were reviewed and evaluated for applicability. Values from references with relevant export coefficients or concentrations were recorded from watersheds with single and mixed land use categories. For mixed land use study areas, the percentage of area was recorded in each of five land use categories: agriculture, urban, forest, wetland, and other. Some of the literature reviewed did not contain additional P export or loading data, but did contain other useful information and are thus cited and included as part of this report. A particularly useful resource, Tunney et al. (1997), contained numerous in-depth discussions of phosphorus leaching issues.

2.3 Results and Discussion

Means and ranges of recent literature export values for single land use categories were calculated (Table 2.1; and Appendix 7.1, Table 1), and found to be within the original broad ranges reported by Budd/Meals. No clear rationale emerged from the literature search by which to alter P export estimates from those used in the Budd/Meals study.

Values were also examined from studies that included mixed land use categories. These mixed land use studies were characteristic of the bulk of available published data. In practice, few drainage areas contain only a single land use category. To compare the Budd/Meals export coefficients with the newly-reported export amounts from these mixed land use studies, annual export was calculated using the published land use category percentages and the Budd/Meals export coefficients (kg/ha/yr) for each of four land use categories (agriculture: 0.5; urban: 1.5; forest: 0.1; wetland: -30). The calculated P exports were then compared to the published export values. Analyses were performed both with and without the P coefficient for wetland land cover.

Percent differences between calculated (from the Budd/Meals coefficients) and published values (from the literature reviewed in this study) were determined: [(calculated-published)*100/published)] (Figure 2.1; and Appendix 7.1, Tables 3 and 5). Differences show a strong tendency toward negative deviations, indicating that the Budd/Meals export coefficients produce estimates that are low in comparison with most of the recently published values. Few absolute deviations are greater than 100%. Because of the relatively low proportion of wetlands in study areas, there is little change in the overall pattern when the wetland coefficient is omitted from the calculation.

Values for P runoff concentrations were found in the recent literature search. Most were only for forested land use (>=90%). Appendix 7.1, Table 2 contains these (or representative) values. Concentrations were within the expected range from the original literature review (Budd and Meals 1994). It is difficult, and of limited value, to use concentrations from mixed land use studies (Appendix 7.1, Table 4) in comparing calculations without corresponding runoff volume estimates.

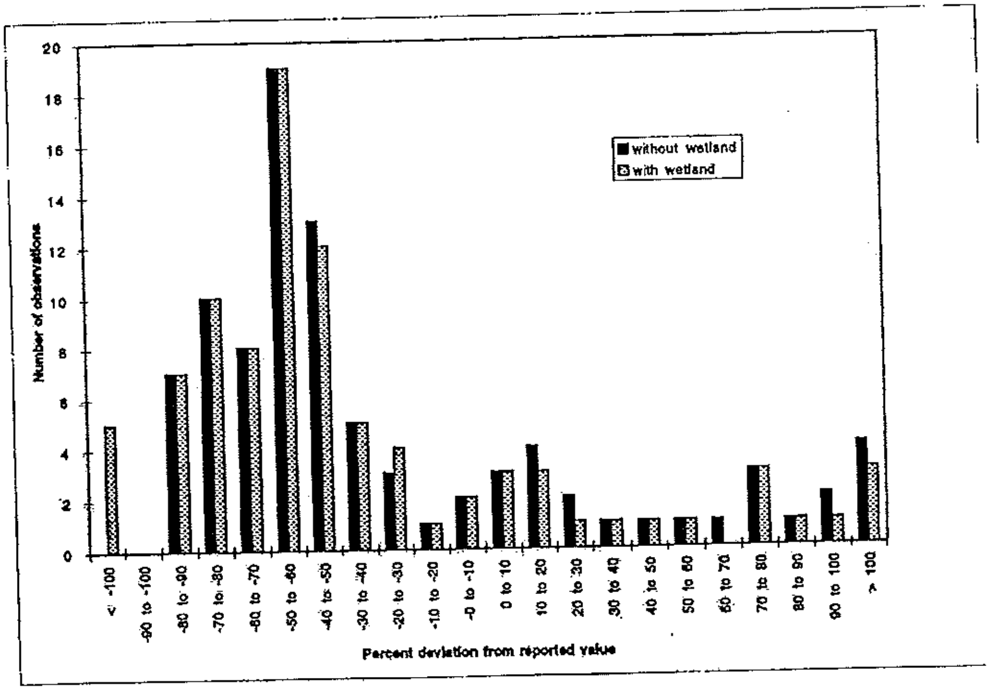


Figure 2.1. Distribution of percent deviations of calculated values from published values for mixed land use study sites. Percent deviation = [(estimate based on previous export coefficients and %land use categories) - (published value)]*100/(published value). Previous export coefficients in kg/ha/yr: agriculture: 0.5; urban: 1.5; forest: 0.1; and wetland: -30.

To determine which, if any, land use category dominates the more extreme deviations, percent differences were plotted against percent land use for each of the four land use categories, and regression equations were calculated. None of these regressions between percent deviation and percent of an individual land use category (e.g., deviation vs. percent forest for each published observation) showed significant trends, indicating that all previous export coefficients are low. No export coefficient for a particular land use category is driving the tendency toward negative deviations.

To see whether the mean of recent published export coefficients (kg/ha/yr) from single land use categories (agriculture: 1.26; urban: 0.83; forest: 0.39; and wetland: -30) more closely reflect the P export from study sites with mixed land uses, percent deviations were calculated and aggregated (Figure 2.2). The bulk of observations produces a fairly clean Gaussian distribution centered close to zero, but the distribution has a very long upper tail (note the shift in the independent axis at 100%).

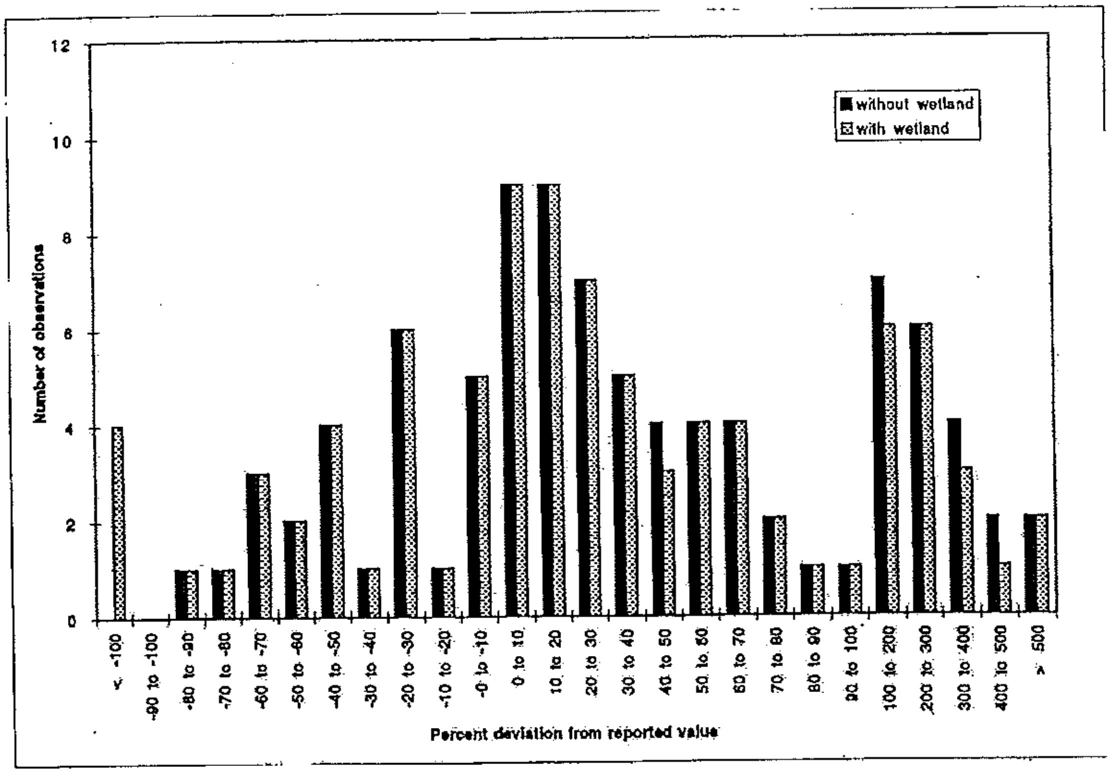


Figure 2.2. Distribution of percent deviations from published values for single land use category study sites. Percent deviation = [(estimate based on the mean of recent export coefficients and % land uses) - (published value)]*100/(published value). Recent export coefficients in kg/ha/yr: (agriculture: 1.26; urban: 0.83; forest: 0.39; and wetland: -30).

2.4 Conclusions

The wide variation in published values for export and loading coefficients between the older and the more recent literature suggests that there is great variation in the processes that deposit and move both anthropogenic and natural sources of phosphorus from land to surface waters. In addition, landscapes and regions are likely to differ widely due to a wide range of physical, biological, geological, and climatological factors. Choosing values out of this diversity can provide a rough estimate of phosphorus loading potential in a particular region, but more accurate predictions need to be based on regionally-obtained data.

3. Estimating Export and Loading Coefficients Using the Diagnostic Feasibility Study

3.1. Introduction

A variety of estimation approaches have been used to predict phosphorus loading to surface waters. These approaches trade off simplicity with realism, ranging from simple unit area export models that fail to take into consideration all of the hydrologic processes that transfer P from soil and transport it through the hydrological network, to more complex and realistic process models that require enormous amounts of descriptive data on land condition, management techniques, and biophysical conditions in the watershed. The latter have recently taken on the form of empirical and process models such as CREAMS-WT (Heatwole et al. 1988), AGNPS (Young et al. 1989) or the Universal Soil Loss Equation (USLE) linked to GIS (Wagner et al. 1996, Lenzi and DiLuzio 1997, Liao and Tim 1997, Rode and Frede 1997, Heidtke and Auer 1993). Models of intermediate complexity have also been developed (e.g., Dikshit and Loucks 1996). The simpler export models (Omernik 1976, Beulac and Reckhow 1982) nevertheless remain popular due to their ease of use, minimal data requirements, and simple integration into a GIS framework (e.g., Johnes 1996, Mattikalli and Richards 1996). Slight modifications in the basic export model approach have been employed that do not require the often difficult-to-obtain data needed for the process models, but use more easily obtainable data available in GIS coverages. Loading models take advantage of extrapolated precipitation and runoff coefficients (either from the literature or from empirical data). Distance models can include information about the proximity of P sources to the surface water network (e.g., Soranno et al. 1996). The export and loading coefficient/GIS approach was used in this study. The proximity analyses could not be applied to the whole Basin because the surface water coverages for New York, Vermont and Canada were of such varying quality and scale, making comparable estimates of proximity impossible to calculate using the existing GIS data.

Export coefficients (export of P to surface water per unit area of specific land use) and loading coefficients (volume-weighted mean concentrations of total P) can be estimated using a variety of approaches. Literature values taken from the large body of research on diffuse pollution provides a general range of values, but site-specific values are difficult to choose. The topography, soil types, precipitation intensity, length of growing season, and different land management practices in specific regions are just a few of the factors that control the flux of P from the land to surface water (Johnson et al. 1976, Sharpley et al. 1993). In addition, the dynamics of P within stream ecosystems can alter the transport of P from land to lakes (as measured by sampling at the mouth of streams and rivers, Wang et al. 1999).

Site specific coefficients for large regions can be obtained from broad-scale sampling of P flux from the many tributaries leading into a water body. Such a study was completed for Lake Champlain for the year 1991 (VT DEC, NYS DEC, 1997, Smeltzer and Quinn, 1996). These data, in concert with detailed land use and regional precipitation data, can form the basis for estimating site-specific export and loading coefficients for the Lake Champlain Basin.

3.2 Methods

3.2.1 The Lake Champlain Basin

The Basin was divided into 31 sub-basins as part of the Diagnostic Feasibility Study (VT DEC, NY DEC, 1997). These 31 watersheds ranged in size from 28 to 3,336 square kilometers. Thirty of these watersheds were used as part of this study. The dominant sources of diffuse P are from agriculture and urban land use areas, with watersheds ranging from 10 percent to 55 percent agricultural and from one percent to 35 percent urban land use. Approximately nine percent of the Basin area was not included in these 30 watersheds because either the land area drained directly into the lake without an identified first order stream or the stream was too small to be included. This nine percent of the Basin area included one Diagnostic Feasibility Study watershed (Little Ausable) that was not used because it was not accurately delineated and available in the GIS at the start of the study.

3.2.2 Data Sources

Land use data for estimating export and loading coefficients were obtained from the 1993 land use cover developed in part with funds from the Lake Champlain Basin Program (Millette, 1997). These data had an estimated overall classification accuracy of 85.9 percent. Data were originally classified into 17 land use categories (Table 3.1) and then regrouped into agricultural, urban, and forest categories. Agricultural and forest wetlands were not included in these larger groupings, as the wetland areas in this region are likely not to be sources of P but rather sinks (Weller et al. 1996).

Table 3.1. Composition of Major Land Use Categories

URBAN (URB)	AGRICULTURE (AGR)	FOREST (FOR)
11 Residential	211 Row Crops	41 Deciduous Forest
12 Commercial	212 Hay/Permanent Pasture	42 Coniferous Forest
13 Industrial	22 Orchards	43 Mixed Forest
14 Transportation/Utilities	24 Other Ag/Mixed Open	
17 Other Urban	3 Brush or Transitional	
excluded ----->	62 Non Forested Wetlands	61 Forested Wetlands

Precipitation data from 1991 for loading method estimates were obtained for 39 precipitation gauging stations in the US and Canadian portion of the Basin (NOAA, various years; Canadian Normals, 1991; and Quebec Ministry of the Environment and Wildlife). Long-term average streamflow data from 11 USGS streamwater gauging stations were used to estimate runoff coefficients for the major Basin land use categories (agriculture, urban, forest).

Spatial data manipulations were accomplished using ArcView software (ESRI, Redlands, CA, Version 3.0) based on a grid cell size of 25x25 meters.

Nonpoint source phosphorus export data (kg P/yr) for each of the 30 monitored watersheds were obtained from the Diagnostic Feasibility Study (VT DEC, NYS DEC 1997). These values were estimated for the base year 1991 from monthly samples at river mouth stations. Thus export and loading coefficients are relevant to this single sample year.

3.2.3 Statistical Analyses

To estimate runoff, export, and loading coefficients, multiple regression was used to select appropriate coefficients based on a simple linear model. JMP software (SAS Associates, Version 3.2) was used to perform the statistical calculations. Both two-variable and three-variable models were specified to assess the variability of the coefficients, especially when the dependent variables (AGR, FOR, URB) were themselves correlated. In addition, in the case of forest, model coefficients were evaluated against watersheds dominated by a single land use category to test the estimated coefficients one at a time. Data were unweighted and not transformed, but left in their original units.

Stepwise regression was used to select the best independent variables out of the set of 15 individual and three aggregated (AGR, FOR, URB) land use categories. In most cases, less-dominant land use categories such as Commercial, Transportation, Barren land, and Orchards never appeared in any stepwise analysis. In addition, categories such as Row Crops correlated strongly (r-square = 0.93) with the aggregated variable AGR and provided very little differentiation in the regression models. Given the difficulty in determining Row Crop coverage, its absence in many GIS databases, and the questionable accuracy of this designation, both for the year of observation (1993) and for any particular year, the aggregated AGR variable was considered to be more useful. Despite occasional appearance in stepwise regressions of the different forest designations (Deciduous, Coniferous, Mixed), given the low P export from these land categories and the probable uniformity of P emission from all forested land, the aggregate variable FOR was preferred for this land use type. Similarly, no individual "urban" variable consistently appeared in stepwise regression analyses, so the aggregate URB category was deemed to be more useful for this Basin-wide analysis.

3.2.4 Calculation of Runoff Coefficients

Runoff coefficients for the major land covers were calculated based on the 11 USGS stream gauges in the Vermont and New York portions of the Basin (Table 3.2). Only non-nested watersheds were used in this analysis to maintain independence of the variables to be used in the regression analysis. Digitized boundaries of the gauged watersheds were obtained by using the 14-digit hydrologic unit boundaries available for the Basin with hand-digitized adjustments for the drainage area near the gauging station. Mean annual stream volume (Q) for each gauged watershed was obtained from USGS for seven to 75 years of record (Water Resources Data 1991).

Stream flow data for most of the watersheds were based on at least 40 years of record. Mean annual precipitation for the Basin was estimated from 57 precipitation stations for the period from 1951-1996 (Fig. 4.1, Appendix 7.3). These data were then plotted in their respective geographical locations in the Basin and used to create a precipitation surface using an inverse distance weighting algorithm in the GIS. These precipitation values were then summed for each gauged watershed and the mean precipitation for each watershed was calculated.

Table 3.2: USGS Gauging Stations

GAGING_ST	ST_Name	AREA (mi^2)	MEAN (in)	STD	Q (in)	Nested
4271500	Gt. Chazy R @ Perry Mills	243	32.79	0.83	14.40	no
4273500	Saranac R. @ Plattsburg	615	36.70	2.27	18.78	no
4275000	E. Br. Ausable R. @ As. Forks	234	36.51	2.07	21.61	no
4276500	Boquet R. nr Willsboro	272	35.17	0.71	14.38	no
4278300	NW Bay Br. Nr Bolton Lnd	22	38.88	0.38	22.59	no
4280350	Mettawee R. nr Pawlet	63	44.85	1.48	22.63	no
4282500	Otter Ck. @ Middlebury	631	39.25	3.36	21.56	no
4289000	Little R. nr Waterbury	112	47.61	5.75	29.59	no
4290500	Winooski R. nr Essex Jct	929	39.45	2.07	22.43	no
4292500	Lamoille R. @ E. Georgia	670	43.71	4.39	24.63	no
4293500	Miss R. nr E. Berkshire	482	45.61	1.71	26.34	no
4286000	Winooski R. @ Montpelier	394	38.74	1.65	20.31	yes
4288000	Mad R. nr Moretown	144	41.61	1.36	25.40	yes
4292000	Lamoille R. @ Johnson	310	41.69	1.88	23.52	yes
4293000	Miss R. nr N. Troy	139	44.14	0.66	27.99	yes
4285500	NBr Winooski @ Wrghtvl	78	40.71	1.00	26.49	yes

Using the general approach of the rational equation relating flow (Q, as peak discharge) to precipitation (maximum rain intensity) and a runoff coefficient, land cover-specific coefficients were estimated for the Lake Champlain Basin. Mean annual precipitation volumes (cubic meters) on AGR, URB, and FOR land cover for each gauged watershed (area * precip.) were used as independent variables and the annual stream flow (cubic meters) of the watershed was used as the dependent variable. The coefficients of the multiple linear regression of streamflow outflow on precipitation input for agricultural, urban, and forest land for each of the 11 gauged watersheds are the region specific runoff coefficients for these land covers. These coefficients could be further subregionalized by breaking the Basin into subunits; however, the relatively small number of gauged watersheds prevents taking this approach. Thus a single set of runoff coefficients for the major land cover categories was calculated for the Basin as a whole.

3.2.5 Calculation of Export Coefficients

A similar multiple linear regression approach was used to estimate export coefficients for the Lake Champlain Basin. P export (kg to the lake in the base year 1991, Diagnostic Feasibility Study, VT DEC, NY DEC 1997) from each of the 30 sampled watersheds was used as the dependent variable, and the land use for each watershed was used as independent variable. The coefficients of regression are thus the "best fit" export coefficients (kg/ha). A variety of two-and three-variable models were explored to evaluate the range of values these coefficients might take. Final selection of the coefficients in a linear model can be subjective, especially if some of the coefficients from regression are not statistically significant or if the independent variables co-vary too closely together.

Identified outliers (see 3.3, Results) were handled using two different approaches. In the first approach, separate AGR coefficients were fitted for the outliers. This assumes that the outliers reflect real differences in P emissions per ha of agricultural land, but we have no other basis to account for these differences. In the second approach, animal unit data available for Vermont, New York, and Quebec (Richard Croft, Eric Smeltzer and Pierre Beaudet, pers. comm.) were used to account for deviations in estimated P export (export coefficients) from the measured P (Diagnostic Feasibility Study). Section 5 provides additional information on this approach as it was generated out of a specific interest in the Missisquoi Bay watersheds.

The reported number of animal units (equivalent US units were used) for the Diagnostic Feasibility Study watersheds was correlated with the area of agricultural land use within each watershed to establish an expected (or average) animal unit population for each watershed. The emission of P from agricultural land is most probably due to both crop and forage practices (fertilization and manure spreading), and thus the estimated P export coefficient includes P resulting from animal presence within the watershed. However, some deviations from the average number of animals per unit area of agricultural land is to be expected. Using the deviations from the average number of animal units, we corrected the predicted amount of P exported based on land area alone with the additional P emission expected if larger numbers of animal were present on the watershed. This correction factor assumes that all deviations of P export from area-based estimates are due to animals. This is an oversimplified approach, but can provide for a better model fit if large deviations in animal unit densities exist.

3.2.6 Calculation of Loading Coefficients

Estimation of loading coefficients requires the calculation of runoff volumes from each land use category. These data were calculated on a cell basis using grid coverages in ArcView. The 1991 precipitation surface was multiplied by the appropriate land use runoff coefficient to yield the amount of runoff from each land cover cell in the 30 watersheds. These data were then summed by land use category for each of the 30 watersheds to estimate runoff volume (in millions of cubic meters) to produce the independent variables. P flux from each of the 30 rivers (Mg in the 1991 base year) was taken as the dependent variable. The regression coefficients from this regression then estimate the loading coefficients or the best-fit volume-weighted average concentration of P (mg/l) in waters leaving each land use type. Again, a variety of models were explored to get a sense of the range of coefficients resulting from this procedure and their statistical significance in different models.

3.2.7 Proximity Analysis

The sensitivity of the proximity of landscape variables to surface water has been tested and evaluated. For, example, Weller et al. (1996) demonstrated the importance of wetlands and their position within a watershed in predicting P loading. Other variables that may be important include proximity of agriculture lands, specifically row crops, to water sources.

After evaluating existing data sources for the Basin, it is clear that variability in the sources severely limits any meaningful analysis as to the effects of proximity on phosphorus loading. Data sources for the hydrographic network differ throughout the Basin. Detailed 1:5,000 scale water data are available for the Vermont portion of the Basin, but New York and Quebec surface water data are 1:24,000 scale and 1:50,000 scale. This makes a Basin-wide evaluation of the effects of phosphorus based on proximity to surface water impossible.

A model developed using one surface water source cannot effectively be applied to another surface water source. Thus, even if a model was developed using the Vermont portion of the Basin where 1:5,000 scale water is available, it would not be applicable to the NY or Quebec portions of the Basin because of the change in the watercourse detail. The study by Weller et al. considered proximity to first-, second-, third-, fourth-, and fifth-order streams. Consistent data of this type is not yet available for the whole Basin.

There are similar issues with wetlands. Wetlands data for the Basin came from a variety of sources including 1:80000 scale National Wetland Inventory (NWI), 1:5000, 1:2400, and spectral-developed. Given the variety of data sources, it is meaningless to develop models based on one wetland source and then apply it to a separate source. This would be especially problematic for the Missisquoi Bay watershed since it occurs in Quebec and Vermont where the data sources are different. Appendix 7.6 includes information on the various sources used to develop the land use data.

There are also accuracy issues with many of the agriculture classifications found in the land use data. These issues are discussed in Section 4.4.5.

3.3 Results and Discussion

3.3.1 Runoff Coefficients

The regression coefficients for AGR, URB and FOR in the equation predicting mean annual streamflow from each gauged watershed were on the high side of reported values (Viessman et al. 1977) for these land use categories in many studied regions (equation 1).

$$\text{streamflow} = (0.75*\text{AGR}) + (0.50*\text{FOR}) + (0.98*\text{URB}) \quad (1)$$

- where AGR is the amount of precipitation (in cubic meters) falling on all agricultural land use categories in each of the 11 gauged watersheds, and FOR and URB are the amounts for forest and urban land use categories, respectively.
- r-square = 0.993.

The forest and agriculture coefficients were statistically significant ($\alpha < 0.0001$ and $\alpha = 0.04$, respectively). The urban coefficient was not ($\alpha = 0.14$). If representative, this very high coefficient reflects a very impervious and actively drained character for urban land use. These annual runoff coefficients are probably higher than reported values for shorter-term studies due to the inclusion of groundwater flux to rivers and streams. The annual discharge includes long periods of base flow, supplied predominantly from shallow groundwater drainage. In this study, these empirically-derived annual runoff coefficients reflect the total flow available to carry phosphorus to the lake, and were thus used to calculate the loading coefficient estimates.

3.3.2 Export Coefficients

Regressions on all 30 Diagnostic Feasibility Study watersheds quickly revealed consistent outliers (Fig. 3.3). The Missisquoi Bay watersheds (Missisquoi, Rock, and Pike Rivers) were always underpredicted by the regression models. This suggests that subregional models may better represent the pattern of P emissions from land that occurs in the Basin. Topography, soil, animal density, and land management practices, among other factors, probably play an important role in determining P emission rates. To accommodate this observed pattern of variation, a separate set of regression coefficients was calculated from 27 watersheds, excluding the northern outliers (Missisquoi, Pike, Rock). The three northernmost watersheds do not permit further regression estimates due to the limitations of the degrees of freedom. However, fitted coefficients for a two-variable model allow subjective evaluation of the magnitude of the coefficients needed to account for the observed export of P to the Lake.

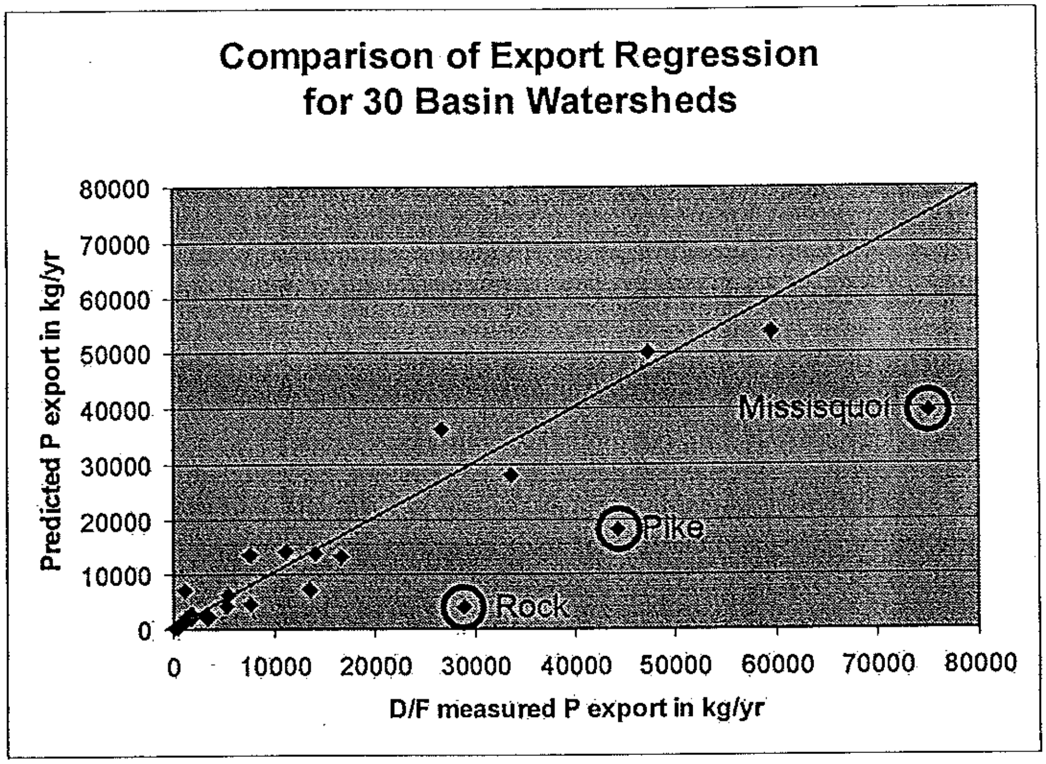


Figure 3.3: Measured vs. Fitted P Export (kg/yr) for 30 Watersheds in the Lake Champlain Basin. Note three outliers.

For the 27 watersheds, regressions of AGR and URB on P kg/yr yielded coefficients of 0.4 and 1.3, respectively. When all three land use categories are included, the coefficients are: AGR: 0.42, URB: 1.5, FOR: 0.04. However, the FOR coefficient is not significant. Given the low range literature estimate for FOR of 0.04 (see literature section above), this value can be specified in the regression model. A closely fitting model then has AGR as 0.42 and URB as 1.5. This set of coefficients was thus selected for the mean export model for the 1991 base year.

$$\text{P export} = (0.42*\text{AGR}) + (0.04*\text{FOR}) + (1.5*\text{URB}) \qquad (2)$$

- where AGR is the land area of agricultural land use category in each of the 27 US gauged watersheds, and FOR and URB are the areas for forest and urban land use categories, respectively.
- r-square = 0.947.
- units = export of P in kg/yr for each watershed

For the three Missisquoi Bay watersheds, adjustments in coefficients were made to account for the observed export of P for the base year 1991. Export of phosphorus from forested land was assumed not to differ between the Missisquoi Bay watersheds and those in the rest of the Basin. Intensive forestry is not practiced in either region so this assumption seems reasonable. In addition, forests do not account for the major flux of P, so it is unlikely that differences in P export from the forests in different watersheds could account for the large differences in measured P. The urban land use category is only a small portion of each Missisquoi Bay watershed, ranging from five percent to seven percent of the total area. Thus, differences in urban sources of phosphorus are also unlikely to account for the large difference in unit area export of P between the Missisquoi Bay and the 27 other watersheds. For these reasons, the agricultural export coefficients were modified to adjust for measured P export. With only one unknown variable to fit the observed data for the base year, the agricultural coefficients (AGR) were simply solved for. The coefficients for the Pike and the Missisquoi were quite close, so a single value was used for both. The resultant equations are indicated below (equations 3 and 4).

Pike and Missisquoi watersheds

$$\text{P export} = (1.4*\text{AGR}) + (0.04*\text{FOR}) + (1.5*\text{URB}) \quad (3)$$

Rock watershed

$$\text{P export} = (4.8*\text{AGR}) + (0.04*\text{FOR}) + (1.5*\text{URB}) \quad (4)$$

3.3.3 Export Model Animal Unit Corrections

An alternative approach to subregional coefficients (equations 3 and 4) is to seek an alternative explanation for the deviations of the outliers (Missisquoi, Pike and Rock watersheds). In this case, animal unit numbers were found to deviate quite significantly in the three outlier watersheds. The expected or average number of animal units (US equivalent units) within each watershed was obtained by regressing animal units (AU) against AGR (agricultural land area, not including wetlands) and fitting the intercept through 0. The three outlier watersheds were not included in this calculation. The R-square of the relationship of AU to AGR was 0.92, and thus the coefficient of 0.7158 (a little less than one animal unit per ha) reflects a fairly strong predictive model of AU.

Observed AU - Expected = Excess AU

Subtracting the expected number of animal units from the observed number yields the deviation, and in the case of the three outlier watersheds the excess, in the number of animal units for each watershed. Each excess animal will produce P, part of which may eventually find its way into surface waters. To find the best fit animal P production coefficient, we numerically fitted the corrected model (export coefficient with animal unit correction) to the observed Diagnostic Feasibility Study P export for each watershed. The best fit animal unit coefficient was 1.75, or 1.75 kg of P per "excess" animal unit in the watershed. The resulting model yielded a slope of 1.003 between the fitted and the observed watershed P values and an r-square of 0.95. This suggests that the model fits the observed data well and explains an important amount of the variation in the P export from each of the watersheds.

Use of the animal unit correction clearly improves the overall fit of the export model to the observed data for the Basin as a whole. This is in large part due to the sizeable contribution of the Missisquoi Bay watersheds to the overall Lake Champlain Basin P load. However, on an individual watershed basis, the correction improves the fit of 13 watersheds and decreases the fit of 17 other watersheds to the observed data. The model fit for four watersheds, all relatively small, becomes very poor. Thus, use of the animal unit correction depends on the objectives of the user of the model. We suggest that use of both the land (AGR, FOR, URB) and the animal unit coefficients be done with care, taking the specific relevance of these parameters to regions in the Basin into consideration.

3.3.4 Loading Coefficients

Regressions of runoff volume from each land use type on P flux resulted in loading coefficients that reflected the strong influence of land use category on P flux. In two-variable models, both AGR and URB, and AGR and FOR coefficients were highly significant (alpha < 0.01). Using all 30 watersheds, comparison of the regression model predictions with the measured loads to the lake show a very similar pattern to that presented by the export coefficient model (Fig. 3.4). The three Missisquoi Bay watersheds remain outliers, so the remaining 27 US watersheds were used to establish loading coefficients and the three Missisquoi Bay watersheds were treated separately.

Agriculture and urban land use categories again dominated as sources of P, with forest being much less important. The AGR coefficient for this study is lower (0.07 mg/l) than the low end coefficient (0.10 mg/l) used in the previous study (Budd and Meals, 1994). The URB coefficient was also lower (0.16 mg/l) than the low-end coefficient used in the previous Budd/Meals study. The forest coefficient was selected to provide a reasonable fit with the observed data because the FOR coefficient in the three variable model (AGR, URB, FOR) was not significant (equation 5).

$$\text{P loading} = (0.07*\text{AGR}) + (0.005*\text{FOR}) + (0.16*\text{URB}) \qquad (5)$$

- where AGR is the runoff from agricultural land in each of the 27 US gauged watersheds, and FOR and URB are the runoff for forest and urban land, respectively.
- r-square = 0.96.
- units = P flux to the lake in kg/yr for each watershed

The loading coefficients for the three Missisquoi Bay watersheds were handled in the same manner as the export coefficients. Only the agriculture coefficient (AGR) was adjusted. The Pike and the Missisquoi watersheds were grouped and the Rock was adjusted individually. This resulted in the following loading coefficient equations (6, 7):

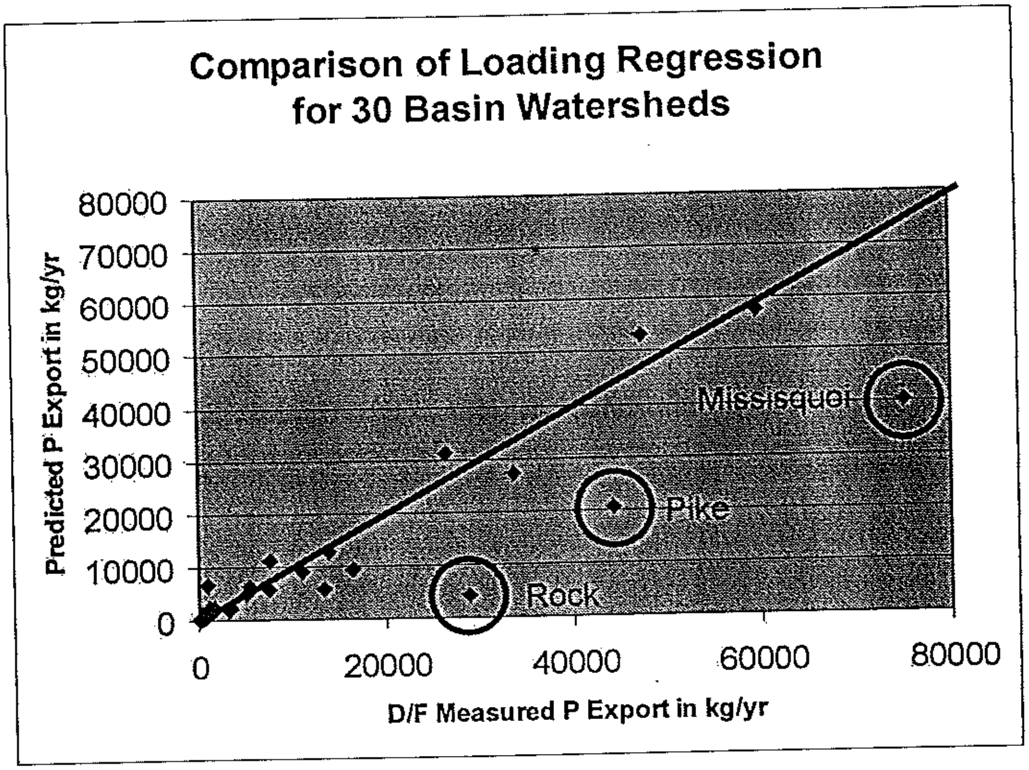
Pike and Missisquoi watersheds

$$\text{P loading} = (0.19*\text{AGR}) + (0.005*\text{FOR}) + (0.16*\text{URB}) \qquad (6)$$

Rock watershed

$$\text{P loading} = (0.6*\text{AGR}) + (0.005*\text{FOR}) + (0.16*\text{URB}) \qquad (7)$$

Figure 3.4: Measured vs. Fitted P Export (kg/yr) for 30 Watersheds in the Lake Champlain Basin. Note three outliers.



3.3.5 Loading Model Animal Unit Corrections

In a similar manner to that used for the export model, a better-fitting model for the three outlier watersheds was obtained after correcting for the excess animal units present in the watersheds. However, in this case, a different animal unit coefficient, 1.6 kg of P per excess animal, was used to correct the loading model estimate, to avoid the use of subregional loading coefficients. The resulting animal unit corrected model had a slope of 1.004 when comparing fitted to observed P export, with an r-square of 0.95. Similar to the situation for the export coefficient model, the correction significantly improved the overall Basin P load prediction because of the importance of the Missisquoi Bay watersheds in total P loading to the lake. However, the fit was improved for only 12 of the 30 watersheds, with four small watersheds seriously mis-predicted.

3.4 Conclusions

Using the estimates of sub-basin P export for 30 sampled rivers and streams in the Lake Champlain Basin permitted the development of regionally specific export and loading coefficients that appear to reflect local conditions of the Basin (Table 3.3). The export values fall within the low and high range of values report by Budd and Meals (1994) resulting from an extensive review of the literature (Appendix 7.1). The coefficients selected in this study are either the same (URB) or lower than those selected in the Budd/Meals study, reflecting the result that when the Budd/Meals coefficients were used to estimate the P output from the Diagnostic Feasibility Study watersheds, an overestimate was obtained.

The regionally specific loading coefficients fall somewhat below the general tendency of values reported by Budd/Meals. This may reflect sampling bias in concentration studies where the volume-weighted average concentration may be difficult to estimate without continuous gauging of the watersheds. Sampling protocols that seek to characterize runoff events may bias averages on the high side.

Table 3.3. Comparison of calculated P export and loading coefficients based on Lake Champlain Basin data with literature values as reported by Budd and Meals (1994).

Export (kg/ha)	AGR	FOR	URB
This study	0.42	0.04	1.5
Low (Budd/Meals)	0.25	0.04	1.0
Selected (Budd/Meals)	0.50	0.10	1.5
High (Budd/Meals)	0.81	0.24	1.91
Loading (mg/l)			
This study	0.07	0.005	0.16
Low (Budd/Meals)	0.1	0.01	0.28
Selected (Budd/Meals)	0.2	0.015	0.35
High (Budd/Meals)	0.3	0.025	0.82

Three sub-basins were clearly outliers in the development of the land use data to P flux relationships. The Rock, Pike, and Missisquoi River watersheds were high outliers in the regression, reflecting the higher than typical P flux from the rivers. The adjusted set of coefficients were assumed to be only necessary for the agricultural land use categories (Export: Rock, AGR = 4, Pike and Missisquoi, AGR = 1.2; Loading: Rock, AGR = 0.6, Pike and Missisquoi, AGR = 0.19). Given the small sample size, these coefficients can only be considered to be provisional, awaiting further empirical research into the P fluxes emitted from the landscape in this region of the Basin.

Perhaps a more reasonable approach would be to use the animal unit data to "explain" major outliers in the Basin. Correcting for the "excess" animals in a watershed (deviations from the average animal density) allowed a much better model fit for the Missisquoi, Pike and Rock watersheds and an overall similarly close fitting model (r-square of 0.95) for the Lake Champlain Basin as a whole. However, the improvement in the Missisquoi Bay watersheds is traded off with large deviations in the model prediction for other watersheds in the Basin (e.g., Stonebridge, Mallets Creek, Mt. Hope, Indian Brook). Thus, neither the loading model alone nor the animal unit correction provide an ideal approach for small watershed-level predictions across the whole of the Lake Champlain Basin.

4. Applying Coefficients to Estimate P Loading to Lake Champlain

4.1 Introduction

This study used a method based on analysis on a cell by cell basis. Each cell or "pixel" is assigned a "value" based on export or loading coefficient yielding two alternative estimates of total P flux in Lake Champlain. The cells were then summarized by 14-digit hydrologic unit, lake segment, and diagnostic feasibility study watershed.

The export and loading methods were used and compared by Budd and Meals in 1994. The export coefficient method uses coefficients related to land use category. The loading coefficient method uses a coefficient for land use category expressed in mg/l along with a runoff coefficient associated with land use type. The runoff coefficient is expressed in percent of total precipitation. Providing results from both models allows the user to evaluate both models and pick the one best suited for the needs and data availability.

Coefficients for both methods were developed for three broad categories of land use: forest, agriculture, and urban. The coefficient for water is 0. Non Forested and Forested lands were also excluded and given a coefficient of 0. Following is the table (4.1) showing the land use groupings. The 1993 land use data contained 17 land use categories. These categories were regrouped into the categories as shown for the purposes of this study.

Table 4.1: Land Use Categories

Category	1993 Land Use
Agriculture	Brush or Transitional
	Orchards
	Other Agricultural/Mixed Open
	Row Crops
	Hay/Permanent Pasture
Forest	Deciduous Forest
	Coniferous Forest
	Mixed Forest
Urban	Residential
	Commercial
	Industrial
	Transportation/Utilities
	Other Urban
Water	Water
	Barren Land
Excluded	Non Forested Wetlands
	Forested Wetlands

The land use data in this study was developed for all of Vermont and the Lake Champlain and Northern Forest Lands regions (Millette, 1997). It was developed from a combination of supervised classification of Landsat Thematic Mapper data and GIS enrichment from land use layers developed by local cooperating organizations. The land use data are stored in a raster grid (34,121,149 cells) with a cell size of 25 meters X 25 meters. Three of the four Landsat images used to develop this data layer were acquired in May of 1993. The fourth image was acquired in April of 1991. Hence, throughout this study, we refer to this newer land use data as "1993 land use data". The land use data covers the entire Lake Champlain Basin. The reported overall accuracy of the classification is 85.9 percent. Complete documentation can be found in the Appendix 7.6.

As described in Section 3, export and loading coefficients were developed for each land use category (forest, agriculture, urban). Table 4.2 shows the export and loading coefficients used to calculate phosphorus loading.

Table 4.2: Export and Loading Coefficients

Area of Basin	Export Coeffecient kg/ha/yr			Loading Coeffecient mg/l		
	Forest	Ag	Urban	Forest	Ag	Urban
Basin-Wide Coefficients	0.04	0.42	1.50	0.005	0.070	0.160

In this study, animal unit corrections were also applied as part of the modeling process. The development of the animal unit coefficients is described in Section 3. Animal unit coefficients were developed for each Diagnostic Feasibility Study watershed. Appendix 7.3 contains a complete list of observed, expected, and excess animal units.

Animal unit corrections are only applied to agricultural land use categories since this is where most if not all the animals occur.

4.2 Methods

4.2.1 Export Method

The export method is a very simple method, which is widely used. It relies on the average or representative values for the mass of pollutant exported per unit area per year (e.g. kg/ha/yr) (Budd and Meals 1994; Reckhow, et al., 1980; Rast and Lee, 1983; Frink, 1991)

Export coefficients were picked for forested, agricultural, and urban areas and applied to each cell in the GIS land use data layer. After the calculation was complete, each cell contained a value in kg/yr. The equation used to calculate total phosphorus for each cell is as follows:

$$LD = EC_K * A \qquad (8)$$

Where LD = annual load for a cell (kg)
EC_K = export coefficient for land use K
A = area of the cell (constant of 0.0625 ha)

Thus, for a cell in agricultural use, the cell value is as follows:

$$LD = 0.42 \text{ kg/ha/yr} \times 0.0625 \text{ ha} = 0.0262 \text{ kg/yr}$$

Animal unit corrections are then applied to each cell in the agricultural land use category. The equation to calculate phosphorus loading for a cell from animal data is as follows.

$$AL = AE_J / AA_J * A * AU \qquad (9)$$

Where AL = annual load for a cell from excess animals (kg)
AE_J = excess animal units for Diagnostic Feasibility Study watershed J
AA_J = agricultural area of Diagnostic Feasibility Study watershed J (ha)
A = area of the cell (constant of 0.0625 ha)
AU = animal unit coefficient (1.75 kg/per animal)

Thus, for a cell in the Great Chazy Diagnostic Feasibility watershed in agricultural use, the cell value is as follows:

AL = 7395 animals / 15549 ha * 0.0625 ha * 1.75 kg/animal = 0.0520 kg/yr

In the case of non-agricultural land use categories (forest and urban), the annual load from excess animal units (AL) is 0

The annual load for a cell from the phosphorus coefficient and excess animal units are then added together as follows:

$$TLD = LD + AL \qquad (10)$$

Where TLD = total annual load for a cell (kg)
LD = annual load for a cell (kg)
AL = annual load for a cell from excess animal units (kg)

Thus, the total value for a cell in the Great Chazy in agricultural use is as follows:

TLD = 0.0262 kg/yr + 0.0520 kg/yr = 0.0782 kg/yr

The annual export for the Basin can then be summarized by any unit desired, such as 14-digit hydrologic unit or lake segment.

The primary advantage of the export method is its simplicity. It relies on one variable, which can be chosen from the literature, or developed through field studies, etc. The simplicity of the export method is also its weakness. There are no provisions for yearly hydrologic variations, thus the model probably works best in years of "average" climatic conditions (Rast and Lee, 1983; Budd and Meals, 1994).

4.2.2 Loading Method

The loading method estimates annual loading as a function of pollutant runoff concentrations and runoff volume (McElroy, et al., 1976; Haith and Shoemaker, 1987; Reckhow et al., 1990; Budd and Meals, 1994). Each cell in the GIS land use layer is assigned a runoff coefficient and concentration coefficient. Average annual precipitation is also used. The land use data containing these values is combined with the average annual precipitation, and a total phosphorus load is calculated for each cell. The equation is as follows:

$$LD = P \times F1 \times F2 \times R_K \times L_K / F3 \qquad (11)$$

Where:

LD = annual load for a cell (kg)
P = mean precipitation value for a cell (in)
$F1$ = inches to meters conversion constant (0.0254)
$F2$ = area constant for each cell (625 m^2)
R_K = runoff coefficient for land use K
L_K = concentration coefficient for land use K
$F3$ = conversion constant (1000) l/m^3

For a cell in agricultural use with a mean precipitation value of 35 inches, a runoff of 0.75 and a concentration coefficient of .07, the cell value is as follows:

$$LD = 35 \text{ in/yr} \times 0.0254 \times 625 \text{ m}^2 \times 0.75 \times 0.07 \text{ mg/l} / 1000 = 0.0292 \text{ kg/yr}$$

Animal unit corrections are then applied to each cell in the agricultural land use category. The equation to calculate phosphorus loading for a cell from animal data is as follows.

$$AL = AE_J / AA_J * A * AU \qquad (12)$$

Where AL = annual load for a cell from excess animals (kg)
AE_J = excess animal units for Diagnostic Feasibility Study watershed J
AA_J = agricultural area of Diagnostic Feasibility Study watershed J (ha)
A = area of the cell (constant of 0.0625 ha)
AU = animal unit coefficient (1.60 kg/per animal)

Thus, for a cell in the Great Chazy Diagnostic Feasibility watershed in agricultural use, the cell value is as follows:

$$AL = 7395 \text{ animals} / 15549 \text{ ha} * 0.0625 \text{ ha} * 1.60 \text{ kg/animal} = 0.0475 \text{ kg/yr}$$

In the case of non-agricultural land use categories (forest and urban), the annual load from excess animal units (AL) is 0

The annual load for a cell from the phosphorus coefficient and excess animal units are then added together as follows:

$$TLD = LD + AL \qquad (13)$$

Where TLD = total annual load for a cell (kg)
LD = annual load for a cell (kg)
AL = annual load for a cell from excess animal units (kg)

Thus, the total value for a cell in the Great Chazy in agricultural use is as follows:

$$TLD = 0.0292 \text{ kg/yr} + 0.0475 \text{ kg/yr} = 0.0767 \text{ kg/yr}$$

Again, the annual export for the Basin can be summarized by any unit desired, such as a 14-digit hydrologic unit or lake segment.

The advantage of the loading model is the introduction of runoff as a variable. This improves the ability to predict phosphorus loading in sub basins and in years where hydrologic conditions vary from the long-term average.

Precipitation Surface

In order to develop runoff for each cell, a precipitation surface was required (Figure 4.1). The precipitation surface was developed using the GIS and long-term records for 57 stations in and around the Basin. Long-term records we gathered from 1951 through 1996. Data for Quebec stations was only available through 1991. Not all stations had complete records, and some stations in Quebec had as few as 11 years worth of data. The names and long-term averages for each of these stations are shown in Table 4.3. Appendix 7.3 also contains detailed tables with annual values for each station.

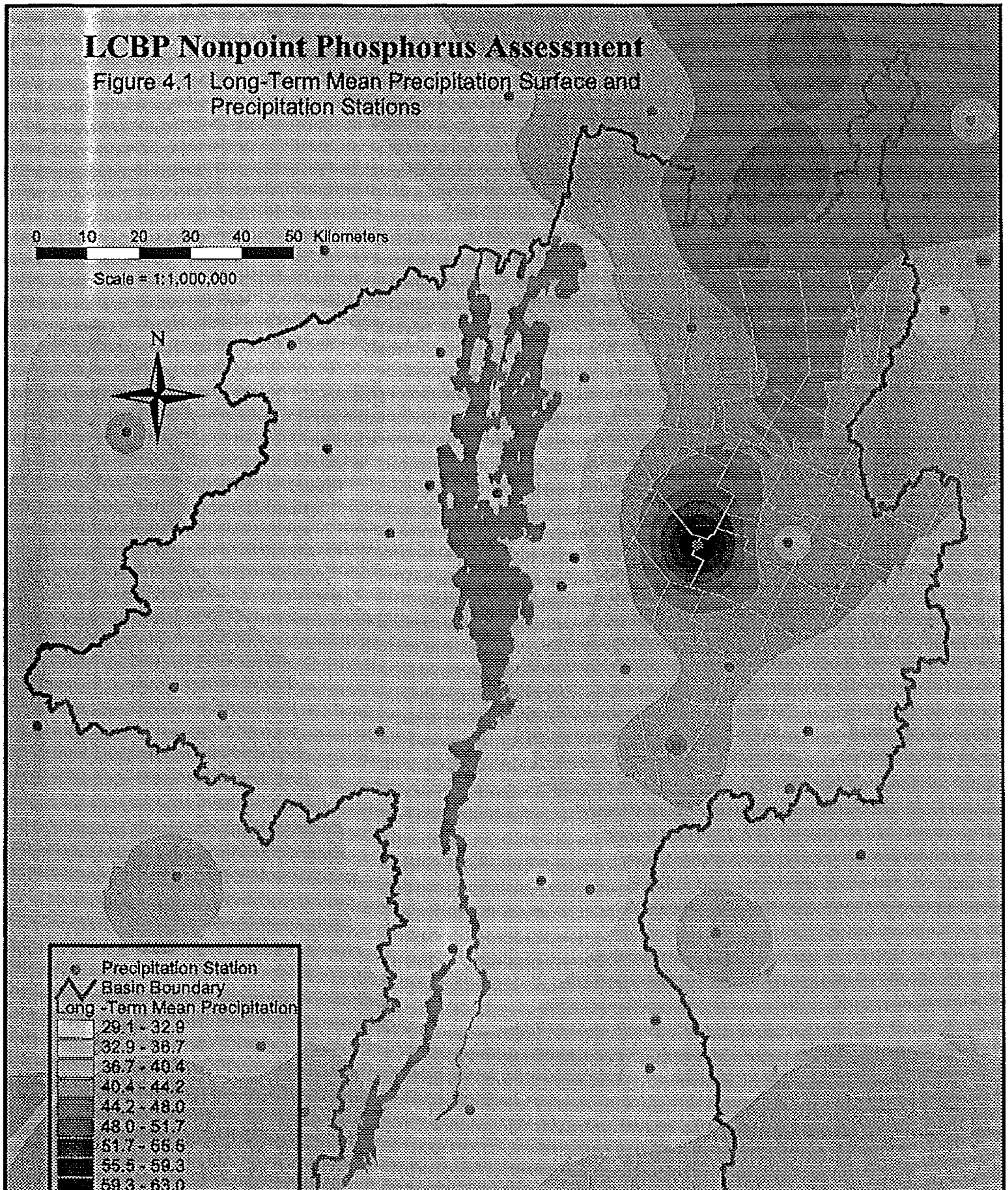
In Table 4.3, the mean is the long-term average. The minimum and maximum precipitation is the 95% confidence interval around the mean (i.e. the mean + - 1.96 x standard deviation). The minimum represents a value that could be expected 5% of the time, and the maximum represents a value that could be expected 5% of the time. This range represents the most likely range for precipitation at each precipitation station.

Table 4.3: Lake Champlain Basin Precipitation Stations

Station_no	Stat_name	Mean	Min_95 percent ci	Max_95 percent ci
301401	CHAZY	32.53	22.59	42.48
301966	DNMORA	34.30	23.11	45.50
302554	E'TOWN	35.38	22.51	48.25
302574	EBRG DEP	30.82	20.80	40.83
303294	G FALLS	36.47	23.00	49.94
304555	L PLACID	38.47	26.93	50.00
305714	NEWCMB	41.40	30.54	52.27
305925	NO CREEK	39.75	26.15	53.35
306538	PERU	29.12	19.25	38.98
306659	P'BURGH	31.89	16.63	47.15
306957	RAYBRK	39.54	30.67	48.40
307818	SMITHBSN	37.01	24.75	49.28
308507	TICOND	32.28	21.51	43.04
308631	TUPPER L	39.69	28.16	51.23
309389	WHITEHLL	37.97	24.65	51.29
308959	WRNBRG	44.24	31.47	57.02
301387	CHASM FALLS	40.90	27.00	54.80
301664	COLTON 2 N	39.91	29.24	50.57
301708	CONKLINGVILLE DAM	43.43	29.78	57.07
303284	GLENS FALLS FARM	43.68	28.41	58.94
304647	LAWRENCEVILLE	34.58	25.52	43.63
308104	SPIER FALLS	38.93	24.75	53.11
431081	BURL	34.31	24.18	44.45
431243	CAVENDISH	43.91	31.07	56.74
431360	CHELSEA	37.02	26.14	47.90
431433	CHITT	40.54	24.92	56.16
431580	CORNWL	32.48	20.26	44.70
431786	DORSET	47.08	34.63	59.53
432769	ENOSBRG	41.60	29.09	54.11
432843	ESSXJCT	36.59	26.13	47.04
434052	HUNTCTR	37.56	25.05	50.07
435278	MPLR	34.48	24.13	44.83
435376	MORRSVL	39.78	27.83	51.73
435416	MTMNSFLD	63.02	35.04	91.01
435542	NEWPORT	38.30	24.74	51.87
435740	NRTHFLD	38.15	24.61	51.68
436335	PERU	50.06	31.80	68.33
436893	ROCHSTR	42.85	29.07	56.62
436995	RUTLAND	35.52	23.74	47.31
437032	STALBANS	34.34	23.55	45.13
437054	STJOHNSB	35.32	25.31	45.32
437098	SALISBRY	35.86	22.81	48.91
437607	SOHERO	30.82	21.24	40.40
438637	WAITSFLD	44.60	30.20	58.99
438815	WATRBRY	40.60	28.34	52.85
7020040	ABRCRN	48.41	37.22	59.60
7020828	BONSEC1	45.94	31.95	59.93
7020840	BROME	49.30	40.42	58.18
7022320	FRNHAM	42.54	30.93	54.14
7022720	GRGVLLE	46.13	35.55	56.70
7023075	HMNGFD	34.25	24.43	44.06
7023270	IBRVLLE	40.14	29.51	50.76
7024440	MAGOG	43.86	34.48	53.24
7026040	PPSBURG	39.93	29.87	49.99
7028280	STANST2	44.31	33.06	55.56
7028295	SUTTON	48.66	37.02	60.29
7028890	WARDEN	49.54	36.99	62.10

An extensive search for appropriate long-term precipitation stations was completed for the Basin and areas directly outside the Basin (NOAA, various years; Canadian Climate Normals, 1991; and Quebec Ministry of the Environment and Wildlife). To create an accurate precipitation surface, it was important to use stations outside the Basin so that the surface generated by the GIS was accurately represented at the edge of the Basin.

The GIS was used to generate a surface using long-term mean precipitation values. The interpolation method used is the inverse distance weighted (IDW) using 12 nearest neighbors and the power of 2 (ARC/INFO default value). The IDW interpolator assumes that each input point has a local influence that diminishes with distance. It puts a greater weight on cells closer to the processing cells. The power of 2 is considered a reasonable value for weighting the influence of local points. Other interpolation methods were considered, but IDW appeared to be the most reasonable for developing a precipitation surface. The Kriging method was considered, but it assumes that the same pattern of variation can be observed at all locations on the surface. This is probably not true for precipitation data. Other factors such as elevation and aspect were not directly considered when developing the surface. Their influence was certainly evident in the data (i.e. Mount Mansfield values), but no other GIS data layers, such as elevation or aspect, were used to refine the influence. Figure 4.1 shows the interpolated surface for the mean annual precipitation. Also shown on this figure are the precipitation stations used to generate the surface.



LCBP Nonpoint Phosphorus Assessment
Figure 4.1 Long-Term Mean Precipitation Surface and Precipitation Stations
0 10 20 30 40 50 Kilometers
Scale = 1:1,000,000
N
Precipitation Station
Basin Boundary
Long -Term Mean Precipitation
29.1 - 32.9
32.9 - 36.7
36.7 - 40.4
40.4 - 44.2
44.2 - 48.0
48.0 - 51.7
51.7 - 55.5
55.5 - 59.3
59.3 - 63.0
Refer to Table 4.3 for long-term mean values for individual precipitation stations.
UVM
ARD/GIS

Runoff Coefficient

A runoff coefficient is applied to each cell based on its land use category. The runoff coefficient is used in conjunction with long-term mean precipitation to calculate runoff. The runoff coefficients were calculated using gauged watersheds and land use. Regression analysis was used to calculate the appropriate runoff coefficients based on the gauged runoff and the percent of land use category in each gauged watershed. Section 3.2.4 describes this process. Any nested watershed was not used in the regression analysis. A total of eleven watersheds were used in the regression analysis. These eleven watersheds were picked because they were easily delineated and contained long-term stream flow data. Table 3.2 shows the gauged watersheds used to calculate runoff coefficients.

Runoff coefficients were derived for agricultural, forest, and urban lands. The appropriate value was then assigned to each cell in the land use data layer.

Following are the runoff coefficients used.

Table 4.4: Runoff Coefficients Used in this Study

Landuse Category	Runoff Coeffecient %
Forest	0.50
Agriculture	0.75
Urban	0.97

4.3 Results

4.3.1 Comparison to Previous Study

Land Use Data Comparison

This study uses newer land use data than Budd/Meals used. As discussed earlier, the land use data were developed for Vermont and the Lake Champlain and Northern Forest Lands regions (Millette, 1997) from a combination of 1991 and 1993 supervised classification of Landsat Thematic Mapper data and GIS enrichment from land use layers developed by local cooperating organizations.

The land use data used by Budd/Meals in 1994 is known as Geographic Information Retrieval and Analysis System (GIRAS) data. It was collected over a period from 1973 to 1976. The GIRAS data provides approximately 40 land use/land cover classes with a minimum mapping unit of 4 hectares for urban land use categories and 16 hectares for other land use categories. It was interpreted from NASA high altitude aerial photographs and National High-Altitude Photography program photographs usually at scales smaller than 1:60,000 and compiled on a 1:250,000 scale base. No classification or positional accuracy information is provided with the data set. The GIRAS land use data did not include data for the Quebec portion of the Basin.

One reason for differences in phosphorus estimates between the Budd/Meals study and this study is the use of this new land use data. Summaries of both land use data layers were created and compared. Table 4.5 and Figures 4.2, 4.3, and 4.4 show the difference in land use categories between the GIRAS data and 1993 land use data. Results are summarized by diagnostic feasibility study watershed. Only watersheds completely in the U.S. portion of the Basin are compared, since no GIRAS land use data were available for the Quebec portion of the Basin.

Table 4.5 - 1974 to 1993 Land Use Comparison
Lake Champlain Basin

D_F Watershed	1974 Urban (km^2)	1993 Urban (km^2)	1974 Ag (km^2)	1993 Ag (km^2)	1974 Forest (km^2)	1993 Forest (km^2)	1974 Water (km^2)	1993 Water (km^2)
Missisquoi	26.6	101.6	568.1	398.7	946.6	1625.1	12.8	114.1
Pike	1.5	30.6	45.5	307.3	21.6	296.1	5.6	33.1
Rock	0.3	8.0	50.3	63.8	23.6	65.7	0.2	9.0
Great Chazy	11.2	24.1	248.8	166.5	475.8	564.4	19.3	18.1
Little Chazy	2.8	5.7	54.2	36.1	71.2	94.7	9.9	1.6
Stevens	7.3	7.2	44.2	32.4	9.2	15.9	0.4	4.5
Lamoille	31.2	110.9	494.4	252.7	1325.8	1381.1	20.2	126.9
Mill	4.7	6.1	40.5	26.2	14.5	23.2	0.3	4.5
Saranac	38.5	53.4	112.6	44.9	1351.3	1368.6	88.7	124.5
Stonebridge	1.2	2.2	24.1	7.2	5.8	19.7	0.0	2.1
Salmon	6.6	10.2	35.2	15.4	132.5	148.0	0.8	1.7
Mallets Creek	4.2	11.0	38.3	18.0	31.7	41.9	1.4	4.6
Winooski	126.6	251.2	631.5	335.1	1966.9	2027.6	27.2	138.7
Ausable	36.4	37.1	73.1	41.9	1197.6	1208.8	21.2	40.6
Indian Brook	4.0	10.1	10.9	6.0	15.4	12.7	0.3	1.7
Highland Furgeh	0.0	0.6	0.0	0.1	28.0	27.2	2.0	2.2
Bouquet	14.0	19.1	80.2	43.6	605.5	628.3	4.5	13.2
LaPlatte	5.4	21.6	95.0	56.7	35.4	51.7	1.4	7.2
Lewis	2.0	10.8	95.2	60.9	111.5	127.5	1.3	10.9
Little Otter	2.0	10.0	136.3	94.8	50.6	70.8	0.1	13.4
Otter	44.4	136.2	991.1	546.3	1391.8	1630.8	14.9	130.6
Hosington	0.8	1.0	6.1	3.3	21.4	23.6	0.0	0.4
Mill (Port Henry)	4.0	4.4	6.4	2.1	60.9	63.7	0.9	2.1
Putnam	0.1	4.4	16.4	14.8	139.7	135.9	3.5	4.8
East	0.2	3.4	61.5	38.1	20.2	35.1	0.9	6.1
LaChute	12.9	28.0	24.3	26.9	512.8	491.1	8.7	13.0
Poultney	15.8	35.9	216.1	125.9	429.8	469.2	19.1	49.7
Mill (Putnam Station)	0.0	1.3	8.0	5.8	21.5	22.2	0.3	0.5
Mettawee/Barge Canal	31.1	71.7	461.7	308.1	593.0	683.1	11.0	34.5
Mt. Hope	0.0	0.5	0.0	1.1	34.6	33.7	1.4	0.7
Total*	**396.3**	**853.8**	**3757.3**	**2144.3**	**10178.6**	**10835.9**	**240.3**	**740.6**

* **NOTE** - Missisquoi, Rock, Pike and Great Chazy are not shown in this table because land use data for 1974 is not complete.

table_45.xls

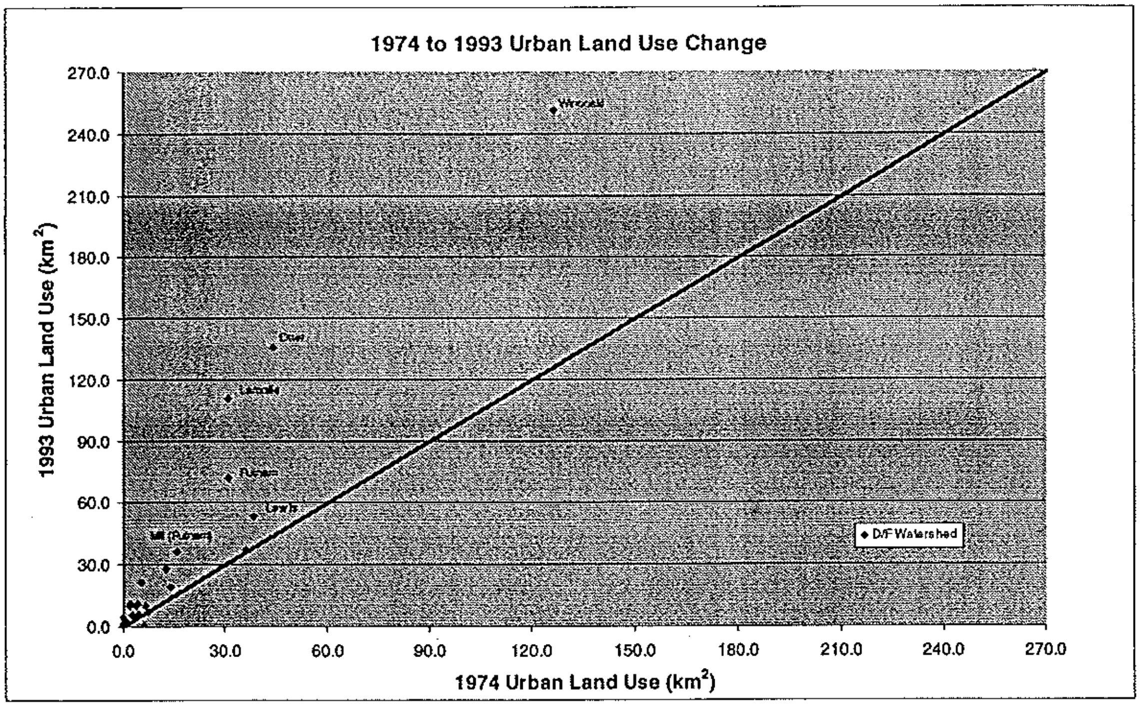


Figure 4.2

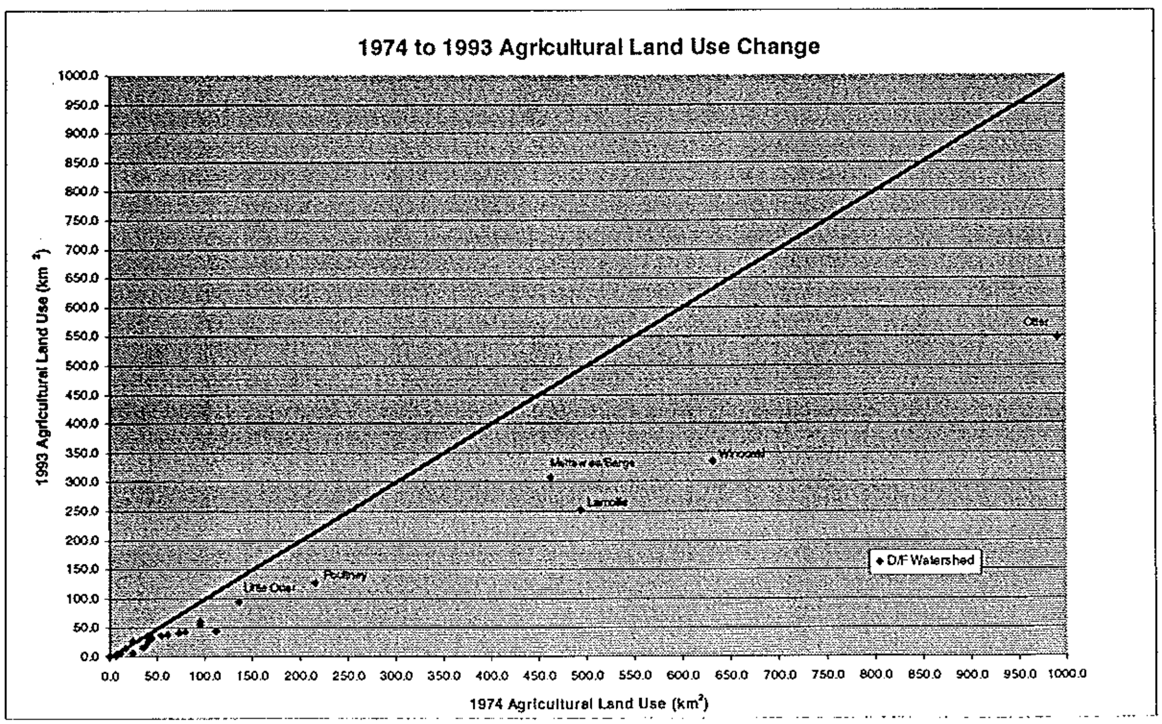


Figure 4.3

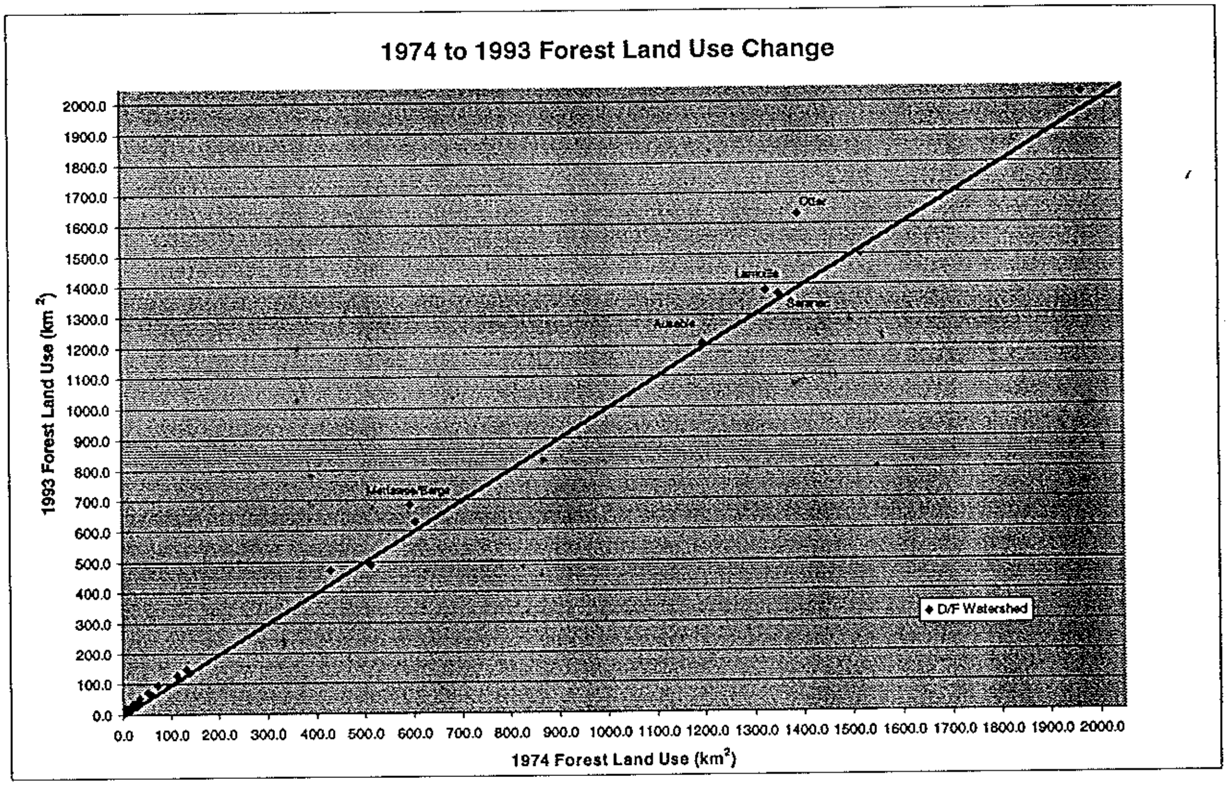


Figure 4.4

The previous tables and figures show that urban land use has increased from 1974 to 1993 in the diagnostic feasibility study watersheds going from approximately 396 km^2 to 853 km^2. Over the same time period, agricultural land use has decreased from 3757 km^2 to 2144 km^2, and forested land use has stayed the same or increased slightly from 10178 km^2 to 10835 km^2. These results must be interpreted cautiously for several reasons. It is probably safe to assume that urban land use has increased from 1974 to 1993 and that agricultural land use has decreased over the same period. However, determining the exact percent change is not possible using these two land use data sources because they are derived from different data sources using different interpretation methodologies and accuracy standards. In addition, it is important to note a significant difference in the amount of water reported for each land use data layer. Between 1974 and 1993, there is a 300 percent increase in water from 240 km^2 to 740 km^2. This increase is unlikely. The differences in reported water are most likely due to different methods of developing the land use data layers.

Method Comparison

We compared the modeling methods used in this study to the modeling methods used by Budd/Meals in 1994. While the variables and equations Budd/Meals use were essentially the same as employed in this study, the method of applying and summarizing the results was different. As a comparison, new modeling methods were applied to the 1974 GIRAS land use data to see how the results compared to those received in 1994 by Budd/ Meals. To do this, the same coefficients used by Budd/Meals were employed. No animal unit corrections were used.

Export Method Comparison – Using Budd/Meals Baseline Coefficients

Baseline coefficients from used by Budd/Meals were applied to the 1974 GIRAS land use data using the analysis methods developed in this study. The results are as follows:

Budd/Meals TP Estimate – 466,947 kg/yr (US portion of the Basin)
Estimate using new analysis methods - 476,818 kg/yr (US portion of the Basin)

The two estimates are very close (approximately 2 percent difference). This is not unusual.

Loading Method Comparison – Using Budd/Meals Baseline Coefficients

New estimates were also calculated using the loading method with the 1974 GIRAS data. Baseline coefficients from the Budd/Meals study were applied. The results are as follows.

Budd/Meals TP Estimate – 756,723 kg/yr (US portion of the Basin)
Estimate using new analysis methods – 1,042,737 (US portion of the Basin)

The difference for the loading method is approximately 286,000 kg/yr which is much more significant than the differences using the export method. Results are discussed in section 4.4.1.

4.3.2 Export Method Estimates

The export method results using best-fit coefficients can be expressed in several different ways. For the purposes of this study, we have focused on summarizing the results by Diagnostic-Feasibility Study watersheds, lake segment, and 14-digit hydrologic unit. The results can be summarized in any desirable fashion because the values are stored cell by cell for the whole Basin (34,121,149 cells). The GIS is used to summarize the results on an "as needed" basis.

Applying the best-fit coefficients and animal unit corrections, and using the methods described in section 4.2.1, the total nonpoint phosphorus load for the Basin is estimated at 472,000 kg/yr.

4.3.3 Loading Method Estimates

The loading method estimates are summarized by Diagnostic Feasibility Study watershed, lake segment, and 14-digit hydrologic unit.

Applying best-fit coefficients and animal unit corrections, and using methods described in section 4.2.2, the total nonpoint phosphorus load for the Basin is estimated at 473,000 kg/yr. This estimate is based on using long-term average annual precipitation values. The estimate is slightly higher than that reported for the export method. This difference is most likely due to the influence of the precipitation.

4.3.4 Results Reported by Diagnostic-Feasibility Study Watersheds

Results of the export model for the Diagnostic Feasibility Study watersheds are shown in Table 4.6. Figures 4.5 and Figure 4.6 show estimates vs. monitored nonpoint phosphorus loads (1991 base year results from Table 28, Page 95, Lake Champlain Diagnostic Feasibility Study Final Report, 1997). The estimated phosphorus vs. the monitored have a high agreement, but this is expected, because the coefficients developed for the model are based on the Diagnostic Feasibility Study watershed monitored values. Section 3 describes the process of developing these coefficients in detail and their relationship to the Diagnostic Feasibility Study watersheds.

The results of the loading model by Diagnostic Feasibility Study watershed are shown in Table 4.7 and Figures 4.7 and 4.8. The loading method values are based on 1991 average annual precipitation values. Similar results were observed for the loading method and the export method. The loading method estimates tend to be slightly higher. Much of this difference occurred in the large watersheds where the estimates were pushed closer to monitored values. There is less agreement in some of the smaller watersheds including Stonebridge, Indian Brook, and Mallets Creek.

The total phosphorus load from the Diagnostic Feasibility Study watersheds is not the same as that reported above for the whole Basin. This is because the 30 Diagnostic Feasibility Study watersheds reported encompass only 91 percent of all the land in the Basin.

**Table 4.6 Phosphorus Values for Diagnostic-Feasibility Study Watersheds
Export Method using Regression Coefficients (With the Influence of Animal Units)**

D_F Watersheds	Area (m^2)	Estimates (mt/yr)	D/F Monitored (mt/yr)
Missisquoi	2240066816	74.3	75.1
Pike	667249984	48.6	44.4
Rock	146615632	17.7	28.9
Great Chazy	773171264	25.1	16.6
Little Chazy	138128752	3.7	3.2
Stevens	61171876	5.4	3.4
Lamoille	1871658112	27.8	26.6
Mill	59925000	5.7	3.5
Saranac	1591349376	12.9	7.7
Stonebridge	31108124	7.1	0.8
Salmon	175259376	2.1	1.7
Mallets Creek	75558128	10.2	1.7
Winooski	2752718848	49.6	59.6
Ausable	1328434944	7.8	11.2
Indian Brook	30555000	5	0.9
Highland Furgeh	30046876	0.2	0.1
Bouquet	704231872	4.9	13.5
LaPlatte	137208128	2.7	7.6
Lewis	210037504	4.7	5.2
Little Otter	188976256	5.9	5.4
Otter	2444116224	48.4	47.4
Hosington	28325000	0.2	0.5
Mill (Port Henry)	72251248	1.1	0.6
Putnam	159893744	0.2	1.3
East	82783128	1.8	1.2
LaChute	559011904	5.1	1.1
Poultney	680833152	6.9	14.1
Mill (Putnam Station)	29801250	0.8	0.4
Mettawee/Barge Canal	1097383808	35.1	33.7
Mt. Hope	36050624	0.6	0.1
TOTAL	**18403921950**	**421.6**	**417.5**

\new_coeff_export_values_au_sum_basin.xls

Table 4.7 Phosphorus Values for Diagnostic-Feasibility Study Watersheds Loading Method using Regression Coefficients (With the Influence of Animal Units)

D_F Watersheds	Area (m^2)	Estimates (mt/yr)	D/F Monitored (mt/yr)
Missisquoi	2240066816	76.91	75.1
Pike	667249984	50.79	44.4
Rock	146615632	17.24	28.9
Great Chazy	773171264	22.85	16.6
Little Chazy	138128752	3.41	3.2
Stevens	61171876	5.18	3.4
Lamoille	1871658112	31.63	26.6
Mill	59925000	5.45	3.5
Saranac	1591349376	10.43	7.7
Stonebridge	31108124	6.57	0.8
Salmon	175259376	1.69	1.7
Mallets Creek	75558128	9.50	1.7
Winooski	2752718848	51.34	59.6
Ausable	1328434944	5.99	11.2
Indian Brook	30555000	4.70	0.9
Highland Furgeh	30046876	0.13	0.1
Bouquet	704231872	3.99	13.5
LaPlatte	137208128	3.28	7.6
Lewis	210037504	5.03	5.2
Little Otter	188976256	6.41	5.4
Otter	2444116224	49.07	47.4
Hosington	28325000	0.15	0.5
Mill (Port Henry)	72251248	0.98	0.6
Putnam	159893744	0.13	1.3
East	82783128	1.92	1.2
LaChute	559011904	4.75	1.1
Poultney	680833152	7.73	14.1
Mill (Putnam Station)	29801250	0.80	0.4
Mettawee/Barge Canal	1097383808	37.10	33.7
Mt. Hope	36050624	0.57	0.1
TOTAL	**18403921950**	**425.73**	**417.5**

\new_coeff_loading_values_var_1991_sum_basin.xls

Figure 4.5

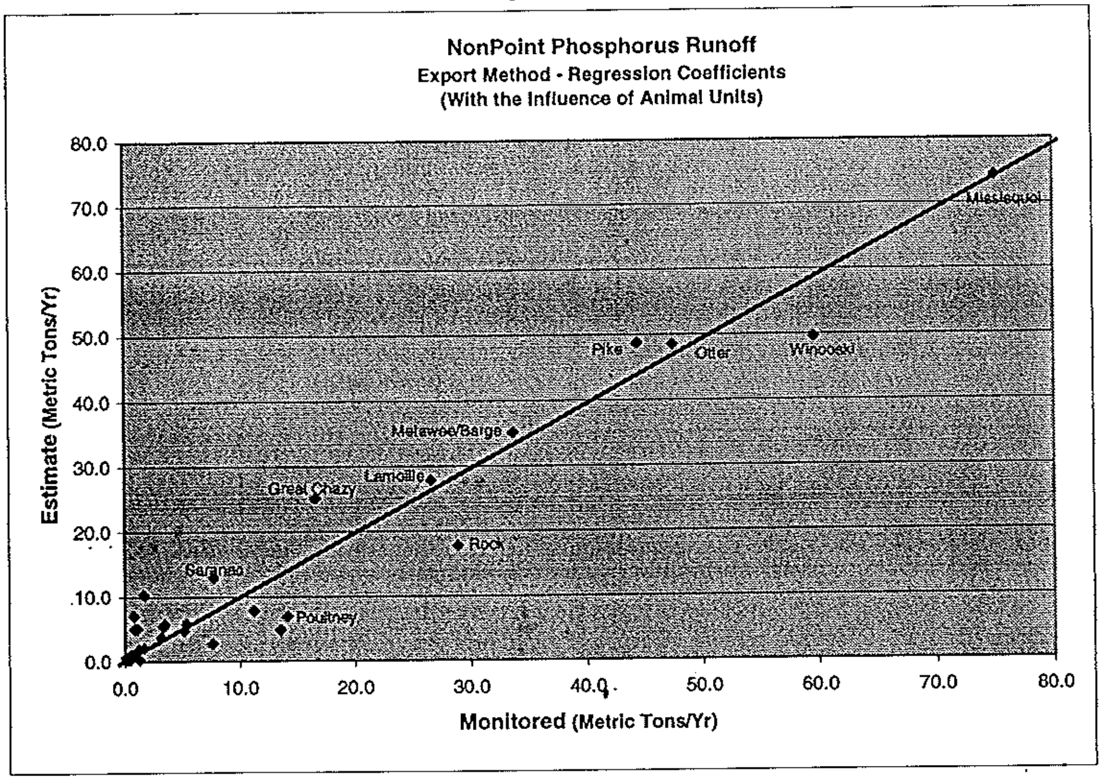


Figure 4.6

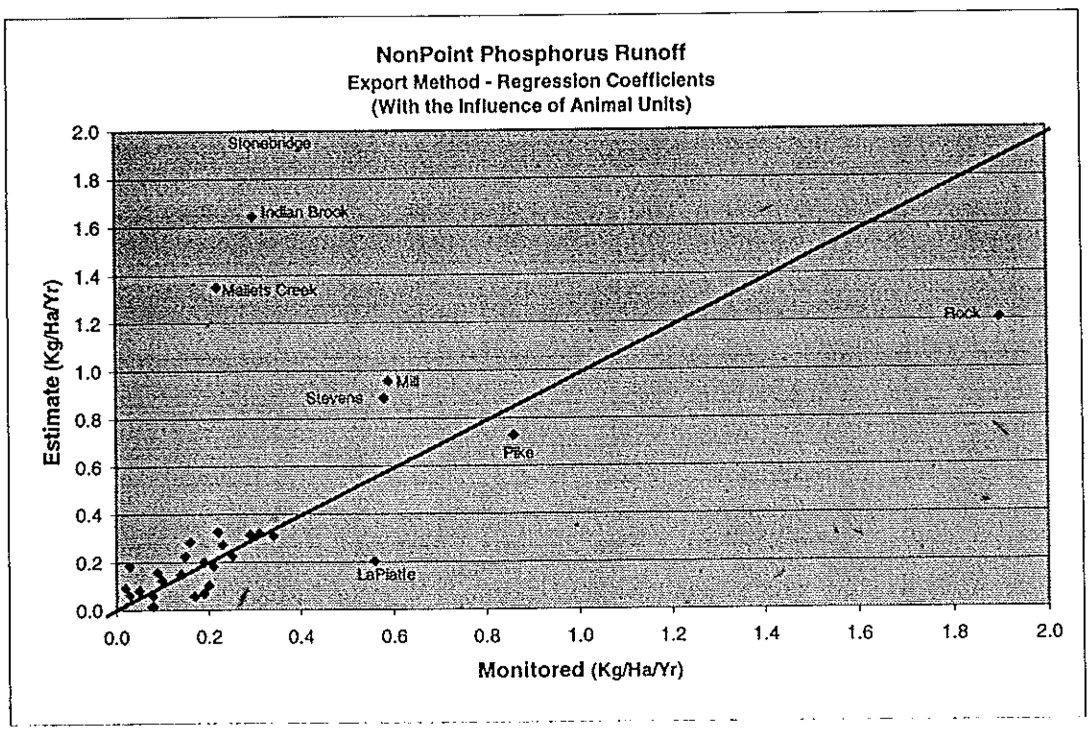


Figure 4.7

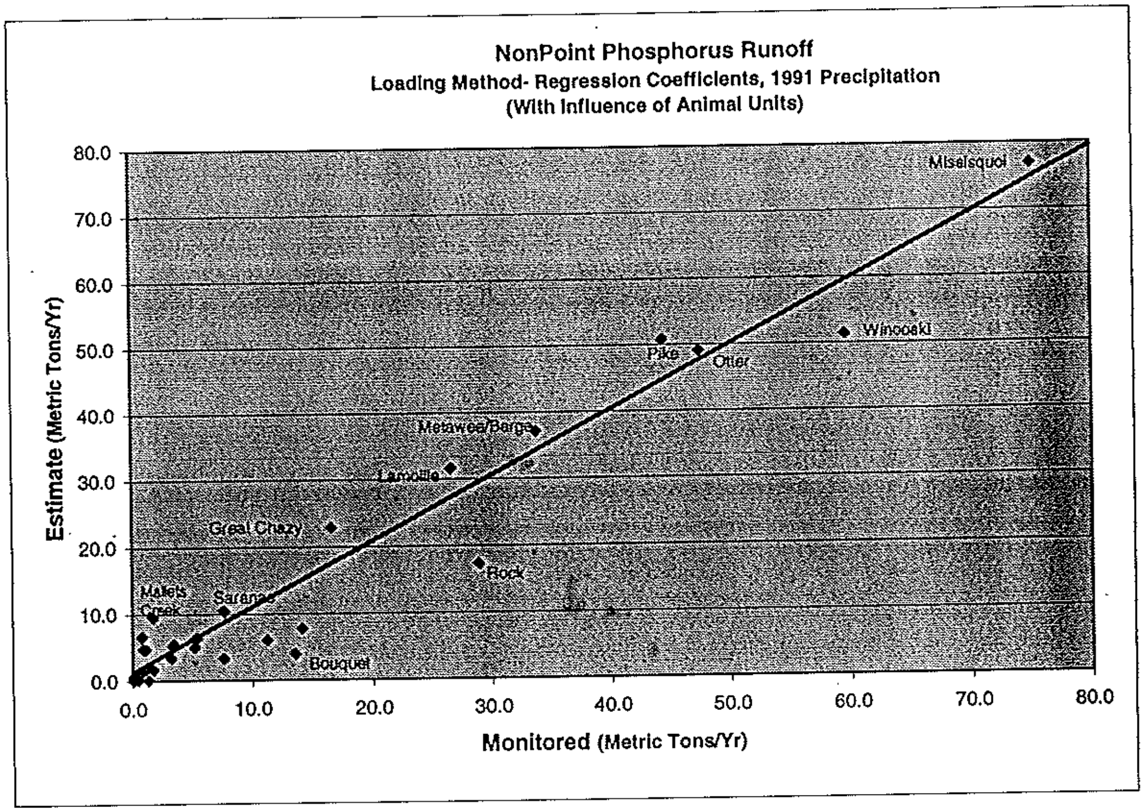
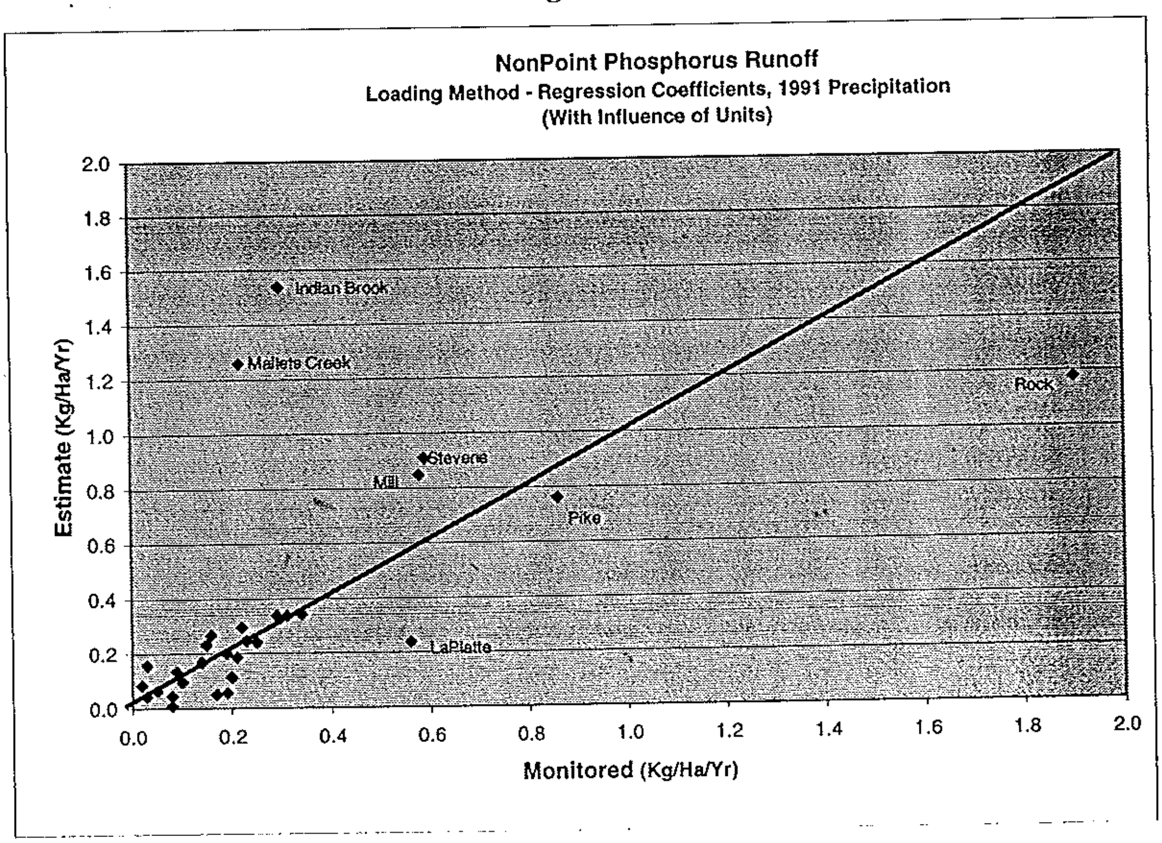


Figure 4.8



4.3.5 Results Reported by Lake Segment

Table 4.8 shows the export method phosphorus estimates reported for each of the 13 lake segments (lake segments adopted in the 1993 Lake Champlain Water Quality Agreement, Lake Champlain Phosphorus Management Task Force, 1993). Figure 4.9 also shows the loading by lake segment.

Overall the Missisquoi Bay segment exports approximately 143,000 kg/yr and is by far the largest contributor of phosphorus to the lake. On a per unit basis, it is the second largest contributor (.46 kg/ha/yr) behind Burlington Bay (1.4 kg/ha/yr). Missisquoi Bay segment is approximately 26 percent agriculture, yet 79 percent of the total phosphorus load is attributed to agricultural practices. Burlington Bay is a relatively small contributor of phosphorus to the lake (1989 kg/yr), but because of the high urban land use (93 percent), it is the largest per unit area contributor to the lake.

Table 4.8 Load Estimate - Export Method, Regression Coefficients with excess Animal Unit Corrections

	Areal Export (kg/ha/yr) Forest	Ag	Urban
Coefficients	0.040	0.42	1.50

		Pollution Load (year)				Source of NPS Load			Land Use			Area Load
Lake Segment	Area (ha)	Forest (ha)	Agriculture (kg)	Urban (kg)	TOTAL (kg)	% Forest	% Ag	% Urban	% Forest	% Ag	% Urban	kg/ha
missisquoi bay	312426	7729	113415	22186	143330	5.4	79.1	15.5	61.8	24.8	4.7	0.46
isle la motte	110135	2460	26795	6725	35980	6.8	74.5	18.7	55.8	27.6	4.1	0.33
northeast arm	23350	349	9973	2148	12470	2.8	80.0	17.2	37.4	35.7	6.1	0.53
st. albans bay	13052	152	9142	2328	11623	1.3	78.7	20.0	29.2	45.8	11.9	0.89
main lake	539315	16796	4940	52087	73824	22.8	6.7	70.6	77.9	9.2	6.4	0.14
malletts bay	201028	5588	17930	21243	44761	12.5	40.1	47.5	69.5	13.2	7.0	0.22
cumberland bay	174006	5598	1591	10471	17660	31.7	9.0	59.3	80.4	5.1	4.0	0.10
otter creek	287570	6930	29083	23977	59991	11.6	48.5	40.0	60.2	23.5	5.6	0.21
burlington bay	1418	2	5	1982	1989	0.1	0.2	99.7	3.9	0.8	93.2	1.40
shelburne bay	17934	223	-149	6175	6250	3.6	0.0	98.8	31.1	36.8	23.0	0.35
port henry	27003	762	2025	2020	4807	15.9	42.1	42.0	70.6	18.3	5.0	0.18
south lake a	102090	2948	4104	6803	13854	21.3	29.6	49.1	64.8	16.0	4.0	0.14
south lake b	198773	5136	22745	16853	44734	11.5	50.8	37.7	64.6	21.9	5.7	0.23
TOTAL	2008100	54674	241600	174996	471270	11.6	51.3	37.1	66.9	17.2	5.5	0.23

\lkseg_export_values_new_coeff_au.xls

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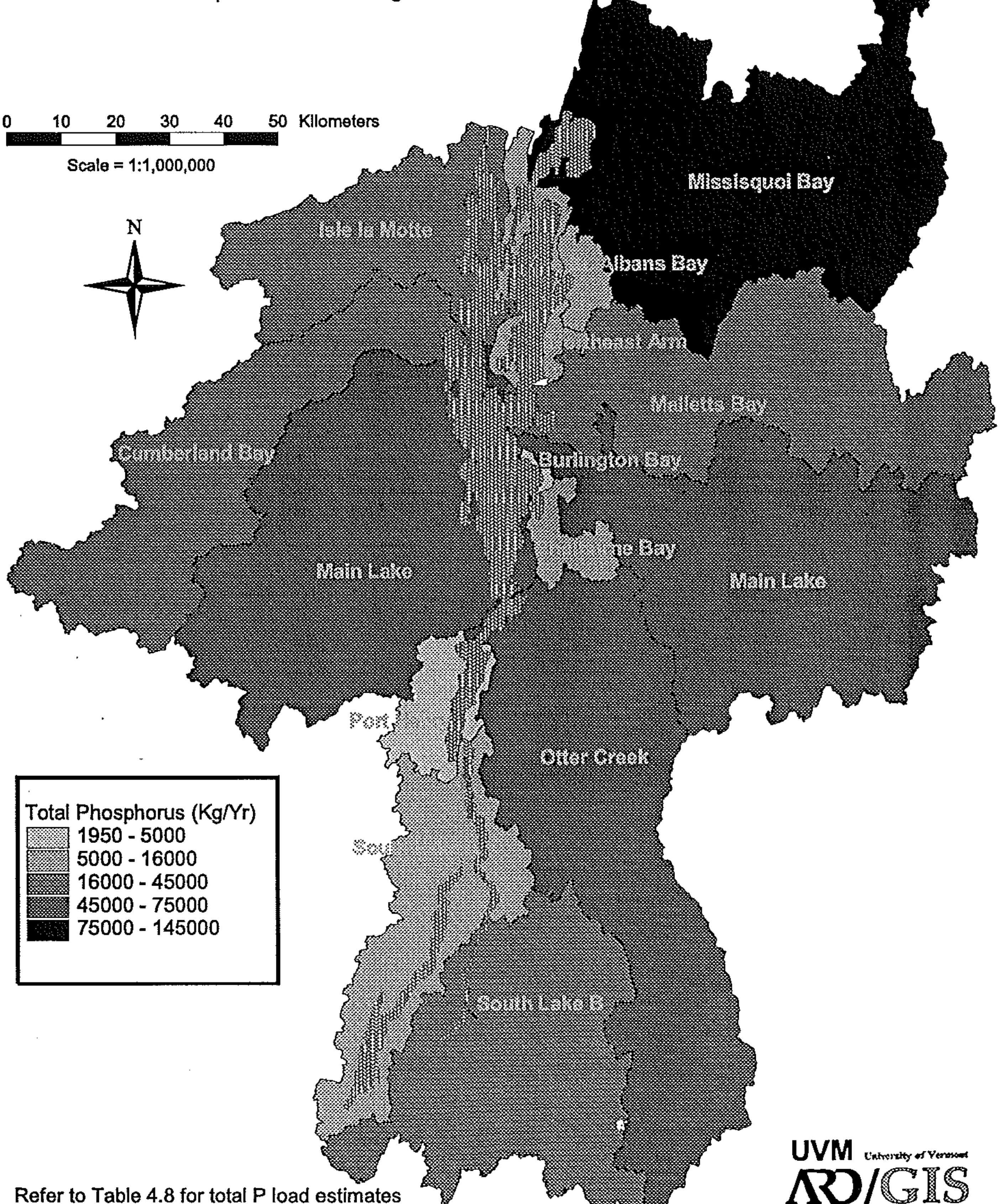
Figure 4.9 Phosphorus Loads for Lake Segments
Export Method - Regression Coefficients



Refer to Table 4.8 for total P load estimates
for individual lake segments.

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The loading method phosphorus estimates reported for each of the 13 lake segments is shown in Table 4.9. Figure 4.10 also shows a map of the estimates. Overall, the Missisquoi Bay segment is the largest phosphorus contributor with 148000 kg/yr. This estimate is slightly higher than that reported by the export method. As with the export model, Burlington Bay is the largest contributor on a per unit basis (1.29 kg/ha/yr). This estimate is 8 percent lower than that reported using the export method.

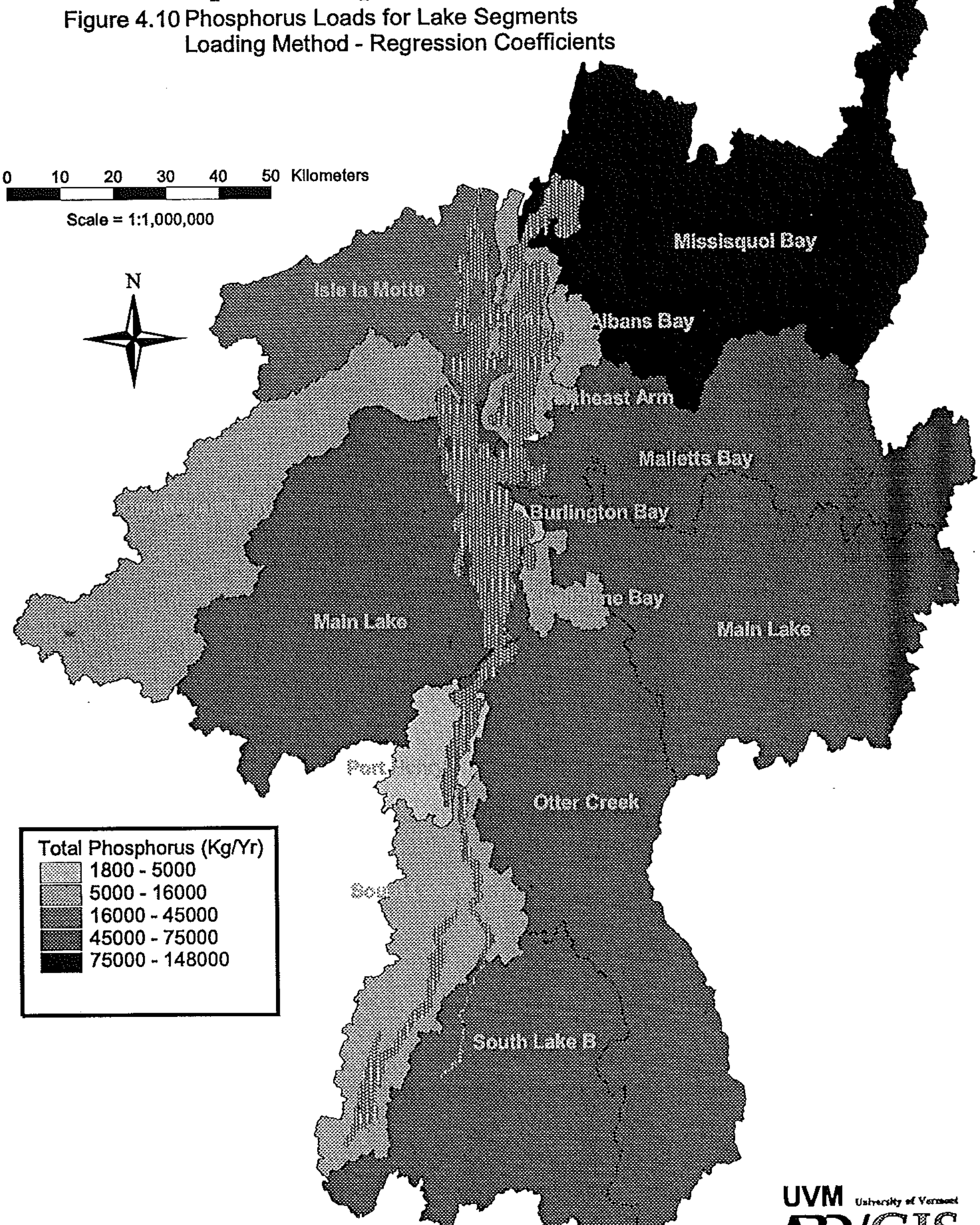
Table 4.9 Load Estimate - Loading Method, Regression Coefficients with Excess Animal Unit Corrections

	Runoff Concentrations (mg/l) Forest	Ag	Urban
Coefficients	**0.005**	**0.07**	**0.16**

		Pollution Load (year)				Source of NPS Load			Land Use			Area Load
Lake Segment	Area (ha)	Forest (kg)	Agriculture (kg)	Urban (kg)	TOTAL (kg)	% Forest	% Ag	% Urban	% Forest	% Ag	% Urban	kg/ha
missisquoi bay	312426	5398	117590	24992	147980	3.6	79.5	16.9	61.8	24.8	4.7	0.47
isle la motte	110135	1287	26321	5887	33495	3.8	78.6	17.6	55.8	27.6	4.1	0.30
northeast arm	23350	191	9772	1950	11913	1.6	82.0	16.4	37.4	35.7	6.1	0.51
st. albans bay	13052	85	8870	2137	11092	0.8	80.0	19.3	29.2	45.8	11.9	0.85
main lake	539315	10040	10036	51085	71162	14.1	14.1	71.8	77.9	9.2	6.4	0.13
malletts bay	201028	3839	20747	22853	47439	8.1	43.7	48.2	69.5	13.2	7.0	0.24
cumberland bay	174006	3241	2005	9515	14761	22.0	13.6	64.5	80.4	5.1	4.0	0.08
otter creek	287570	4299	33494	23731	61523	7.0	54.4	38.6	60.2	23.5	5.6	0.21
burlington bay	1418	1	5	1828	1835	0.1	0.3	99.7	3.9	0.8	93.2	1.29
shelburne bay	17934	132	578	5900	6610	2.0	8.7	89.3	31.1	36.8	23.0	0.37
port henry	27003	430	2284	1882	4596	9.4	49.7	41.0	70.6	18.3	5.0	0.17
south lake a	102090	1730	5142	6571	13443	12.9	38.3	48.9	64.8	16.0	4.0	0.13
south lake b	198773	3204	26604	17396	47204	6.8	56.4	36.9	64.6	21.9	5.7	0.24
TOTAL	2008100	33877	263447	175727	473052	7.2	55.7	37.1	66.9	17.2	5.5	0.24

LCBP Nonpoint Phosphorus Assessment

Figure 4.10 Phosphorus Loads for Lake Segments
Loading Method - Regression Coefficients



Refer to Table 4.9 for total P load estimates
for individual lake segments.

4.3.6 Results Reported by 14-digit Hydrologic Unit

The table results for the 14-digit hydrologic units are grouped by 8-digit hydrologic unit. Reporting the results in this manner make it easier to understand but allows individual units to be analyzed as well. Table 4.10 shows the 8-digit groups. They include:

Table 4.10: 8-Digit Hydrologic Groups

Hydrologic Group Names
Poultney/Metawee
South Basin, NY
Otter/Lewis
Winooski
Boquet/Ausable, NY
Lamoille/Grand Isle
Saranac/Chazy, NY
Missisquoi

There are also two hydrologic units that do not have an official code. They are two small islands in Lake Champlain which were not coded during the development of the hydrologic units coding scheme.

Table 4.11 shows the phosphorus contributions, using the export method, reported by 14-digit hydrologic unit. Figures 4.11 shows per unit load (kg/ha/yr) for each hydrologic unit.

Table 4.11 Load Estimate - Export Method, Regression Coefficients with Excess Animal Unit Corrections

	Areal Export (kg/ha/yr)		
	Forest	Ag	Urban
Coefficients	0.04	0.42	1.5

		Pollution Load(kg/year)				Source of NPS Load			Land Use			Area Load
Hu Number	Area (ha)	Forest	Agriculture	Urban	TOTAL	% Forest	% Ag	% Urban	% Forest	% Ag	% Urban	Kg/Ha
Poultney/Metawee												
02010001010010	11360	357	-24.3	518.1	850	41.9	-2.9	60.9	79.1	12.7	3.0	0.07
02010001010020	4993	108	-22.0	723.0	809	13.4	-2.7	89.3	56.2	26.9	9.7	0.16
02010001010030	12130	372	-20.4	944.3	1296	28.7	-1.6	72.9	80.1	11.1	5.2	0.11
02010001010040	13581	346	-23.0	1572.0	1895	18.3	-1.2	83.0	68.8	11.3	7.7	0.14
02010001010050	3074	82	-8.3	292.3	366	22.4	-2.3	79.9	66.8	15.8	6.3	0.12
02010001010060	11489	273	-50.9	702.3	924	29.5	-5.5	76.0	60.5	26.3	4.1	0.08
02010001010070	4841	111	-25.0	223.3	309	35.9	-8.1	72.2	58.9	31.1	3.1	0.06
02010001090010	16187	488	1798.7	782.0	3069	15.9	58.6	25.5	76.4	15.5	3.2	0.19
02010001090020	14420	385	1837.4	995.0	3217	12.0	57.1	30.9	69.2	17.8	4.6	0.22
02010001090030	4244	120	593.0	232.1	945	12.7	62.7	24.6	71.9	19.3	3.6	0.22
02010001270010	8278	140	1190.8	516.1	1847	7.6	64.5	27.9	42.4	46.0	4.2	0.22
02010001270020	5750	139	612.5	270.8	1022	13.6	59.9	26.5	62.0	25.6	3.1	0.18
02010001270030	7255	46	2232.4	446.4	2725	1.7	81.9	16.4	16.0	73.3	4.1	0.38
02010001270040	3555	32	952.6	397.6	1382	2.3	68.9	28.8	22.4	63.8	7.5	0.39
Total	**121157**	**2999**	**9043.6**	**8615.3**	**20658**	**14.5**	**43.8**	**41.7**	**63.7**	**24.3**	**4.7**	**0.17**
South Basin												
02010001080000	3399	74	-19.3	171.6	226	32.7	-8.5	75.8	57.7	34.8	3.4	0.07
02010001100000	3216	87	-12.0	238.6	314	27.8	-3.8	76.1	70.1	22.6	4.9	0.10
02010001110000	1083	27	247.7	82.8	357	7.5	69.3	23.2	62.4	32.2	5.1	0.33
02010001120000	18502	443	4180.2	1513.3	6137	7.2	68.1	24.7	61.5	31.5	5.5	0.33
02010001130000	2743	55	808.7	255.3	1119	4.9	72.3	22.8	51.5	41.2	6.2	0.41
02010001140000	52558	1142	12320.4	6891.8	20355	5.6	60.5	33.9	56.0	33.5	8.7	0.39
02010001150000	11340	404	598.2	226.1	1229	32.9	48.7	18.4	91.6	4.7	1.3	0.11
02010001160000	5079	159	211.5	310.4	681	23.4	31.1	45.6	80.4	11.1	4.1	0.13
02010001170000	2980	86	564.1	194.5	845	10.2	66.8	23.0	74.5	19.6	4.4	0.28
02010001180000	4083	111	389.9	271.4	772	14.4	50.5	35.1	69.6	23.6	4.4	0.19
02010001190000	48707	1727	-633.3	3552.9	4646	37.2	-13.6	76.5	89.2	3.6	4.9	0.10
02010001200000	7194	225	-338.0	653.5	541	41.6	-62.5	120.9	78.7	13.3	6.1	0.08
02010001210000	4854	78	998.4	279.5	1356	5.7	73.6	20.6	41.8	52.9	3.8	0.28
02010001220000	15989	484	-914.1	655.1	225	214.9	-405.7	290.7	85.0	9.2	2.7	0.01
02010001230000	4796	118	533.6	268.9	921	12.8	58.0	29.2	66.9	27.8	3.7	0.19
02010001240000	2986	83	193.4	362.9	640	13.0	30.2	56.7	73.7	17.1	8.1	0.21
02010001250000	7225	241	227.6	660.1	1129	21.4	20.2	58.5	88.1	2.9	6.1	0.16
02010001260000	10887	342	498.5	492.9	1333	25.6	37.4	37.0	80.2	15.6	3.0	0.12
Total	**207623**	**5888**	**19855.6**	**17081.7**	**42825**	**13.7**	**46.4**	**39.9**	**73.2**	**19.2**	**5.5**	**0.21**
Otter/Lewis												
02010002010010	15546	526	321.3	636.6	1484	35.5	21.6	42.9	87.6	5.2	2.7	0.10
02010002010020	13072	390	642.2	950.3	1982	19.7	32.4	47.9	77.4	12.2	4.8	0.15
02010002010030	18439	602	416.7	1514.7	2533	23.8	16.4	59.8	84.2	5.6	5.5	0.14
02010002010040	16360	481	485.4	3265.7	4232	11.4	11.5	77.2	74.5	7.6	13.3	0.26
02010002010050	15872	488	410.4	2000.6	2899	16.8	14.2	69.0	78.9	6.6	8.4	0.18
02010002010060	12263	355	629.7	1128.2	2113	16.8	29.8	53.4	76.8	12.7	6.1	0.17
02010002010070	3143	70	194.2	830.6	1095	6.4	17.7	75.9	59.7	17.4	17.6	0.35
02010002020010	11472	365	488.0	701.3	1554	23.5	31.4	45.1	81.4	10.5	4.1	0.14
02010002020020	9032	239	571.9	799.5	1610	14.8	35.5	49.6	72.3	17.6	5.9	0.18
02010002020030	5247	163	187.7	534.3	885	18.4	21.2	60.4	80.5	8.8	6.8	0.17
02010002020040	6334	106	542.1	618.1	1266	8.4	42.8	48.8	64.6	26.0	6.5	0.20
02010002020050	9741	254	397.9	573.0	1224	20.7	32.5	46.8	76.1	11.2	3.9	0.13
02010002020060	10640	85	1505.9	1106.2	2697	3.2	55.8	41.0	47.8	42.6	6.9	0.25
02010002020070	1204	18	242.3	145.9	406	4.4	59.7	35.9	37.2	48.6	8.1	0.34
02010002030010	16266	509	718.4	831.4	2059	24.7	34.9	40.4	80.7	11.1	3.4	0.13
02010002040010	17492	582	510.4	805.3	1898	30.7	26.9	42.4	84.9	7.4	3.1	0.11
02010002040020	12648	319	1343.4	781.2	2444	13.1	55.0	32.0	64.9	25.9	4.1	0.19
02010002050010	1532	24	278.7	146.2	449	5.4	62.1	32.6	40.2	43.7	6.4	0.29
02010002050020	8852	99	2054.1	871.8	3025	3.3	67.9	28.8	28.1	55.3	6.6	0.34
02010002060010	11337	173	2402.9	619.0	3195	5.4	75.2	19.4	38.7	51.1	3.6	0.28
02010002060020	12182	171	2791.8	701.7	3664	4.7	76.2	19.2	35.6	55.2	3.8	0.30
02010002070010	15738	107	4701.2	882.0	5690	1.9	82.6	15.5	16.9	71.2	3.7	0.36
02010002080010	18898	255	4151.7	1493.2	5900	4.3	70.4	25.3	37.5	50.2	5.3	0.31
02010002090010	10061	297	711.1	670.7	1678	17.7	42.4	40.0	75.0	15.7	4.4	0.17
02010002090020	10942	185	1908.4	952.3	3046	6.1	62.6	31.3	47.6	41.2	5.8	0.28
Total	**284313**	**6862**	**28607.7**	**23559.7**	**59029**	**11.6**	**48.5**	**39.9**	**64.3**	**24.7**	**5.5**	**0.21**

		Pollution Load(kg/year)				Source of NPS Load			Land Use			Area Load
Hu Number	Area (ha)	Forest	Agriculture	Urban	TOTAL	% Forest	% Ag	% Urban	% Forest	% Ag	% Urban	Kg/Ha
Winooski												
02010003010010	12446	358	207.6	1870.1	2435	14.7	8.5	76.8	73.8	14.1	10.0	0.20
02010003010020	17371	386	508.8	4252.7	5147	7.5	9.9	82.6	57.3	24.1	16.3	0.30
02010003020010	12663	371	187.5	1079.7	1638	22.7	11.4	65.9	75.0	12.3	5.7	0.13
02010003020020	16609	504	231.6	1485.1	2220	22.7	10.4	66.9	78.0	11.7	6.0	0.13
02010003020030	13740	384	175.3	1409.5	1969	19.5	8.9	71.6	73.5	11.3	6.8	0.14
02010003020040	8994	194	290.5	1523.9	2009	9.7	14.5	75.9	56.6	26.7	11.3	0.22
02010003020050	20150	664	121.4	1435.7	2221	29.9	5.5	64.6	83.7	5.2	4.7	0.11
02010003030010	12985	427	140.3	1235.6	1803	23.7	7.8	68.5	83.2	9.0	6.3	0.14
02010003030020	11068	356	122.6	1513.7	1992	17.9	6.2	76.0	80.7	9.1	9.1	0.18
02010003030030	8495	270	77.9	1181.4	1529	17.7	5.1	77.3	79.6	7.5	9.3	0.18
02010003030040	19814	659	182.0	1849.2	2690	24.5	6.8	68.7	83.5	7.5	6.2	0.14
02010003030050	17473	580	191.2	1613.0	2384	24.3	8.0	67.6	83.4	8.9	6.2	0.14
02010003030060	10421	305	139.0	1500.0	1944	15.7	7.2	77.2	73.5	11.0	9.6	0.19
02010003040010	13465	413	199.2	837.5	1450	28.5	13.7	57.8	77.5	12.4	4.1	0.11
02010003040020	15555	483	128.0	955.4	1567	30.8	8.2	61.0	78.4	6.9	4.1	0.10
02010003040030	13364	454	54.9	910.6	1419	32.0	3.9	64.2	85.3	3.4	4.5	0.11
02010003040040	17214	563	151.6	1303.7	2018	27.9	7.5	64.6	82.1	7.3	5.0	0.12
02010003040050	15194	394	278.1	2834.5	3506	11.2	7.9	80.8	66.5	15.9	12.4	0.23
02010003040060	12751	134	354.6	7332.5	7821	1.7	4.5	93.7	28.7	24.2	38.3	0.61
02010003040070	5499	71	236.5	1556.7	1864	3.8	12.7	83.5	35.4	38.5	18.9	0.34
02010003050010	13721	195	-670.5	3233.3	2758	7.1	-24.3	117.2	37.7	41.4	15.7	0.20
02010003050020	6084	73	1325.7	1354.5	2753	2.6	48.2	49.2	29.9	51.9	14.8	0.45
02010003050030	5547	27	504.9	5013.8	5545	0.5	9.1	90.4	12.7	22.7	60.3	1.00
Total	**300623**	**8264**	**5138.5**	**47282.2**	**60685**	**13.6**	**8.5**	**77.9**	**70.0**	**14.5**	**10.5**	**0.20**
Boquet/Ausable												
02010004010000	3265	61	590.5	261.1	913	6.7	64.7	28.6	50.4	43.9	5.3	0.28
02010004020000	25788	914	-74.4	863.1	1703	53.7	-4.4	50.7	92.9	3.3	2.2	0.07
02010004030000	44635	1501	-302.6	1998.9	3198	46.9	-9.5	62.5	87.1	7.8	3.0	0.07
02010004040000	10189	348	132.4	591.8	1072	32.4	12.4	55.2	89.2	3.9	3.9	0.11
02010004050000	51239	1875	-589.8	1567.8	2853	65.7	-20.7	54.9	94.1	2.2	2.0	0.06
02010004060000	60530	2123	-563.4	2462.7	4022	52.8	-14.0	61.2	91.4	1.9	2.7	0.07
02010004070000	21823	682	-1040.4	1559.1	1201	56.8	-86.6	129.8	81.3	9.2	4.8	0.06
02010004080000	20857	611	1491.0	1566.8	3669	16.7	40.6	42.7	76.2	17.6	5.0	0.18
02010004090000	18592	581	120.0	2556.8	3257	17.8	3.7	78.5	81.0	8.9	9.2	0.18
Total	**256917**	**8696**	**-236.8**	**13428.0**	**21887**	**39.7**	**-1.1**	**61.4**	**87.9**	**6.1**	**3.5**	**0.09**
Lamoille/Grand Isle												
02010005010010	15041	455	358.9	1175.3	1989	22.9	18.0	59.1	78.8	10.0	5.2	0.13
02010005010020	15240	422	599.2	1269.8	2291	18.4	26.2	55.4	72.1	16.8	5.6	0.15
02010005010030	21279	670	428.4	1281.8	2380	28.1	18.0	53.9	81.5	8.5	4.0	0.11
02010005010040	5005	166	18.2	94.6	278	59.5	6.5	34.0	87.3	2.2	1.3	0.06
02010005010050	23733	635	1058.6	2232.0	3926	16.2	27.0	56.9	69.0	18.8	6.3	0.17
02010005010060	16769	514	369.5	1158.9	2042	25.2	18.1	56.7	79.3	9.7	4.6	0.12
02010005020010	13955	393	270.0	2724.8	3388	11.6	8.0	80.4	72.5	8.8	13.0	0.24
02010005020020	9954	234	489.0	1126.6	1849	12.6	26.4	60.9	62.5	21.9	7.5	0.19
02010005030010	15769	523	180.7	481.6	1185	44.1	15.2	40.6	85.0	5.3	2.0	0.08
02010005030020	13400	419	295.0	889.2	1604	26.1	18.4	55.5	79.0	9.7	4.4	0.12
02010005030030	23250	626	1001.7	2004.3	3632	17.2	27.6	55.2	69.3	18.5	5.7	0.16
02010005030040	13770	267	762.9	2196.8	3227	8.3	23.6	68.1	53.9	24.3	10.6	0.23
02010005040010	13717	260	11995.2	4649.4	16905	1.5	71.0	27.5	51.5	20.1	22.6	1.23
02010005040020	6163	148	7015.8	658.3	7822	1.9	89.7	8.4	65.0	22.4	7.1	1.27
02010005040030	6779	98	4838.5	1227.8	6165	1.6	78.5	19.9	38.3	42.4	12.1	0.91
02010005040040	6117	52	4282.6	1080.2	5415	1.0	79.1	19.9	26.0	53.0	11.8	0.89
02010005040050	5349	33	721.7	502.8	1257	2.6	57.4	40.0	28.7	53.6	6.3	0.24
02010005050010	24905	332	4750.0	2402.3	7485	4.4	63.5	32.1	38.3	45.5	6.4	0.30
02010005050020	177	4	12.7	23.4	41	11.0	31.2	57.8	64.5	18.0	8.9	0.23
Total	**250373**	**6252**	**39448.6**	**27179.8**	**72880**	**8.6**	**54.1**	**37.3**	**65.7**	**19.9**	**7.2**	**0.29**
Saranac/Chazy												
02010006010000	91945	3027	-92.5	3177.5	6112	49.5	-1.5	52.0	85.5	1.1	2.3	0.07
02010006020000	33175	1249	0.0	731.7	1981	63.1	0.0	36.9	94.1	0.0	1.5	0.06
02010006030000	25987	870	-243.6	1760.9	2387	36.4	-10.2	73.8	84.4	8.8	4.5	0.09
02010006040000	8028	188	-115.9	2341.0	2413	7.8	-4.8	97.0	63.0	14.5	19.4	0.30
02010006050000	11352	167	1810.4	1777.4	3755	4.5	48.2	47.3	47.2	41.6	10.4	0.33
02010006060000	2597	33	567.6	143.3	744	4.5	76.3	19.3	40.4	54.9	3.7	0.29
02010006070000	16565	368	3207.2	1105.2	4680	7.9	68.5	23.6	62.7	31.5	4.4	0.28
02010006080000	51058	1519	8732.7	1910.3	12162	12.5	71.8	15.7	79.8	14.9	2.5	0.24
02010006090000	26651	479	10903.3	1720.6	13103	3.7	83.2	13.1	59.0	35.1	4.3	0.49
02010006100000	2355	20	447.2	406.3	873	2.3	51.2	46.5	34.3	52.6	11.5	0.37
02010006110000	3166	22	793.5	220.9	1037	2.2	76.5	21.3	18.1	61.3	4.7	0.33
02010006120000	2904	31	563.4	558.6	1153	2.7	48.9	48.4	35.3	50.6	12.8	0.40
Total	**275783**	**7973**	**26573.3**	**15853.7**	**50400**	**15.8**	**52.7**	**31.5**	**77.1**	**13.6**	**3.8**	**0.18**

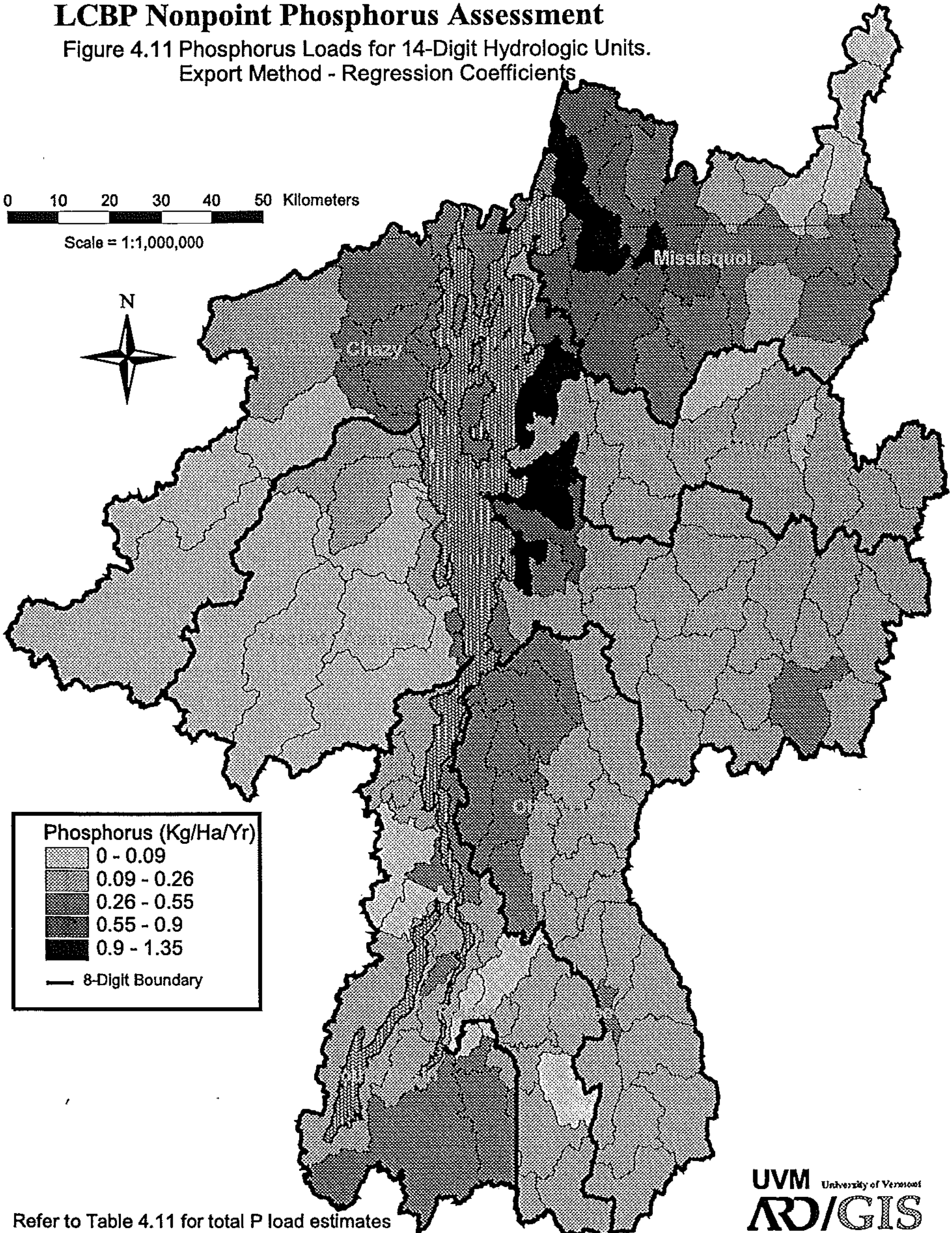
		Pollution Load(kg/year)				Source of NPS Load			Land Use			Area Load
Hu Number	Area (ha)	Forest	Agriculture	Urban	TOTAL	% Forest	% Ag	% Urban	% Forest	% Ag	% Urban	Kg/Ha
Missisquoi												
02010007010010	8356	275	943.0	391.6	1609	17.1	58.6	24.3	84.2	6.8	3.1	0.19
02010007010020	17175	526	3536.2	1293.0	5355	9.8	66.0	24.1	79.1	12.3	5.0	0.31
02010007010030	11155	313	2922.8	887.5	4123	7.6	70.9	21.5	72.3	17.7	5.3	0.37
02010007010040	14857	361	5536.9	939.4	6838	5.3	81.0	13.7	64.3	27.9	4.2	0.46
02010007020010	7787	245	-47.5	491.3	688	35.5	-6.9	71.4	79.6	9.1	4.2	0.09
02010007020020	9888	340	-32.6	498.1	805	42.2	-4.0	61.8	86.0	4.8	3.4	0.08
02010007020030	10219	327	-80.4	705.5	952	34.4	-8.4	74.1	80.3	11.4	4.6	0.09
02010007030010	2635	90	34.7	139.1	264	34.2	13.1	52.7	87.9	4.6	3.5	0.10
02010007030020	10536	379	-21.6	401.0	758	50.0	-2.8	52.9	89.9	4.6	2.5	0.07
02010007030030	15185	438	3746.1	1090.3	5274	8.3	71.0	20.7	73.4	16.3	4.8	0.35
02010007040010	5260	149	-65.7	593.4	677	22.0	-9.7	87.7	70.8	18.1	7.5	0.13
02010007040020	11553	343	331.3	746.9	1421	24.1	23.3	52.6	74.8	17.5	4.3	0.12
02010007050010	14749	512	1310.8	541.9	2365	21.7	55.4	22.9	87.3	5.3	2.4	0.16
02010007050020	6899	218	1297.5	354.6	1870	11.7	69.4	19.0	80.0	11.4	3.4	0.27
02010007060010	7481	151	4503.3	737.1	5391	2.8	83.5	13.7	52.0	35.8	6.6	0.72
02010007060020	14968	446	3795.1	874.9	5116	8.7	74.2	17.1	76.5	15.5	3.9	0.34
02010007070010	14410	416	3669.8	832.5	4918	8.5	74.6	16.9	75.1	16.2	3.8	0.34
02010007070020	16695	374	8122.2	972.0	9468	3.9	85.8	10.3	60.1	29.5	3.9	0.57
02010007080010	5348	90	3703.0	382.2	4175	2.1	88.7	9.2	47.4	41.1	4.8	0.78
02010007080020	11533	212	6456.8	1209.7	7878	2.7	82.0	15.4	51.5	33.9	7.0	0.68
02010007080030	7317	84	3155.3	1159.3	4398	1.9	71.7	26.4	41.7	37.5	10.6	0.60
02010007090010	12032	180	14621.7	943.2	15745	1.1	92.9	6.0	42.0	46.6	5.2	1.31
02010007090020	2630	55	1659.8	252.0	1967	2.8	84.4	12.8	58.3	29.6	6.4	0.75
02010007100010	267	5	13.4	122.8	141	3.4	9.5	87.1	52.4	13.1	30.9	0.53
02010007110010	12939	318	7697.5	1015.3	9031	3.5	85.2	11.2	62.6	28.0	5.2	0.70
02010007110020	3656	58	3714.9	262.6	4035	1.4	92.1	6.5	45.3	30.5	4.8	1.10
02010007110030	12016	294	4178.1	822.3	5294	5.5	78.9	15.5	61.9	29.9	4.6	0.44
02010007110040	10962	217	6583.8	811.5	7612	2.9	86.5	10.7	51.4	40.3	4.9	0.69
02010007110050	7088	72	5261.2	631.1	5965	1.2	88.2	10.6	25.5	63.6	5.9	0.84
02010007110060	11513	141	8294.1	435.2	8871	1.6	93.5	4.9	31.7	61.7	2.5	0.77
02010007110070	8553	49	7153.3	610.0	7812	0.6	91.6	7.8	15.6	74.6	4.8	0.91
02010007120010	4810	38	1191.3	841.3	2071	1.8	57.5	40.6	20.4	61.3	11.7	0.43
Total	**310469**	**7715**	**113186.2**	**21988.6**	**142890**	**5.4**	**79.2**	**15.4**	**64.4**	**25.8**	**4.7**	**0.46**
Unknown												
00000000000099	451	17	3.3	0.1	20	83.8	15.9	0.3	95.0	1.8	0.0	0.05
TOTAL BASIN	**2007709**	**54666**	**241620.0**	**174988.9**	**471275**	**11.6**	**51.3**	**37.1**	**66.9**	**17.2**	**5.5**	**0.23**

table_411.xls

Note - Negative numbers found in some colums are expected given the introduction of animal unit correction data. For a full explaination, see Section 4.4.4.

LCBP Nonpoint Phosphorus Assessment

Figure 4.11 Phosphorus Loads for 14-Digit Hydrologic Units.
Export Method - Regression Coefficients



Refer to Table 4.11 for total P load estimates
for individual hydrologic units.

The 8-digit grouping with the highest loading is the Missisquoi. The area of this 8-digit group is not significantly larger than some of the other units, such as the Winooski, but the phosphorus load is almost 3 times as high. Table 4.11 shows the largest contributors on an annual basis. These contributors are not necessarily the largest contributors on a per unit basis (Figure 4.11). The kg/ha basis is generally much lower for NY than Vermont and Quebec.

Table 4.12 shows the phosphorus contributions, using the loading method, reported by 14-digit hydrologic unit. Figure 4.12 shows the per unit load (kg/ha/yr) for each hydrologic unit.

Again with the loading method, the Missisquoi Bay has the highest loading and is also relatively high on a per unit basis.

Table 4.12: Load Estimate - Loading Method, Regression Coefficients with excess Animal Unit corrections

	Runoff Concentrations (mg/l)		
	Forest	Ag	Urban
Coefficients	0.005	0.07	0.16

		Pollution Load(kg/year)				Source of NPS Load			Land Use			Area Load
Hu Number	**Area (ha)**	**Forest**	**Agriculture**	**Urban**	**TOTAL**	**% Forest**	**% Ag**	**% Urban**	**% Forest**	**% Ag**	**% Urban**	**Kg/Ha**
Poultney/Metawee												
02010001010010	11360	224	182	540	946	23.7	19.2	57.1	79.1	12.7	3.0	0.08
02010001010020	4993	66	149	732	947	7.0	15.7	77.3	56.2	26.9	9.7	0.19
02010001010030	12130	224	126	935	1286	17.4	9.8	72.7	80.1	11.1	5.2	0.11
02010001010040	13581	207	144	1569	1920	10.8	7.5	81.7	68.8	11.3	7.7	0.14
02010001010050	3074	49	51	291	391	12.5	13.0	74.5	66.8	15.8	6.3	0.13
02010001010060	11489	159	270	676	1105	14.4	24.4	61.2	60.5	26.3	4.1	0.10
02010001010070	4841	66	141	219	426	15.5	33.1	51.5	58.9	31.1	3.1	0.09
02010001090010	16187	349	2152	917	3417	10.2	63.0	26.8	76.4	15.5	3.2	0.21
02010001090020	14420	250	2090	1065	3405	7.4	61.4	31.3	69.2	17.8	4.6	0.24
02010001090030	4244	82	692	259	1032	7.9	67.0	25.1	71.9	19.3	3.6	0.24
02010001270010	8278	78	1375	472	1925	4.1	71.4	24.5	42.4	46.0	4.2	0.23
02010001270020	5750	80	698	256	1033	7.7	67.5	24.8	62.0	25.6	3.1	0.18
02010001270030	7255	25	2431	403	2859	0.9	85.0	14.1	16.0	73.3	4.1	0.39
02010001270040	3555	18	1072	370	1460	1.2	73.4	25.4	22.4	63.8	7.5	0.41
Total	**121157**	**1877**	**11571**	**8704**	**22151**	**8.5**	**52.2**	**39.3**	**63.7**	**24.3**	**4.7**	**0.18**
South Basin												
02010001080000	3399	44	119	171	335	13.3	35.7	51.0	57.7	34.8	3.4	0.10
02010001100000	3216	53	80	241	374	14.2	21.4	64.5	70.1	22.6	4.9	0.12
02010001110000	1083	17	273	85	375	4.5	72.8	22.7	62.4	32.2	5.1	0.35
02010001120000	18502	276	4632	1571	6479	4.3	71.5	24.2	61.5	31.5	5.5	0.35
02010001130000	2743	33	875	255	1163	2.8	75.2	21.9	51.5	41.2	6.2	0.42
02010001140000	52558	703	13367	7164	21234	3.3	63.0	33.7	56.0	33.5	8.7	0.40
02010001150000	11340	248	593	229	1069	23.1	55.5	21.4	91.6	4.7	1.3	0.09
02010001160000	5079	94	250	304	649	14.5	38.5	46.9	80.4	11.1	4.1	0.13
02010001170000	2980	49	567	183	799	6.2	71.0	22.8	74.5	19.6	4.4	0.27
02010001180000	4083	60	417	241	718	8.3	58.1	33.6	69.6	23.6	4.4	0.18
02010001190000	48707	1062	-380	3651	4332	24.5	-8.8	84.3	89.2	3.6	4.9	0.09
02010001200000	7194	120	-263	561	417	28.7	-63.1	134.4	78.7	13.3	6.1	0.06
02010001210000	4854	41	1055	245	1342	3.1	78.6	18.3	41.8	52.9	3.8	0.28
02010001220000	15989	267	-738	597	126	211.6	-584.4	472.8	85.0	9.2	2.7	0.01
02010001230000	4796	66	595	249	911	7.3	65.4	27.3	66.9	27.8	3.7	0.19
02010001240000	2986	47	219	339	605	7.8	36.1	56.1	73.7	17.1	8.1	0.20
02010001250000	7225	137	223	617	977	14.0	22.8	63.2	88.1	2.9	6.1	0.14
02010001260000	10887	192	600	456	1249	15.4	48.1	36.6	80.2	15.6	3.0	0.11
Total	**207623**	**3510**	**22485**	**17160**	**43154**	**8.1**	**52.1**	**39.8**	**73.2**	**19.2**	**5.5**	**0.21**
Otter/Lewis												
02010002010010	15546	388	465	773	1626	23.9	28.6	47.5	87.6	5.2	2.7	0.10
02010002010020	13072	262	865	1054	2181	12.0	39.7	48.3	77.4	12.2	4.8	0.17
02010002010030	18439	400	542	1635	2577	15.5	21.0	63.4	84.2	5.6	5.5	0.14
02010002010040	16360	290	575	3153	4018	7.2	14.3	78.5	74.5	7.6	13.3	0.25
02010002010050	15872	302	491	1938	2731	11.1	18.0	71.0	78.9	6.6	8.4	0.17
02010002010060	12263	221	785	1146	2152	10.3	36.5	53.2	76.8	12.7	6.1	0.18
02010002010070	3143	42	231	817	1090	3.8	21.2	75.0	59.7	17.4	17.6	0.35
02010002020010	11472	227	609	725	1561	14.5	39.0	46.5	81.4	10.5	4.1	0.14
02010002020020	9032	145	698	806	1648	8.8	42.3	48.9	72.3	17.6	5.9	0.18
02010002020030	5247	97	221	524	842	11.5	26.3	62.2	80.5	8.8	6.8	0.16
02010002020040	6334	62	626	595	1283	4.8	48.8	46.4	64.6	26.0	6.5	0.20
02010002020050	9741	146	453	543	1142	12.8	39.7	47.5	76.1	11.2	3.9	0.12
02010002020060	10640	47	1645	1009	2700	1.7	60.9	37.4	47.8	42.6	6.9	0.25
02010002020070	1204	10	270	135	415	2.4	65.1	32.5	37.2	48.6	8.1	0.34
02010002030010	16268	298	813	793	1904	15.6	42.7	41.7	80.7	11.1	3.4	0.12
02010002040010	17492	369	652	846	1868	19.8	34.9	45.3	84.9	7.4	3.1	0.11
02010002040020	12648	187	1556	758	2501	7.5	62.2	30.3	64.9	25.9	4.1	0.20
02010002050010	1532	14	316	137	467	2.9	67.7	29.4	40.2	43.7	6.4	0.31
02010002050020	8852	57	2350	829	3235	1.8	72.6	25.6	28.1	55.3	6.6	0.37
02010002060010	11337	96	2645	565	3306	2.9	80.0	17.1	38.7	51.1	3.6	0.29
02010002060020	12182	92	3002	625	3719	2.5	80.7	16.8	35.6	55.2	3.8	0.31
02010002070010	15738	59	5235	812	6106	1.0	85.7	13.3	16.9	71.2	3.7	0.39
02010002080010	18898	152	4797	1464	6413	2.4	74.8	22.8	37.5	50.2	5.3	0.34
02010002090010	10061	185	851	686	1722	10.7	49.4	39.9	75.0	15.7	4.4	0.17
02010002090020	10942	113	2243	954	3310	3.4	67.8	28.8	47.6	41.2	5.8	0.30
Total	**284313**	**4259**	**32936**	**23321**	**60516**	**7.0**	**54.4**	**38.5**	**64.3**	**24.7**	**5.5**	**0.21**

		Pollution Load(kg/year)				Source of NPS Load			Land Use			Area Load
Hu Number	Area (ha)	Forest	Agriculture	Urban	TOTAL	% Forest	% Ag	% Urban	% Forest	% Ag	% Urban	Kg/Ha
Winooski												
02010003010010	12446	214	383	1836	2433	8.8	15.8	75.4	73.8	14.1	10.0	0.20
02010003010020	17371	224	884	4064	5172	4.3	17.1	78.6	57.3	24.1	16.3	0.30
02010003020010	12663	231	381	1112	1724	13.4	22.1	64.5	75.0	12.3	5.7	0.14
02010003020020	16609	310	456	1510	2276	13.6	20.0	66.4	78.0	11.7	6.0	0.14
02010003020030	13740	244	364	1481	2089	11.7	17.4	70.9	73.5	11.3	6.8	0.15
02010003020040	8994	117	540	1499	2156	5.4	25.1	69.5	56.6	26.7	11.3	0.24
02010003020050	20150	430	258	1500	2188	19.7	11.8	68.6	83.7	5.2	4.7	0.11
02010003030010	12985	264	275	1256	1795	14.7	15.3	70.0	83.2	9.0	6.3	0.14
02010003030020	11068	214	230	1494	1939	11.1	11.8	77.1	80.7	9.1	9.1	0.18
02010003030030	8495	169	160	1204	1533	11.0	10.5	78.5	79.6	7.5	9.3	0.18
02010003030040	19814	437	431	2057	2925	15.0	14.7	70.3	83.5	7.5	6.2	0.15
02010003030050	17473	380	434	1758	2573	14.8	16.9	68.3	83.4	8.9	6.2	0.15
02010003030060	10421	198	310	1611	2119	9.4	14.6	76.0	73.5	11.0	9.6	0.20
02010003040010	13465	332	599	1066	1997	16.6	30.0	53.4	77.5	12.4	4.1	0.15
02010003040020	15555	350	331	1106	1787	19.6	18.5	61.9	78.4	6.9	4.1	0.11
02010003040030	13364	299	124	989	1411	21.2	8.8	70.1	85.3	3.4	4.5	0.11
02010003040040	17214	353	302	1327	1982	17.8	15.2	66.9	82.1	7.3	5.0	0.12
02010003040050	15194	255	564	2945	3763	6.8	15.0	78.2	66.5	15.9	12.4	0.25
02010003040060	12751	78	608	6895	7581	1.0	8.0	91.0	28.7	24.2	38.3	0.59
02010003040070	5499	41	398	1456	1894	2.1	21.0	76.9	35.4	38.5	18.9	0.34
02010003050010	13721	116	-10	3175	3281	3.5	-0.3	96.8	37.7	41.4	15.7	0.24
02010003050020	6084	42	1546	1305	2894	1.5	53.4	45.1	29.9	51.9	14.8	0.48
02010003050030	5547	15	569	4634	5218	0.3	10.9	88.8	12.7	22.7	60.3	0.94
Total	300623	5313	10136	47279	62728	8.5	16.2	75.4	70.0	14.5	10.5	0.21
Boquet/Ausable												
02010004010000	3265	34	663	244	942	3.6	70.4	25.9	50.4	43.9	5.3	0.29
02010004020000	25788	501	-3	789	1288	38.9	-0.2	61.3	92.9	3.3	2.2	0.05
02010004030000	44635	848	2	1854	2704	31.3	0.1	68.6	87.1	7.8	3.0	0.06
02010004040000	10189	187	146	526	859	21.8	17.0	61.2	89.2	3.9	3.9	0.08
02010004050000	51239	1088	-461	1459	2086	52.1	-22.1	69.9	94.1	2.2	2.0	0.04
02010004060000	60530	1227	-401	2388	3214	38.2	-12.5	74.3	91.4	1.9	2.7	0.05
02010004070000	21823	349	-891	1303	762	45.9	-117.0	171.1	81.3	9.2	4.8	0.03
02010004080000	20857	298	1436	1261	2996	10.0	47.9	42.1	76.2	17.6	5.0	0.14
02010004090000	18592	295	174	2142	2611	11.3	6.7	82.0	81.0	8.9	9.2	0.14
Total	256917	4828	667	11965	17461	27.7	3.8	68.5	87.9	6.1	3.5	0.07
Lamoille/Grand Isle												
02010005010010	15041	295	567	1265	2128	13.9	26.7	59.5	78.8	10.0	5.2	0.14
02010005010020	15240	272	935	1353	2560	10.6	36.5	52.9	72.1	16.8	5.6	0.17
02010005010030	21279	444	692	1401	2537	17.5	27.3	55.2	81.5	8.5	4.0	0.12
02010005010040	5005	112	30	105	246	45.4	12.1	42.5	87.3	2.2	1.3	0.05
02010005010050	23733	434	1704	2440	4579	9.5	37.2	53.3	69.0	18.8	6.3	0.19
02010005010060	16769	359	642	1341	2342	15.3	27.4	57.3	79.3	9.7	4.6	0.14
02010005020010	13955	315	498	3305	4117	7.6	12.1	80.3	72.5	8.8	13.0	0.30
02010005020020	9954	148	726	1157	2031	7.3	35.8	56.9	62.5	21.9	7.5	0.20
02010005030010	15769	366	319	559	1243	29.4	25.6	45.0	85.0	5.3	2.0	0.08
02010005030020	13400	328	576	1128	2032	16.2	28.3	55.5	79.0	9.7	4.4	0.15
02010005030030	23250	461	1716	2382	4559	10.1	37.6	52.3	69.3	18.5	5.7	0.20
02010005030040	13770	154	1024	2077	3255	4.7	31.5	63.8	53.9	24.3	10.6	0.24
02010005040010	13717	150	11217	4378	15744	1.0	71.2	27.8	51.5	20.1	22.6	1.15
02010005040020	6163	81	6517	602	7200	1.1	90.5	8.4	65.0	22.4	7.1	1.17
02010005040030	6779	55	4674	1133	5863	0.9	79.7	19.3	38.3	42.4	12.1	0.86
02010005040040	6117	29	4170	985	5184	0.6	80.4	19.0	26.0	53.0	11.8	0.85
02010005040050	5349	19	829	481	1329	1.4	62.4	36.2	28.7	53.6	6.3	0.25
02010005050010	24905	179	5169	2158	7506	2.4	68.9	28.8	38.3	45.5	6.4	0.30
02010005050020	177	2	14	21	38	6.6	37.1	56.3	64.5	18.0	8.9	0.21
Total	250373	4203	42020	28272	74494	5.6	56.4	38.0	65.7	19.9	7.2	0.30
Saranac/Chazy												
02010006010000	91945	1830	28	3207	5065	36.1	0.6	63.3	85.5	1.1	2.3	0.06
02010006020000	33175	713	0	690	1403	50.8	0.0	49.2	94.1	0.0	1.5	0.04
02010006030000	25987	465	-78	1551	1938	24.0	-4.0	80.1	84.4	8.8	4.5	0.07
02010006040000	8028	98	-53	1975	2020	4.8	-2.6	97.8	63.0	14.5	19.4	0.25
02010006050000	11352	86	1873	1512	3471	2.5	54.0	43.6	47.2	41.6	10.4	0.31
02010006060000	2597	17	591	124	732	2.4	80.7	16.9	40.4	54.9	3.7	0.28
02010006070000	16565	192	3193	951	4336	4.4	73.6	21.9	62.7	31.5	4.4	0.26
02010006080000	51058	791	8305	1630	10726	7.4	77.4	15.2	79.8	14.9	2.5	0.21
02010006090000	26651	253	10515	1513	12280	2.1	85.6	12.3	59.0	35.1	4.3	0.46
02010006100000	2355	11	484	366	862	1.2	56.2	42.5	34.3	52.6	11.5	0.37
02010006110000	3166	12	893	205	1110	1.1	80.4	18.5	18.1	61.3	4.7	0.35
02010006120000	2904	16	584	477	1077	1.5	54.2	44.3	35.3	50.6	12.8	0.37
Total	275783	4484	26335	14201	45020	10.0	58.5	31.5	77.1	13.6	3.8	0.16

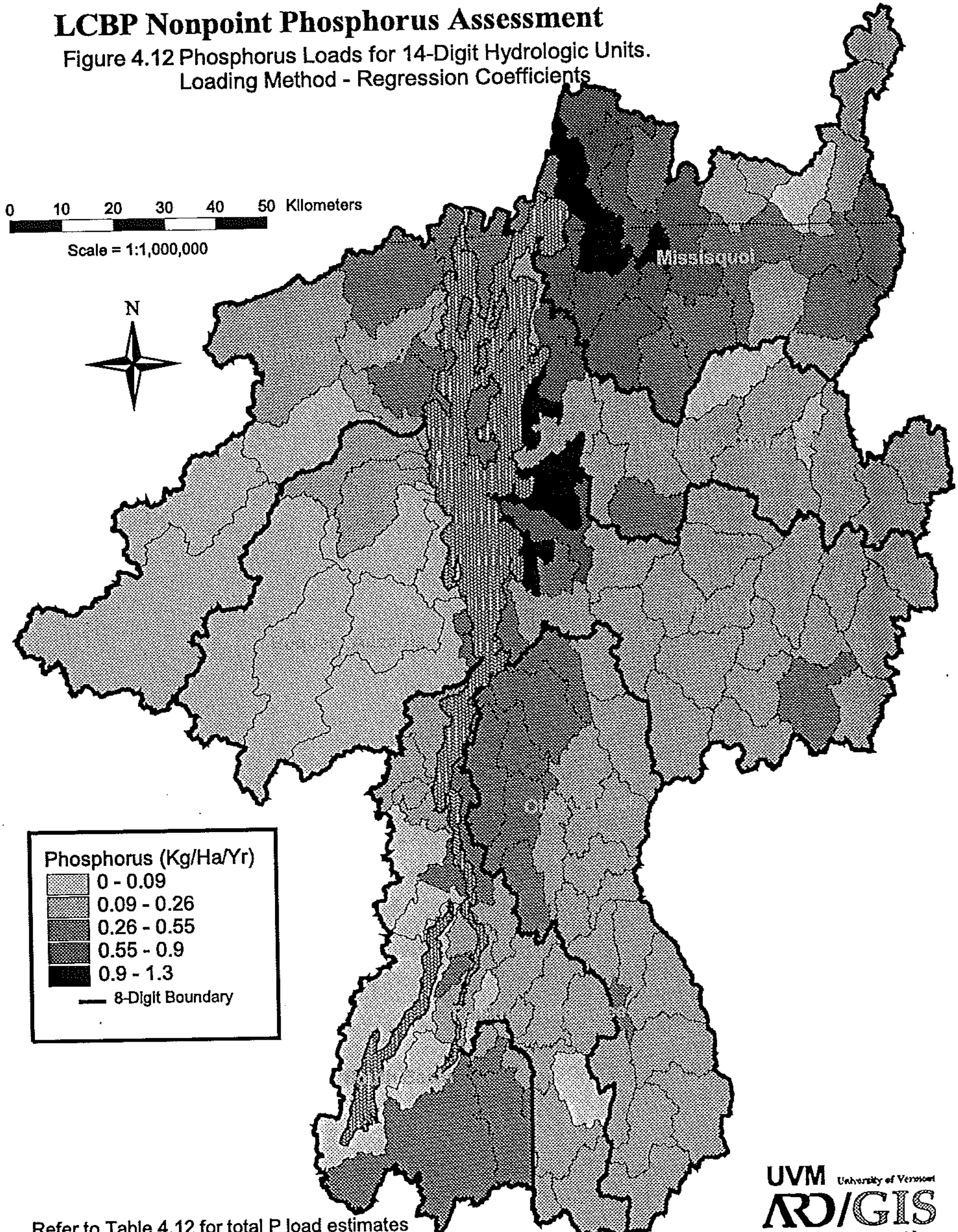
		Pollution Load(kg/year)				Source of NPS Load			Land Use			Area Load
Hu Number	Area (ha)	Forest	Agriculture	Urban	TOTAL	% Forest	% Ag	% Urban	% Forest	% Ag	% Urban	Kg/Ha
Missisquoi												
02010007010010	8356	193	973	454	1620	11.9	60.1	28.0	84.2	6.8	3.1	0.19
02010007010020	17175	366	3639	1487	5492	6.7	66.3	27.1	79.1	12.3	5.0	0.32
02010007010030	11155	222	3067	1041	4331	5.1	70.8	24.0	72.3	17.7	5.3	0.39
02010007010040	14857	249	5825	1062	7136	3.5	81.6	14.9	64.3	27.9	4.2	0.48
02010007020010	7787	179	117	597	894	20.1	13.1	66.8	79.6	9.1	4.2	0.11
02010007020020	9888	251	81	607	940	26.7	8.7	64.6	86.0	4.8	3.4	0.10
02010007020030	10219	240	193	853	1287	18.7	15.0	66.3	80.3	11.4	4.6	0.13
02010007030010	2635	66	58	168	292	22.6	19.9	57.5	87.9	4.6	3.5	0.11
02010007030020	10536	283	96	495	874	32.4	11.0	56.6	89.9	4.6	2.5	0.08
02010007030030	15185	323	3990	1339	5652	5.7	70.6	23.7	73.4	16.3	4.8	0.37
02010007040010	5260	114	187	753	1054	10.8	17.8	71.4	70.8	18.1	7.5	0.20
02010007040020	11553	261	815	942	2017	12.9	40.4	46.7	74.8	17.5	4.3	0.17
02010007050010	14749	365	1360	637	2361	15.4	57.6	27.0	87.3	5.3	2.4	0.16
02010007050020	6899	154	1346	416	1916	8.1	70.3	21.7	80.0	11.4	3.4	0.28
02010007060010	7481	102	4591	821	5515	1.9	83.3	14.9	52.0	35.8	6.6	0.74
02010007060020	14968	302	3867	977	5147	5.9	75.1	19.0	76.5	15.5	3.9	0.34
02010007070010	14410	278	3722	919	4919	5.6	75.7	18.7	75.1	16.2	3.8	0.34
02010007070020	16695	228	8056	987	9270	2.5	86.9	10.6	60.1	29.5	3.9	0.56
02010007080010	5348	59	3747	417	4224	1.4	88.7	9.9	47.4	41.1	4.8	0.79
02010007080020	11533	129	6333	1216	7679	1.7	82.5	15.8	51.5	33.9	7.0	0.67
02010007080030	7317	50	3096	1146	4293	1.2	72.1	26.7	41.7	37.5	10.6	0.59
02010007090010	12032	116	14216	999	15331	0.8	92.7	6.5	42.0	46.6	5.2	1.27
02010007090020	2630	35	1608	264	1907	1.8	84.3	13.9	58.3	29.6	6.4	0.73
02010007100010	267	3	17	129	149	2.0	11.4	86.6	52.4	13.1	30.9	0.56
02010007110010	12939	228	7797	1201	9227	2.5	84.5	13.0	62.6	28.0	5.2	0.71
02010007110020	3656	39	3586	293	3919	1.0	91.5	7.5	45.3	30.5	4.8	1.07
02010007110030	12016	206	4554	956	5716	3.6	79.7	16.7	61.9	29.9	4.6	0.48
02010007110040	10962	146	6804	902	7853	1.9	86.6	11.5	51.4	40.3	4.9	0.72
02010007110050	7088	48	5625	699	6373	0.8	88.3	11.0	25.5	63.6	5.9	0.90
02010007110060	11513	97	8887	488	9472	1.0	93.8	5.2	31.7	61.7	2.5	0.82
02010007110070	8553	32	7540	654	8226	0.4	91.7	8.0	15.6	74.6	4.8	0.96
02010007120010	4810	24	1512	877	2413	1.0	62.6	36.4	20.4	61.3	11.7	0.50
Total	310469	5389	117310	24796	147495	3.7	79.5	16.8	64.4	25.8	4.7	0.48
Unknown												
00000000000099	451	9	3	0	12	71.2	28.1	0.6	95.0	1.8	0.0	0.03
TOTAL BASIN	2007709	33872	263463	175698	473033	7.2	55.7	37.1	66.9	17.2	5.5	0.24

table_412.xls

Note - Negative numbers found in some colums are expected given the introduction of animal unit correction data. For a full explaination, see Section 4.4.4.

LCBP Nonpoint Phosphorus Assessment

Figure 4.12 Phosphorus Loads for 14-Digit Hydrologic Units.
Loading Method - Regression Coefficients



Refer to Table 4.12 for total P load estimates
for individual hydrologic units.

4.3.7 Results Reported by Land Use Category

Following is a summary of the phosphorus contributions by land use category. For comparison, Budd/Meals estimates (1994) for low-end literature coefficients using the loading model are also provided.

Table 4.13: Phosphorus Loading by Land Use Category

Scenario	Load (mt/yr)	% Forest	%Agriculture	%Urban
Export Method	472	11.6	51.3	37.1
Loading Method	473	7.2	55.7	37.1
Budd/Meals (low-end lit. coeff)	457	15.9	66.0	18.0

The loading model shifts 4% of the loading burden from forests to agricultural land. Some of this might be explained by the influence of runoff which is a variable in the loading model. For both the export and loading models, the contributions of phosphorus from agricultural sources was considerably lower (10 to 15%) than those reported by Budd/Meals. Urban contributions were consistently higher than those reported by Budd/Meals. This in large part is due to the increased amount urban land use area between the 1974 GIRAS and 1993 land use data layers. Land use summaries for the Basin are found in Appendix 7.2.

4.4 Discussion

4.4.1 Comparison of Budd/Meals Modeling Methods to Those Used in This Study

The results received when comparing the new modeling methods to those used by Budd/Meals are expected. The export method uses only one parameter to calculate phosphorus loads. The difference in the Budd/Meals estimate and the new estimate is most likely due to the several factors. First, the 1974 GIRAS land use data used by Budd/Meals was stored as polygons. The data had to be converted from a polygon data layer to a grid with a 25-meter cell size. During the conversion from polygons to grid cells, some areas on the edge of polygons may have been re-coded. This "rounding error" is inevitable. The second and more likely cause of the difference is the one-mile discrepancy in the US/Quebec border. The GIRAS land use data stops at the Quebec border, but there is a discrepancy in the border shown in the GIRAS land use data. The hydrologic units data layer used by Budd/Meals did extend into Quebec. Since Budd/Meals results were reported by hydrologic unit, it is possible that part of a hydrologic units which spans across the border could have been attributed to Quebec. Lastly, in the Budd/Meals study, some small watersheds in Vermont could have been attributed to Quebec since a subjective method was used to assign watersheds along the border to either Quebec or Vermont.

The difference for the loading method is approximately 286,000 kg/yr which is much more significant than the differences using the export method. The differences mentioned above for export method also apply to the loading method. One factor causing a difference between the Budd/Meals estimate and the new estimate is due to change in methodology. This difference is expected. The methodology employed in this study used a precipitation surface generated from 57 long-term precipitation stations. Each of the approximately 34,000,000 cells in the precipitation surface has a unique value. In the Budd/Meals study, Theissen polygons were generated from 47 precipitation stations. All precipitation values within a Theissen polygon are the same. This creates just 47 unique precipitation values for the whole Basin. While Theissen polygons are an acceptable method of developing a precipitation data layer, using GIS to develop a precipitation surface is a well accepted practice and allows the user to generate a surface that probably better represents the precipitation distribution for the Basin.

Runoff coefficients for this study were different from Budd/Meals and were applied in a different manner. This probably played large role in creating the differences between the two estimates. In the current study, each cell received its own runoff value based on a land use category. Budd/Meals assigned runoff values to hydrologic units.

4.4.2 Comparison of Export and Loading Methods

In making estimates of P flux from landscapes such as the Lake Champlain Basin, the choice of the export or loading method is largely determined by data availability. The export method benefits from the simplicity of needed data and calculations. Reasonably current land cover data generalized to the very basic land use categories of agriculture, forest, or urban allows an estimate of P export from the land to be made. However, any annual fluctuations in precipitation and resultant stream water flow are not taken into consideration. This limitation diminishes the use of the export approach and prevents year to year estimates from being made. The particular loading method used in this report accounts for annual fluctuations in stream flow by incorporating the amount of precipitation received in the year to be included in the estimate. Thus for example, the possible consequences in a wet year of high P flux to a lake segment could be predicted. However, it is likely that a wet year would be characterized by extreme high flow events, which would probably require an adjustment of the volume-weighted concentration of total P, and thus altering loading coefficients.

In this study, both methods were calibrated to relevant data collected in 1991 (precipitation, streamflow, total P concentrations, and annual flux estimates). Thus, for that year, both estimates are equally appropriate. This does not hold true when using the long-term average precipitation value, because the 1991 base year had lower runoff (35.8 inches) than the long-term average year (38.5 inches). Thus, the long-term average P flux using the export method is slightly lower. For any specific year, the loading method probably provides a better estimate of the true flux of P to the Lake. These flux estimates are for the Lake Champlain Basin as a whole. Application of coefficients to individual sub-basins is probably not warranted unless the sub-basin is sufficiently large to reflect an average condition of agricultural practice and urban uses. With the scripts written in ArcView and available as part of this project (Appendix 7.4), it is easy to vary precipitation or coefficients and rerun the model to compare results.

4.4.3 Outlier Analysis

Perhaps the most useful application of either the export or the loading method of P flux estimation is the ability of these approaches to identify outliers when compared to empirical P flux data. In devising strategies for reducing diffuse P pollution, targeting smaller regions within the 8,200 square mile Basin permits a more efficient use of the limited resources allocated to diffuse pollution programs. Clear outliers on the high side (the equations under-predict the measured flux) may require special management programs and additional process-based studies in the field. However, success in diffuse P management in these areas may result in more important reductions of total P flux to the Lake.

4.4.4 Patterns of P Loading in the Lake Champlain Basin

When dealing with lake segments, it is important to know total phosphorus load because that load affects the individual section of the lake. The Missisquoi Bay segment contributes the most phosphorus, which is not surprising. This section of the lake is also relatively shallow, and phosphorus is likely to have a greater affect. The Otter Creek segment also contributes significant phosphorus to the lake. Since this segment of lake is relatively small and shallow, special attention may be warranted to reduce nonpoint phosphorus loading for this area of the Basin. The Main Lake segment also contributes significant phosphorus, but the Main Lake area of Lake Champlain is relatively large compared to some of the other areas.

Nonpoint phosphorus reported by hydrologic units is best expressed and understood on a per unit basis (kg/ha/yr) since land based strategies are used to reduce phosphorus in each hydro unit. On a per unit basis, the Missisquoi Bay and St. Albans Bay are noteworthy. Burlington Bay is also very high and this is explained by concentration of urban area. The hydrologic units around Barre and Montpelier also have high loads per unit area. This again is explained by the concentration of urban area. The whole Champlain Valley also has a high per unit phosphorus loading and is best explained by the high concentration of agricultural area.

The patterns of P loading differ very little between the export and loading models. The loading model predicts slightly higher phosphorus loading for the Basin, but overall this does not affect the overall patterns observed.

Some smaller 14-digit hydrologic units show negative P loading for the agricultural portion. This has to do with the way the model works and the introduction of animal unit correction data. The animal unit corrections are actually excess animal unit corrections. In some cases, such as in the Boquet, the excess animal units are a negative number meaning that the observed number of animals is less than the expected. This creates a negative excess animal unit correction. When this number is added to the phosphorus load for a cell, the total number for that cell becomes negative. When all the agricultural cells are summed, a negative number is displayed. It is important to note that the total phosphorus load (forest, agriculture, and urban) for any lake segment, or 14-digit hydrologic unit is not a negative number. The modeling approach used is a valid and reasonable approach with accepted procedures.

4.4.5 Land Use Data and Implications for its Use

As described in Section 4.3.1, there are differences in the composition of the 1993 land use data layer and the 1974 GIRAS land use data layer. This produces different predictions for phosphorus loading. Information is known about the methods of development and accuracy for the 1993 land use data. It is also more recent than the GIRAS data. For the purposes of this study, the 1993 land use data are considered a more reliable data source for the basis of predicting nonpoint phosphorus.

The 1993 land use data is not without problems. During this study, investigations were carried out on this land use data to check the accuracy and suitability. In order to do this, land use types were interpreted from 1995 digital orthophotos and compared to the 1993 land use types. Little Otter Creek watershed was picked for this comparison because it is the site of a similar phosphorus loading study. Figure 4.13 shows the percentage of each land use category from the digital orthophotos and the 1993 land use data sets. The percentage of agricultural land in the digital orthophotos land use layer is approximately 48 percent. The 1993 land use layer shows 47 percent agricultural land. Forested area summaries differ slightly between land use data layers, but none of the general categories show tremendous differences. This suggests that the 1993 land use data, when grouped in the broad categories of forest, agriculture and urban, is relatively accurate and suitable for use in this study.

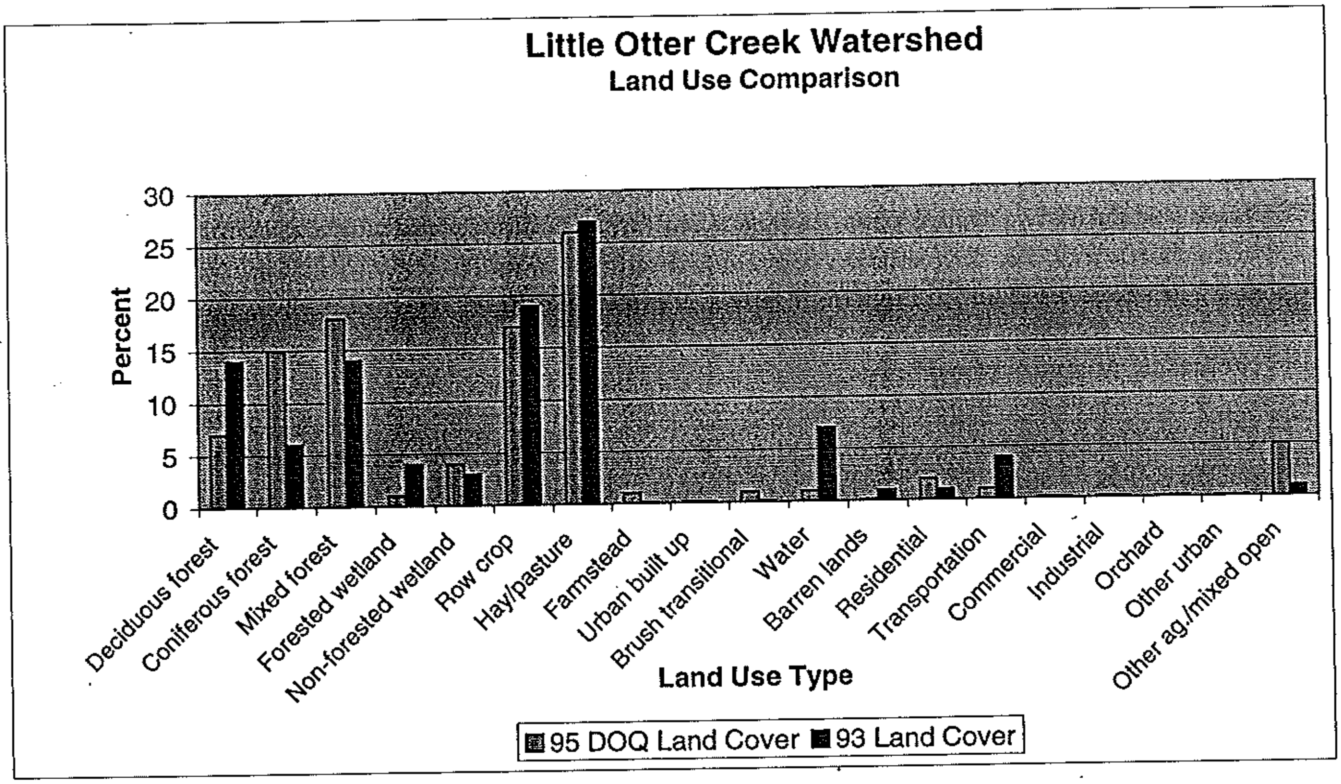


Figure 4.13
Nonpoint Phosphorus Export - Little Otter Creek

Figures 4.14 and 4.15 show the spatial distribution of each land use layer. It is important to note that the total area for each category of land use may be similar, but as Figures 4.14 and 4.15 show, the geographic distribution of land use types vary considerably between the 1993 land use data and the digital orthophoto land use data. For calculating general summaries by HU or watershed, this difference may not matter, but the differences will have an effect when proximity of agricultural land to water sources is considered as a factor in phosphorus runoff.

Developing detailed land use categories from digital orthophotos is desirable for detailed studies, but the cost may be prohibitive for an area the size of the Lake Champlain Basin.

Figure 4.14 - 1993 Land Use Data, Row Crop and Water Classification

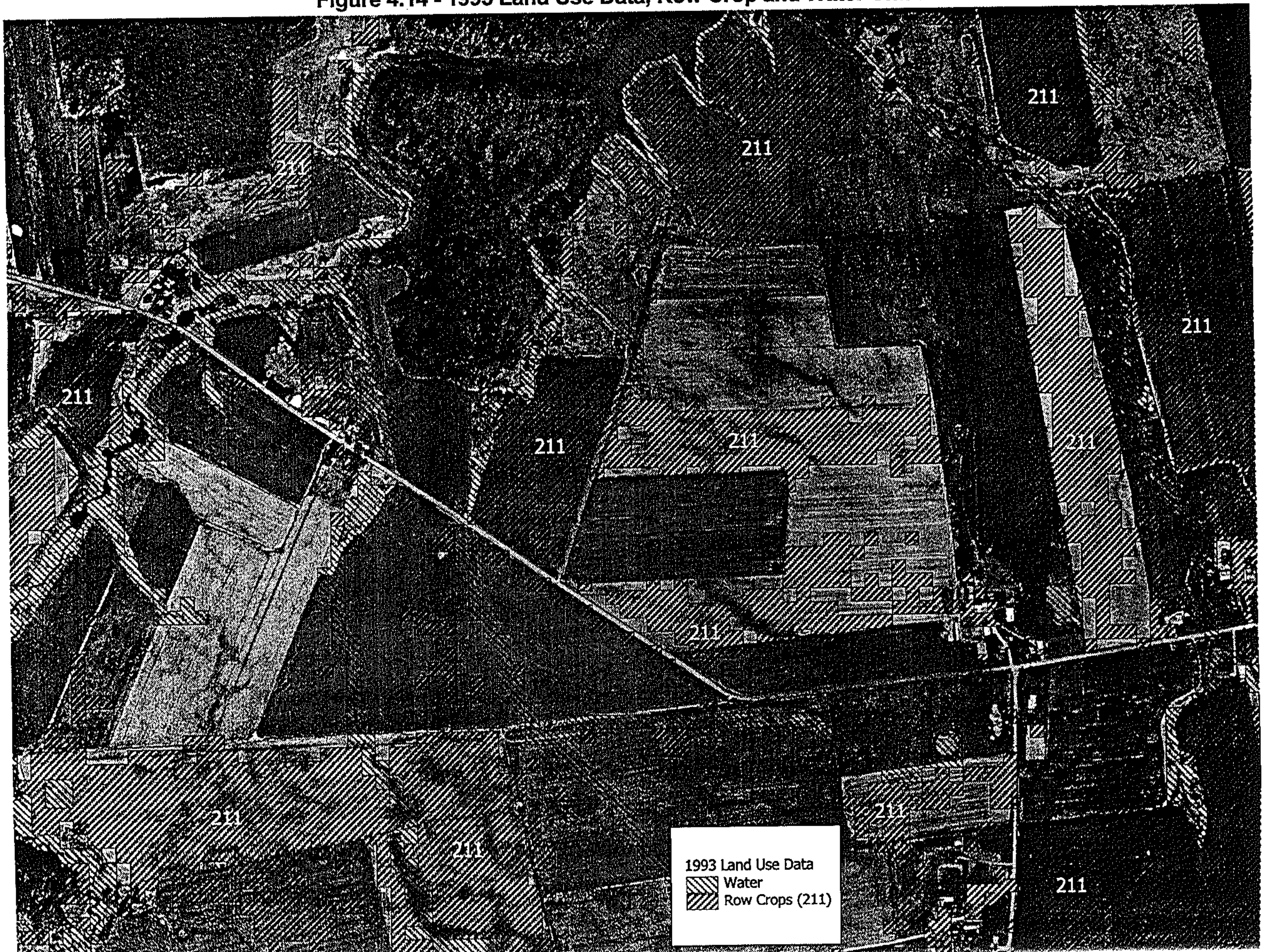
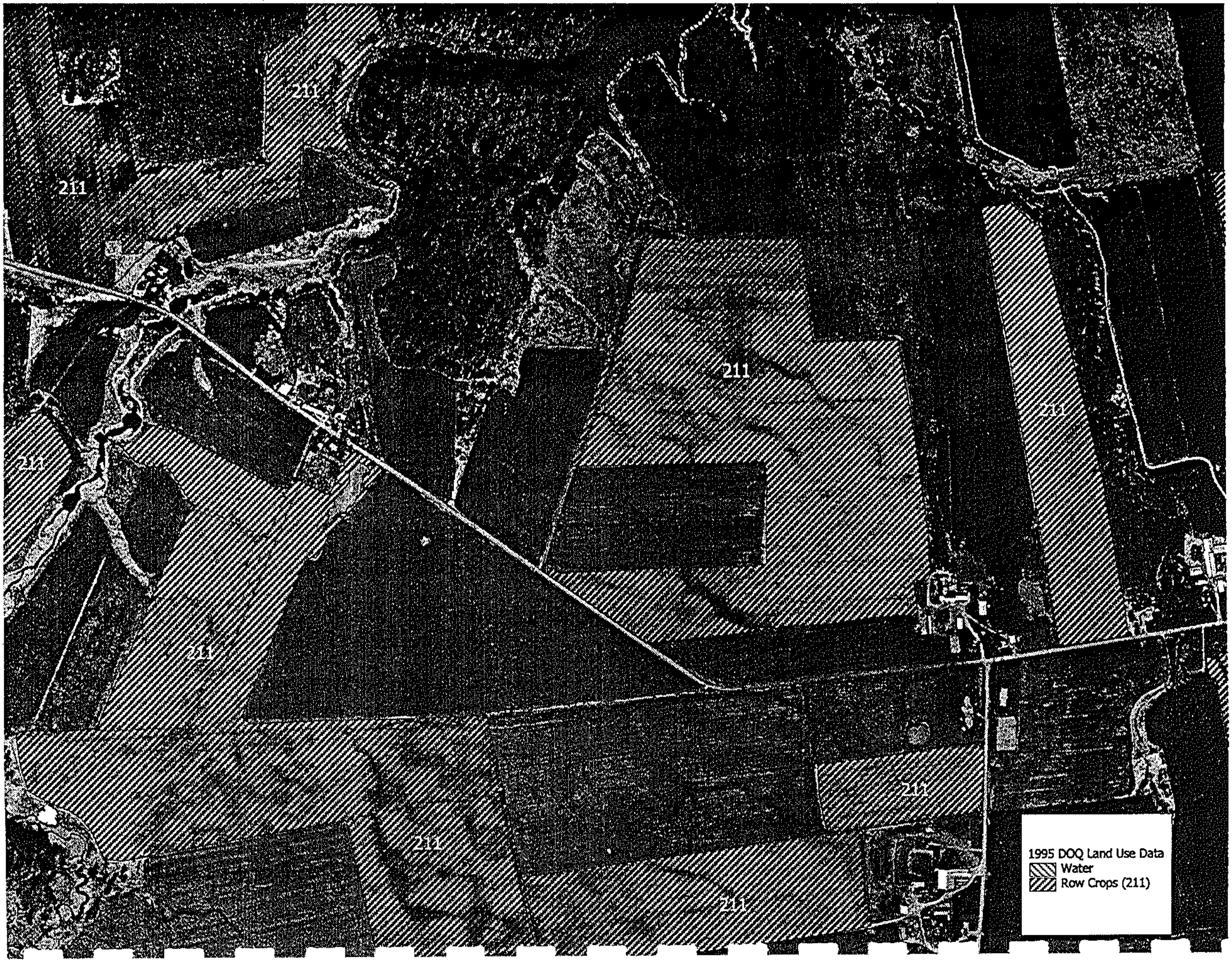


Figure 4.15 - 1995 DOQ Land Use Data, Row Crop and Water Classification



4.5 Summary and Conclusions

For any specific year, the loading method probably provides a better estimate of the true flux of P to the Lake primarily because of the introduction of runoff into the model. Given the available data for the Basin, this model can be easily updated and run to investigate the use of different coefficients or hydrologic conditions years. The current export and loading models require the input of animal unit data. If this data is not available, the models can still be run, but variable coefficients may be needed to account for outlier watersheds such as the Missisquoi, Rock, and Pike.

Phosphorus contributions from agricultural sources constitute approximately 55% of the total load to the Basin, thus efforts must be made to reduce this. Phosphorus contributions from urban sources are twice as high as reported by Budd/Meals in their 1994 report. This stems from the fact that the new land use data shows over twice as much urban land (5.5%) as the 1974 land use data (2.5%). The increase in urban contributions of nonpoint phosphorus within the Basin probably warrants more investigation and specific reduction measures since it is likely that urban land uses will continue to increase. In addition, urban land constitutes 5.5% of the land but contributes 37% of the phosphorus.

The application of the coefficients and the use of the 1993 land use data to individual sub-basins are probably not warranted unless the sub-basin is sufficiently large to reflect an average condition of agricultural practice and urban uses. The 1993 land use data is best used on a basin-wide scale and has limitations when applied to small sub-basins because of the inaccuracies in the geographic distribution of the land classification. It cannot be used confidently for proximity analysis.

The raster GIS analysis used in this study proves to be an excellent way to store data, analyze and summarizing the results.

5. Missisquoi Bay Studies

5.1 Introduction

As discussed in Section 3 in the comparison of watersheds within the Lake Champlain Basin, some watersheds were clearly different from the others in terms of flux and concentration of total phosphorus in surface waters. This difference was reflected in these watersheds being clear outliers in the regression analyses (Fig. 3.3). In particular, the Rock, Pike, and Missisquoi watersheds had higher fluxes of total P than would be expected given the area of the watersheds and their particular land use categories as recorded in the GIS database. All three watersheds drain into Missisquoi Bay. As a result of the measured differences in phosphorus flux discovered during the Diagnostic Feasibility Study (VT DEC, NYS DEC 1997), separate export and loading function coefficients were used to represent these watersheds in the respective models (see Section 3). In addition, available animal unit data were also used to help explain the outliers. In this section we evaluate the Missisquoi Bay watersheds based on animal units, tile drainage, and results of a brief synoptic sampling of small subwatersheds in the watershed.

5.2 Methods

5.2.1 Animal Unit and Tile Drainage Data Analyses

Animal unit data for the three Missisquoi Bay watersheds were requested from agencies in Vermont and Quebec. Vermont data were provided by the Vermont Department of Agriculture (Philip Benedict, pers. comm.) from collections made in the early 1990's. Data for Quebec were provided by Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (MAPAQ) from 1997 data collections (Pierre Beaudet, pers. email). If the numbers of animals in the watersheds exceeded that from other areas in the Basin, then this increased number of animals might explain the higher P export from these watersheds. In addition, if among the three watersheds (Rock, Pike, and Missisquoi), a greater density of animals was found on one versus the others, this also might correlate with differences in P flux among the watersheds. While a sample size of three will not permit any statistically reliable estimate of the animal unit contributions, it would be helpful in suggesting a possible cause of the differences and support additional data collection.

Tile drainage information for the three Missisquoi Bay watersheds was also requested from appropriate agencies in Vermont and Quebec. However, only tile drainage data for portions of the Canadian part of the Pike River watershed were obtained from the Ministère de l'Environnement et de la Faune du Quebec (Diagnostic Environnemental de la Rivière aux Brochets, Août 1994). No other tile drainage data were available for this study.

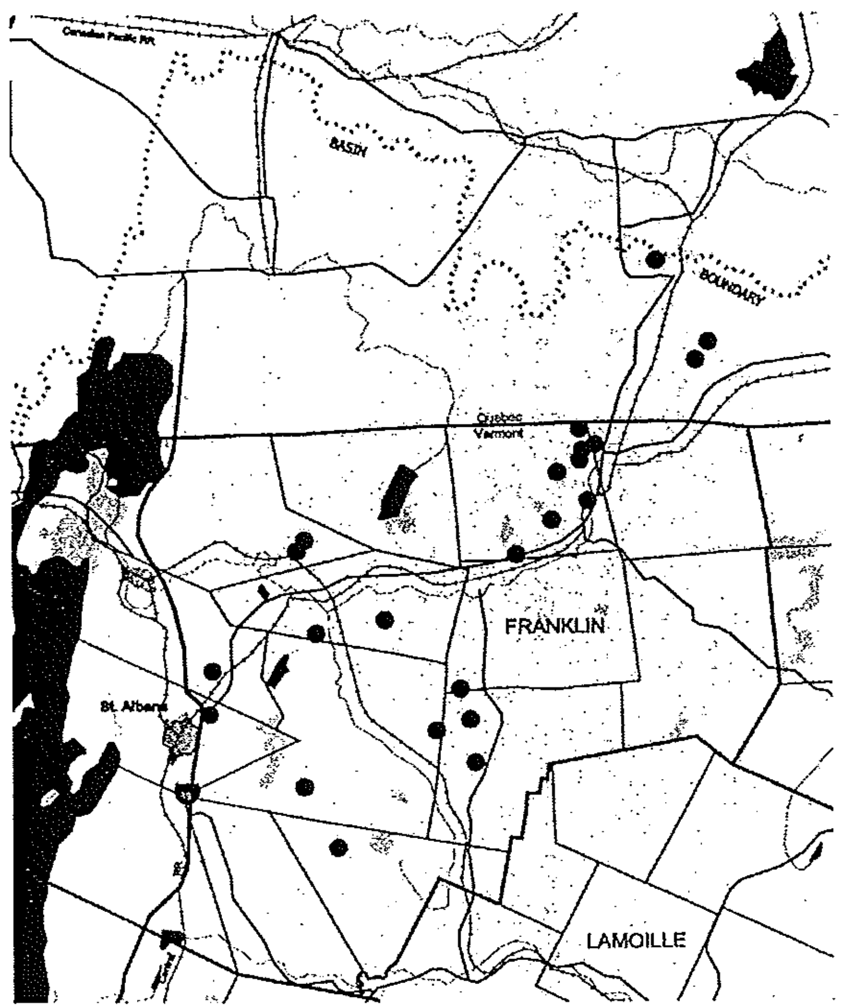
The possibility of different patterns and degree of tile drainage in the three watersheds would permit, as for animal unit data, a rough estimate of the potential for this land management practice to result in higher total P fluxes from these watersheds than for other watersheds in the Basin. Similarly, comparisons among the three watersheds could provide some clues to the degree of this tile drainage effect. Because the Rock watershed exports so much more P per unit area than the Pike and the Missisquoi watersheds, these watershed comparisons could provide a useful insight.

5.2.2 Synoptic Sampling

To provide some field data to suggest whether the patterns of P flux in the Missisquoi watershed were dramatically different from other watersheds, a synoptic study of stream water quality was conducted on two occasions in the spring and summer of 1998. The objective for this aspect of the study was to demonstrate the potential for using the existing loading coefficient procedure along with synoptic sampling at high flows, to characterize spatial and temporal patterns of P export at the small watershed scale. To accomplish this, we first characterized the total phosphorus and total suspended solid concentration of surface water collected from 20 subwatersheds within the Missisquoi Basin (Fig. 5.1).

Collections (1 April, 1998 and 26 August, 1998) were nearly synoptic on each sampling date, to allow comparison among sites and to view concentration patterns during spring and summer high flow events. These samples provided insight into the variability of P export from a variety of mixed land use subwatersheds, and allowed comparison with the patterns predicted by the previously used loading coefficient procedure (Budd and Meals 1994).

The sub-watersheds of each of the sample stations were manually delineated on USGS 7.5 minute topographic sheets and digitized into the GIS. Areas for each category found in the 1993 land use data was then summarized for each sub-watershed.



● = Synoptic sampling site

Figure 5.1: Synoptic Sampling

Total phosphorus (TP) was measured for each grab sample. In addition, samples were analyzed for total suspended solids (TSS) which is an important component of total phosphorus transport

(Hoffmann, et al. 1996). We chose to sample during a high flow event in the spring because these events have been documented to deliver a high percentage of the annual net input of phosphorus into Lake Champlain (Braun 1997). For our purposes, a high flow event was considered to occur when the mean daily (24 hr) flows at the Missisquoi gauging station at East Berkshire, VT were within the upper quartile of flow within the past five years of gauging station data. All samples on each collection date were collected within a 12-hour window of time (start-to-finish of sampling).

Site selection was based on the need to collect synoptic samples. Therefore, our strategy was to locate stream sampling sites in reasonable proximity to each other to reduce travel time, and to find sites easily accessible from the existing network of paved roads. In addition, because sites were located in both the U.S. and Canada, multiple international border crossings were avoided in order to minimize travel time. Sampled subwatersheds corresponded to first- or second-order streams and watersheds ranged from 10 to 1313 ha in size. This maintained an adequate size to insure a representative area of sampling, maximized the nonpoint emission signal from area sources, and minimized the contribution of in-stream pollutant loading or deposition. Subwatersheds were selected, based on these criteria, to cover a range of mixed land use categories from forest-dominated to agriculture-dominated. Subwatersheds with urban point sources were avoided.

Water collections included grab sampling only. Samples were placed into a cooler at the time of collection, and transferred to a refrigerator (4 C) upon return from the field until analysis. Grab samples for TP (50 ml) were collected into borosilicate glass digestion tubes to avoid sample transfer prior to digestion. TSS samples were collected in pre-washed 250 ml polyethylene bottles. Photographs were taken at each field site during the April collection.

For the 1 April 1998 sampling date, stream flow for a subset of the sites was estimated using current velocity and cross-sectional area of the stream at the point of sampling. Stream flow was measured using a portable flow meter (Flow Probe, Global Water, Inc.). Depth along an evenly-spaced, five-point stream transect and total width at the time of sampling were measured with a meter stick and tape to the nearest centimeter. The stream flow data were then combined with TP concentrations to calculate a TP flux.

TP samples were refrigerated and delivered to the VT DEC water quality laboratory as soon as possible after collection (within a week) for analysis. TP was analyzed using an automated colorimetric procedure following persulfate digestion (EPA 365.4) at the VT DEC Laboratory. TSS was analyzed via glass-fiber filtration, drying and gravimetric analysis (EPA 160.2).

Five percent of the samples were collected in duplicate and analyzed separately. Duplicate results were acceptable if the relative percent difference (RPD) was less than or equal to one-quarter of the mean value. Target precision of TP analyses is 0.030 mg/L. For TP, laboratory duplicates, blanks and spikes followed standard procedures of the VT DEC laboratory (Quality Assurance Plan for Long-Term Water Quality and Biological Monitoring Project for Lake Champlain, VT DEC, May 1997). Routine calibration of scales used for TSS analyses was conducted using Class S weights.

Regression analyses were based on use of concentration data (TP and TSS) as the dependent variable and percentage of land use in agriculture (AGR), forest (FOR), and urban use (URB) as independent variables. For the April sampling, flux data were used as the dependent variable for the 13 stations where flow data were possible to collect.

5.3 Results and Discussion

5.3.1 Tile Drainage and Animal Unit Data

Tile drainage data were only available for the Quebec portion of the Pike watershed. Given the lack of tile drainage data, it is impossible to make any predictions about how it affects phosphorus loading in the Basin at this time.

Animal unit data were available for both the Missisquoi Bay watersheds and the Lake Champlain Basin watersheds as a whole (Diagnostic Feasibility Study watersheds). Available animal unit data information were used to suggest that animal presence in these watersheds can account for the higher per unit area rates of P export (see Section 3).

A review of literature can suggest how much P each animal unit might contribute to the overall P flux into surface waters. Johnes et al. (1996), suggested that three percent of manure either applied to the land or directly voided to the land by cattle might enter surface waters. Assuming 20 kg of P is excreted per animal unit per year (Johnes et al. 1996), we can estimate a coefficient of 0.6 kg P/animal unit. Using another approach to approximating animal unit P export, Stewart (1997) suggested one AU/ha would correspond to a total P export rate of one kg/ha/yr. Other values reported by Johnes et al. (1996) suggest a range of unit area P export for various lands used for animal production (without reference to animal unit density). For cattle, reported values range from 7.65 to 17.6 kg/ha/yr for each animal unit. For pigs, this value is somewhat lower, 1.4 to 5.63 kg/ha/yr, and for sheep even lower, 1.47-1.8 kg/ha/yr. Values this high could clearly account for the per unit area differences in coefficients used for the Missisquoi Bay watersheds and the other watersheds. For example, the agricultural coefficient used for the Basin is 0.42 kg/ha/yr while the region-specific coefficients used for the Rock and the Pike/Missisquoi are 4.0 and 1.2 kg/ha/yr, respectively. Clearly, the range of values reported in the literature are high enough to account for this magnitude of differences even if only a small percentage of the land in the watershed is devoted to animal husbandry. For example, taking this animal export value as eight kg/ha/yr, only 10 percent of the land area needs to be devoted to this animal use to account for the 0.8 kg/ha/yr difference between the Pike and Missisquoi and the other watersheds.

The animal unit P coefficient can also be fitted to the observed P export data from the Diagnostic Feasibility Study. This can be done for the group of 30 watersheds as was done in Section 3, or for just the Missisquoi Bay watersheds. In this analysis we estimated 1.75 kg P/AU. Using the land area coefficients (AGR, FOR, URB) and then solving for the animal unit coefficient needed to fit the Diagnostic Feasibility Study P export for just the Missisquoi, Pike and Rock watersheds, we calculate an animal unit coefficient of 1.9 kg P/AU (Table 5.1). This animal unit coefficient is calculated on just the "excess" animal units for the watersheds, as we theoretically include animal activity in AGR coefficient when fitting this coefficient to the Lake Champlain Basin as a whole. The two estimates are fairly close, and we suggest that either could be used, depending on the context for their use (i.e., basin-wide vs. local application).

Table 5.1 P Export Model using Animal Units in Missisquoi Bay Watersheds
Coefficient - 1.75 kg P/AU

Watershed	Observed P (kg/yr)	Export Model and AU Excess Predicted Total	P from Excess AU	P from Export Model alone
Missisquoi	75100	74440	37143	37297
Pike	44400	48737	30288	18449
Rock	28900	17735	13761	3974

Animal unit data were divided into the US and Quebec portions for each of the three Missisquoi Bay watersheds (Table 5.2). US data reflected dairy cows and Quebec data included all animal production including, for example, ducks and chinchillas, but was also dominated by cows. In Vermont one animal unit (1 AU) is equal to 1000 lbs. of animal. In Quebec 1 AU = 500 kg of animal, yielding a rough conversion of: 1 VT AU = 0.91 Quebec AU. This equivalence is very rough relative to P production in manures.

Table 5.2 Distribution of Animal Units in Missisquoi Bay Watersheds

Watershed	US portion		Quebec portion	
	Animal Units (AU)	AU/ha	Animal Units (AU)	AU/ha
Missisquoi River	45,135 (agr = 30286 ha)	1.5	2,972 (agr = 6784 ha)	0.4
Pike River	7,900 (agr = 3144 ha)	2.5	31,074 (agr = 27144 ha)	1.1
Rock River	7,168 (agr = 3607 ha)	2.0	5,035 (agr = 2457 ha)	2.1

These data were separated by the US and Quebec portion to allow for appropriate allocation of animal units in the raster model used to calculate basin-wide P loading (Section 4).

5.3.2 Phosphorus Loading Results for the Missisquoi Bay Watersheds

Following are the predicted phosphorus loads for the Missisquoi Bay watersheds broken down by Vermont and Quebec portions. Included are results for the export and loading models. The animal unit P coefficients used for the export and loading models are 1.75 kg P/AU and 1.60 kg P/AU respectively. Tables 5.3, 5.4. 5.5. and 5.6 are followed by Table 5.7 which is a reference table for the 14-digit hydrologic units. Figure 5.2 shows the specific 14-digit hydrologic units for the Missisquoi Bay watersheds.

Table 5.3 Missisquoi Bay Watersheds - Vermont Portion

Load Estimate - Export Method, Regression Coefficients
with Excess Animal Unit Correction Applied

	Areal Export (kg/ha/yr) Forest	Ag	Urban
Coefficients	0.04	0.42	1.50

Hydrologic Unit		Pollution Load (kg/yr)				Source of NPS Load			Land Use			Area Load
Hu Number	Area (Ha)	Forest	Agriculture	Urban	Total	% Forest	% Ag	%Urban	% Forest	% Ag	%Urban	Kg/Ha
Missisquoi River												
02010007010010	8356	275	943	392	1609	17.1	58.6	24.3	82.3	6.5	3.1	0.19
02010007010020	17175	526	3536	1293	5355	9.8	66.0	24.1	76.6	11.9	5.0	0.31
02010007010030	10447	297	2936	825	4058	7.3	72.3	20.3	71.0	16.2	5.3	0.39
02010007010040	9292	193	5592	658	6443	3.0	86.8	10.2	52.0	34.8	4.7	0.69
02010007030010	1075	37	41	43	121	30.4	34.0	35.6	85.4	2.2	2.7	0.11
02010007030020	483	18	11	0	29	62.2	37.8	0.0	94.1	1.3	0.0	0.06
02010007030030	12728	356	3760	927	5044	7.1	74.6	18.4	69.9	17.1	4.9	0.40
02010007040020	443	4	437	47	487	0.8	89.7	9.5	21.9	56.9	7.0	1.10
02010007050010	14749	512	1311	542	2365	21.7	55.4	22.9	86.8	5.1	2.4	0.16
02010007050020	6899	218	1297	355	1870	11.7	69.4	19.0	79.0	10.9	3.4	0.27
02010007060010	7481	151	4503	737	5391	2.8	83.5	13.7	50.4	34.7	6.6	0.72
02010007060020	14968	446	3795	875	4824	9.2	78.7	18.1	74.4	14.6	3.9	0.32
02010007070010	14410	416	3670	833	4641	9.0	79.1	17.9	72.2	14.7	3.8	0.32
02010007070020	16695	374	8122	972	9144	4.1	88.8	10.6	55.9	28.1	3.9	0.55
02010007080010	5348	90	3703	382	4048	2.2	91.5	9.4	42.0	40.0	4.8	0.76
02010007080020	11533	212	6457	1210	7475	2.8	86.4	16.2	45.9	32.3	7.0	0.65
02010007080030	7317	84	3155	1159	4012	2.1	78.7	28.9	28.6	24.9	10.6	0.55
Total	159399	4207	53271	11249	66916	6.3	79.6	16.8	66.0	19.3	4.7	0.42
Rock River												
02010007090010	7620	103	8882	628	9613	1.1	92.4	6.5	33.8	44.1	5.5	1.26
02010007090020	1581	35	659	121	815	4.3	80.9	14.9	54.9	15.8	5.1	0.52
Total	9201	138	9541	749	10428	1.3	91.5	7.2	37.4	39.2	5.4	1.13
Pike River												
02010007110010	4286	87	5262	304	5653	1.5	93.1	5.4	50.8	34.5	4.7	1.32
02010007110020	3583	55	3715	263	4032	1.4	92.1	6.5	38.2	29.1	4.9	1.13
02010007110040	2307	50	2230	133	2413	2.1	92.4	5.5	54.5	27.1	3.8	1.05
Total	10176	192	11207	700	12098	1.6	92.6	5.8	47.2	30.9	4.6	1.19
Direct Drainage												
02010007100010	174	3	12	52	67	4.5	17.9	77.6	46.3	16.3	19.8	0.38
02010007120010	1	0	0	0	0	100.0	0.0	0.0	8.3	0.0	0.0	0.00
Total	175	3	12	52	67	4.5	17.9	77.6	46.2	16.2	19.7	0.38
TOTAL	178951	4540	74030	12749	89509	5.1	82.7	14.2	63.0	21.0	4.7	0.50

table_53.xls

Note - Negative numbers found in some colums are expected given the introduction of animal unit correction data. For a full explaination, see Section 4.4.4.

Table 5.4 Missisquoi Bay Watersheds - Quebec Portion

Load Estimate - Export Method, Regression Coefficients with Excess Animal Unit Correction Applied

	Areal Export (kg/ha/yr)		
	Forest	Ag	Urban
Coefficients	0.04	0.42	1.50

Hydrologic Unit		Pollution Load (kg/yr)				Source of NPS Load			Land Use			Area Load
Hu Number	Area (Ha)	Forest	Agriculture	Urban	Total	%Forest	%Ag	%Urban	%Forest	%Ag	%Urban	Kg/Ha
Missisquoi River												
02010007010030	708	16	-13	62	65	24.9	-20.5	95.6	57.3	27.3	5.9	0.09
02010007010040	5565	168	-55	282	395	42.6	-14.0	71.3	75.6	14.6	3.4	0.07
02010007020010	7787	245	-47	491	688	35.5	-6.9	71.4	78.5	8.8	4.2	0.09
02010007020020	9888	340	-33	498	805	42.2	-4.0	61.8	86.0	4.8	3.4	0.08
02010007020030	10219	327	-80	705	952	34.4	-8.4	74.1	80.1	11.4	4.6	0.09
02010007030010	1560	54	-6	96	143	37.4	-4.4	67.0	85.9	5.9	4.1	0.09
02010007030020	10052	361	-33	401	729	49.5	-4.5	55.0	89.7	4.7	2.7	0.07
02010007030030	2458	82	-14	163	230	35.5	-6.2	70.7	83.1	8.9	4.4	0.09
02010007040010	5260	149	-66	593	677	22.0	-9.7	87.7	70.8	18.1	7.5	0.13
02010007040020	11109	339	-106	700	934	36.3	-11.3	75.0	76.4	15.7	4.2	0.08
Total	64607	2081	-454	3993	5620	37.0	-8.1	71.0	80.5	10.5	4.1	0.09
Rock River												
02010007090010	4411	77	5740	315	6132	1.3	93.6	5.1	43.6	47.3	4.8	1.39
02010007090020	1050	20	1000	131	1151	1.8	86.9	11.3	48.2	35.0	8.3	1.10
Total	5461	97	6740	446	7284	1.3	92.5	6.1	44.4	45.0	5.4	1.33
Pike River												
02010007110010	8652	231	2436	711	3378	6.8	72.1	21.0	66.7	24.1	5.5	0.39
02010007110020	73	3	0	0	3	100.0	0.0	0.0	100.0	0.0	0.0	0.04
02010007110030	12016	294	4178	822	5294	5.5	78.9	15.5	61.1	29.8	4.6	0.44
02010007110040	8655	167	4354	679	5199	3.2	83.7	13.1	48.2	43.1	5.2	0.60
02010007110050	7088	72	5261	631	5965	1.2	88.2	10.6	25.5	63.6	5.9	0.84
02010007110060	11513	141	8294	435	8871	1.6	93.5	4.9	30.7	61.7	2.5	0.77
02010007110070	8553	49	7153	610	7812	0.6	91.6	7.8	14.4	71.6	4.8	0.91
Total	56549	957	31676	3888	36522	2.6	86.7	10.6	42.3	48.0	4.6	0.65
Direct Drainage												
02010007100010	93	2	1	71	74	2.1	2.0	95.9	40.0	3.9	52.2	0.80
02010007120010	4810	39	1191	841	2072	1.9	57.5	40.6	19.9	59.0	11.7	0.43
Total	4903	41	1193	912	2146	1.9	55.6	42.5	20.3	58.0	12.4	0.44
TOTAL	**131519**	**3176**	**39156**	**9239**	**51571**	**6.2**	**75.9**	**17.9**	**60.3**	**29.8**	**4.7**	**0.39**

table_54.xls

Note - Negative numbers found in some colums are expected given the introduction of animal unit correction data. For a full explaination, see Section 4.4.4.

Table 5.5 Missisquoi Bay Watersheds - Vermont Portion

Load Estimate - Loading Method, Regression Coefficients with Excess Animal Unit Corrections Applied

	Runoff Concentrations (mg/l)		
	Forest	Ag	Urban
Coefficients	0.005	0.07	0.16

Hydrologic Unit		Pollution Load (kg/yr)				Source of NPS Load			Land Use			Area Load
Hu Number	Area (Ha)	Forest	Agriculture	Urban	Total	% Forest	% Ag	%Urban	% Forest	% Ag	%Urban	Kg/Ha
Missisquoi River												
02010007010010	8356	193	973	454	1620	11.9	60.1	28.0	82.3	6.5	3.1	0.19
02010007010020	17175	366	3639	1487	5492	6.7	66.3	27.1	76.6	11.9	5.0	0.32
02010007010030	10447	211	3037	967	4214	5.0	72.1	22.9	71.0	16.2	5.3	0.40
02010007010040	9292	130	5703	730	6563	2.0	86.9	11.1	52.0	34.8	4.7	0.71
02010007030010	1075	27	43	52	121	22.0	35.4	42.6	85.4	2.2	2.7	0.11
02010007030020	483	13	12	0	25	53.5	46.5	0.0	94.1	1.3	0.0	0.05
02010007030030	12728	262	3949	1136	5346	4.9	73.9	21.2	69.9	17.1	4.9	0.42
02010007040020	443	3	464	58	525	0.6	88.3	11.1	21.9	56.9	7.0	1.18
02010007050010	14749	365	1360	637	2361	15.4	57.6	27.0	86.8	5.1	2.4	0.16
02010007050020	6899	154	1346	416	1916	8.1	70.3	21.7	79.0	10.9	3.4	0.28
02010007060010	7481	102	4591	821	5515	1.9	83.3	14.9	50.4	34.7	6.6	0.74
02010007060020	14968	302	3867	977	5147	5.9	75.1	19.0	74.4	14.6	3.9	0.34
02010007070010	14410	278	3722	919	4919	5.6	75.7	18.7	72.2	14.7	3.8	0.34
02010007070020	16695	228	8056	987	9270	2.5	86.9	10.6	55.9	28.1	3.9	0.56
02010007080010	5348	59	3747	417	4224	1.4	88.7	9.9	42.0	40.0	4.8	0.79
02010007080020	11533	129	6333	1216	7679	1.7	82.5	15.8	45.9	32.3	7.0	0.67
02010007080030	7317	50	3096	1146	4293	1.2	72.1	26.7	28.6	24.9	10.6	0.59
Total	159399	2872	53939	12419	69229	4.1	77.9	17.9	66.0	19.3	4.7	0.43
Rock River												
02010007090010	7620	66	8639	663	9368	0.7	92.2	7.1	33.8	44.1	5.5	1.23
02010007090020	1581	22	639	127	787	2.8	81.1	16.1	54.9	15.8	5.1	0.50
Total	9201	88	9277	790	10155	0.9	91.4	7.8	37.4	39.2	5.4	1.10
Pike River												
02010007110010	4286	61	5109	351	5521	1.1	92.5	6.4	50.8	34.5	4.7	1.29
02010007110020	3583	37	3586	293	3916	0.9	91.6	7.5	38.2	29.1	4.9	1.09
02010007110040	2307	34	2150	147	2330	1.4	92.3	6.3	54.5	27.1	3.8	1.01
Total	10176	132	10846	791	11768	1.1	92.2	6.7	47.2	30.9	4.6	1.16
Direct Drainage												
02010007100010	174	2	15	54	71	2.8	21.0	76.2	46.3	16.3	19.8	0.41
02010007120010	1	0	0	0	0	100.0	0.0	0.0	8.3	0.0	0.0	0.00
Total	175	2	15	54	71	2.8	21.0	76.2	46.2	16.2	19.7	0.41
TOTAL	178951	3093	74077	14054	91223	3.4	81.2	15.4	63.0	21.0	4.7	0.51

table_55.xls

Note - Negative numbers found in some colums are expected given the introduction of animal unit correction data. For a full explaination, see Section 4.4.4.

Table 5.6 Missisquoi Bay Watersheds - Quebec Portion

Load Estimate - Loading Method, Regression Coefficients with Excess Animal Unit Corrections Applied

	Runoff Concentrations (mg/l)		
	Forest	Ag	Urban
Coefficients	0.005	0.07	0.16

Hydrologic Unit		Pollution Load (kg/yr)				Source of NPS Load				Land Use		Area Load
Hu Number	Area (Ha)	Forest	Agriculture	Urban	Total	%Forest	%Ag	%Urban	%Forest	%Ag	%Urban	Kg/Ha
Missisquoi												
02010007010030	708	12	30	74	116	10.1	26.2	63.8	57.3	27.3	5.9	0.16
02010007010040	5565	119	122	331	573	20.8	21.3	57.9	75.6	14.6	3.4	0.10
02010007020010	7787	179	117	597	894	20.1	13.1	66.8	78.5	8.8	4.2	0.11
02010007020020	9888	251	81	607	940	26.7	8.7	64.6	86.0	4.8	3.4	0.10
02010007020030	10219	240	193	853	1287	18.7	15.0	66.3	80.1	11.4	4.6	0.13
02010007030010	1560	39	15	116	171	23.0	8.9	68.1	85.9	5.9	4.1	0.11
02010007030020	10052	269	85	495	849	31.7	10.0	58.3	89.7	4.7	2.7	0.08
02010007030030	2458	61	41	203	306	20.1	13.5	66.4	83.1	8.9	4.4	0.12
02010007040010	5260	114	187	753	1054	10.8	17.8	71.4	70.8	18.1	7.5	0.20
02010007040020	11109	258	351	883	1492	17.3	23.5	59.2	76.4	15.7	4.2	0.13
Sub Total	64607	1543	1224	4913	7680	20.1	15.9	64.0	80.5	10.5	4.1	0.12
Rock River												
02010007090010	4411	50	5578	336	5964	0.8	93.5	5.6	43.6	47.3	4.8	1.35
02010007090020	1050	13	969	138	1120	1.2	86.6	12.3	48.2	35.0	8.3	1.07
Sub Total	5461	63	6547	474	7083	0.9	92.4	6.7	44.4	45.0	5.4	1.30
Pike River												
02010007110010	8652	167	2688	850	3706	4.5	72.5	22.9	66.7	24.1	5.5	0.43
02010007110020	73	2	0	0	2	100.0	0.0	0.0	100.0	0.0	0.0	0.03
02010007110030	12016	206	4554	956	5716	3.6	79.7	16.7	61.1	29.8	4.6	0.48
02010007110040	8655	113	4654	756	5523	2.0	84.3	13.7	48.2	43.1	5.2	0.64
02010007110050	7088	48	5625	699	6373	0.8	88.3	11.0	25.5	63.6	5.9	0.90
02010007110060	11513	97	8887	488	9472	1.0	93.8	5.2	30.7	61.7	2.5	0.82
02010007110070	8553	32	7540	654	8226	0.4	91.7	8.0	14.4	71.6	4.8	0.96
Sub Total	56549	665	33948	4404	39017	1.7	87.0	11.3	42.3	48.0	4.6	0.69
Direct Drainage												
02010007100010	93	1	2	75	78	1.3	2.4	96.3	40.0	3.9	52.2	0.84
02010007120010	4810	24	1512	877	2413	1.0	62.6	36.4	19.9	59.0	11.7	0.50
Sub Total	4903	25	1514	952	2491	1.0	60.8	38.2	20.3	58.0	12.4	0.51
TOTAL	**131519**	**2296**	**43233**	**10742**	**56272**	**4.1**	**76.8**	**19.1**	**60.3**	**29.8**	**4.7**	**0.43**

table_56.xls

Note - Negative numbers found in some colums are expected given the introduction of animal unit correction data. For a full explaination, see Section 4.4.4.

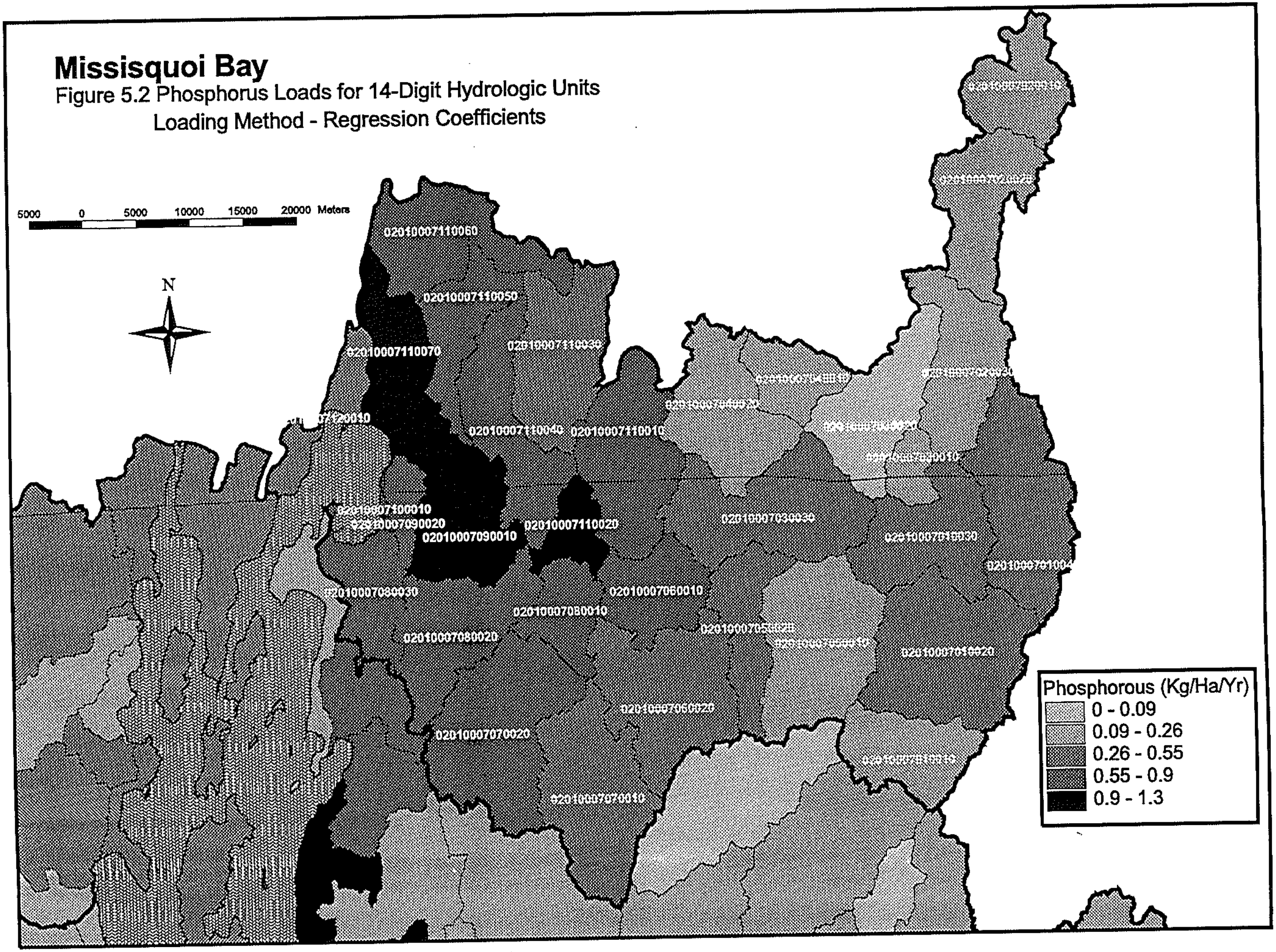
Table 5.7 Missisquoi Bay Watersheds - Hydrologic Unit Reference Table

Hu Number	Code 8	Code 11	Code 14	Quebec Code	Watershed Name
Missisquoi River					
02010007010010	02010007	-010	+010		Missisquoi River: headwaters to confluence with McAllister Pond drainage
02010007010020	02010007	-010	+020		Missisquoi River: confluence McAllister Pond drainage to confluence Coburn Brook
02010007010030	02010007	-010	+030	02010007100010	Missisquoi River: confluence with Coburn Brook to conflunce/North Missisquoi R.
02010007010040	02010007	-010	+040	02010007100010	Mud Creek: headwaters to mouth
02010007020010	02010007	-020	+010	02010007080010	North Missisquoi R.:headwaters to confluence w/unnamed trib south of Lac dArgent
02010007020020	02010007	-020	+020	02010007080010	North Missisquoi R.:confluence/unnamed trib to confluence/Ruisseau de West Field
02010007020030	02010007	-020	+030	02010007090010	North Missisquoi R.:confluence/Ruisseau de West Field to mouth
02010007030010	02010007	-030	+010	02010007100010	Missisquoi River: confluence/North Missisquoi R. to confluence/Ruisseau Ruiter
02010007030020	02010007	-030	+020	02010007120010	Missisquoi River: confluence/Ruisseau Ruiter to confluence/Ruiss Davis
02010007030030	02010007	-030	+030	02010007120010	Missisquoi River: confluence/Ruiss Davis to confluence/Trout River
02010007030030	02010007	-030	+030	02010007110020	Missisquoi River: confluence/Ruiss Davis to confluence/Trout River
02010007040010	02010007	-040	+010	02010007110010	Sutton River: headwaters to confluence/unnamed trib southwest of Ville de Sutton
02010007040020	02010007	-040	+020	02010007110010	Sutton River: confluence/unnamed trib southwest of Ville de Sutton to mouth
02010007050010	02010007	-050	+010		Trout River from headwaters to confluence with Black Falls Brook
02010007050020	02010007	-050	+020		Trout R. from confluence Black Falls Bk to confluence Missisquoi River
02010007060010	02010007	-060	+010		Missisquoi River: confluence with Trout River to confluence Tyler Branch
02010007060020	02010007	-060	+020		Tyler Branch: headwaters to mouth
02010007070010	02010007	-070	+010		Black Creek: headwaters to confluence Fairfield River
02010007070020	02010007	-070	+020		Black Creek: confluence Fairfield River to mouth
02010007080010	02010007	-080	+010		Missisquoi River: confluence Tyler Branch to confluence Black Creek
02010007080020	02010007	-080	+020		Missisquoi River: confluence Black Creek to confluence Hungerford Brook
02010007080030	02010007	-080	+030		Missisquoi River: confluence Hungerford Brook to mouth
Rock River					
02010007090010	02010007	-090	+010	02010007180010	La Roche River (Rock R.):headwaters to Saint-Armand Station
02010007090020	02010007	-090	+020	02010007180010	La Roche River (Rock R.):Saint-Armand Station to mouth
Pike River					
02010007110010	02010007	-110	+010	02010007130010	Aux Brochets River (Pike River):headwaters to confluence/Ruisseau Leavitt
02010007110020	02010007	-110	+020	02010007130010	Lake Carmi outflow to confluence with Aux Brochets River (Pike River)
02010007110030	02010007	-110	+030	02010007130010	Aux Brochets R. (Pike R.):confluence Ruisseau Leavitt to confluence/N. Aux Brochets R
02010007110040	02010007	-110	+040	02010007140010	Aux Brochets R. (Pike R.):confluence/N. Aux Brochets R. to confluence/? (in Bedford)
02010007110050	02010007	-110	+050	02010007150010	Aux Brochets R. (Pike R.):confluence/? (in Bedford) to confluence/Ruisseau Morpions
02010007110060	02010007	-110	+060	02010007160010	Ruisseau Morpions:headwaters to mouth
02010007110070	02010007	-110	+070	02010007170010	Aux Brochets R. (Pike R.):confluence/Ruisseau Morpions to mouth
Direct Drainage					
02010007100010	02010007	-100	+010	02010007180010	Lake Champlain direct drainage
02010007120010	02010007	-120	+010	02010007190010	Lake Champlain direct drainage

table_57.xls

Missisquoi Bay

Figure 5.2 Phosphorus Loads for 14-Digit Hydrologic Units
Loading Method - Regression Coefficients



5.3.3 Water Quality and Land Use Relationships

TP flux data were available for only a subset of the total number of grab sample sites. Regressions from this restricted set of data provided no significant relationships.

Concentrations of TP and TSS in grab samples collected on 1 April and 26 August were generally lower than the predicted volume-weighted average concentrations resulting from the regression analyses (Section 3). One clear outlier with very high TP concentrations came from a drainage leading from an animal feeding area. This high variability, if characteristic of the pattern of flux from these watersheds, makes accurate average coefficients difficult to establish. High concentrations were generally consistent from the April to the August sampling (Fig. 5.3). However, the bulk of the samples from the measured subwatersheds were low in TP. Relationships among concentrations of TSS and TP were not strong for either sampling date, especially for the samples with lower concentrations of TP (Fig. 5.4a/b). This suggests a variety of different phosphorus transport processes may be operational during the time of sampling.

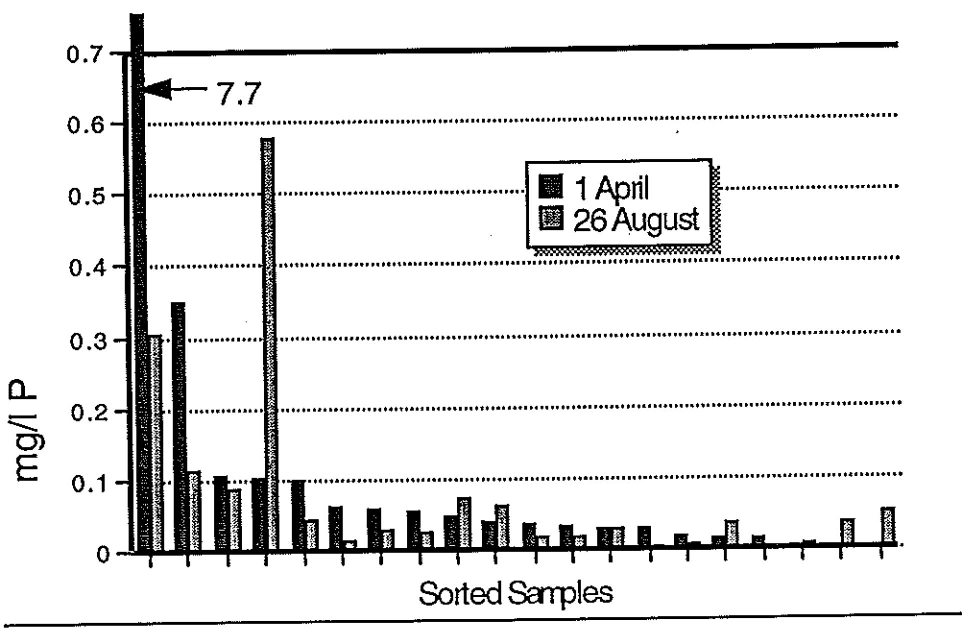


Figure 5.3 Comparison of TP (mg/l) between samples collected 1 April and 26 August 1998 in the Missisquoi Watershed. Sample stations are sorted from highest to lowest for the 1 April sampling date.

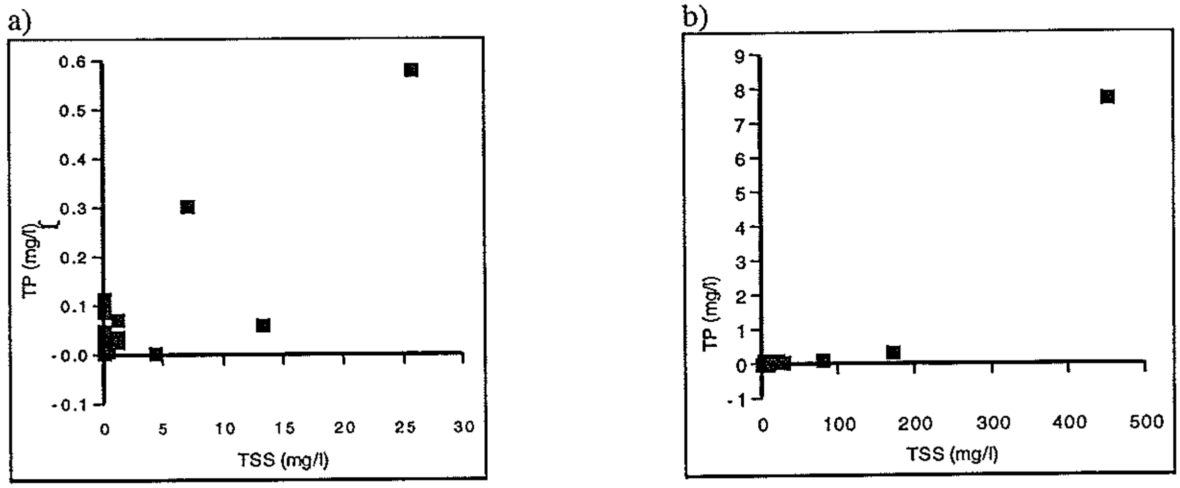


Figure 5.4 Correlation of TSS and TP for 1 April 1998 samples (a) and 26 August 1998 samples (b).

Using land use data to explain the pattern of TP or TSS concentrations for the 1 April 1998 sample date did not yield significant regressions. Land use, as an explanatory variable for both TSS and TP, produced no relationships with an r-square greater than 0.30. The samples fell into two groups -- samples with TP concentrations less than or greater than 0.10 mg/l P (see Fig. 5.3). The lower concentration samples showed little relationship to any land use category combinations. While the above 0.10 mg/l P samples generally came from subwatersheds with a higher percentage of the land area in agriculture, the variability was quite high and there were only five sample sites to analyze in this category. Thus no important relationship was detectable.

For the 1 April sampling date, phosphorus flux (TP g/sec) for 14 stations was available in conjunction with stream flow measurements. No significant regressions with AGR, FOR, or URB were found with the TP flux data.

The TSS samples for 26 August 1998 were less useful because a large proportion of them had concentrations less than the detection limit. Excluding these samples and then running regression analyses yielded no significant models despite r-square values being greater than 0.5 for some models. This is due to the small sample size (n=8). In contrast, regression of TP on land use type showed significant relationships taking all samples or just those with detectable TSS. Using all 18 stations for the August sampling resulted in an r-square of 0.58 for a regression model including AGR, FOR, and URB land areas. Thus more than half the variation in TP concentration from station to station is "explainable" using rough categories of land use category. The coefficients for AGR (0.126) and FOR (0.098) were highly statistically significant (alpha < 0.01). If we limit the analyses to only those samples with detectable TSS, which focuses on sediment-bound TP from surface erosion processes, the extent of the relationship increases. Again using all three land use categories, the r-square increases to 0.89 and the AGR (0.064) and the FOR (0.056) coefficients remain statistically significant (alpha < 0.10), despite the much smaller sample size (n = 8).

Because land areas (AGR, FOR, URB) were used to explain concentrations of TP in event grab samples, the magnitude of the coefficients is relatively meaningless in this context. However, the goal was to assess the importance of land use category in potentially influencing P export, and to compare the importance of different land use types. Consistent with the annual TP export data (see Section 3), the agricultural and forest land use categories are apparently important factors in determining TP export. This is the expected result. However, the closeness of the estimated coefficients is a bit surprising. In the annual regression models based on the 27 US watersheds, a hectare of agricultural land yields about 10 times the TP as a hectare of forested land, whether using an export model or a loading model. For the Missisquoi, the grab sample data suggest that this ratio is closer to 1:1. This suggests that under the conditions of the two synoptic samples, either the agriculture land produces relatively less phosphorus in runoff than in the other 27 watersheds or the forest produces more. Extrapolating this result to an annually-based coefficient seems unwarranted at this time.

5.4 Conclusions

Estimated phosphorus export from field sampling in the Diagnostic Feasibility Study (VT DEC, NYS DEC 1997) point out the higher unit area export of TP from the three northern watersheds draining into the Missisquoi Bay. Table 5.8 provides a summary. Without looking to extensive new data collection, clues from existing data and short-term synoptic surveys were used to try to understand this difference. Animal unit data suggest that higher than typical animal densities may account for the elevated unit area TP export in this region of the Lake Champlain Basin. Tile drainage data were severely limited and could provide no additional clues to the difference. Two synoptic surveys during high flows in April and August of 1998 suggest that agricultural and forested land use categories dominate the TP export phenomenon. These data suggest that forest land or forest practice in this region may also be linked to higher than typical unit area TP export rates at certain times of the year. Given the extent of and type of data available for the Missisquoi Bay watershed, we suggest that animal unit data provide the best explanation at this time for the higher than normal P export from these watersheds.

Table 5.8 Summary: Missisquoi Bay Watersheds Phosphorus Contributions

	Area (ha)	Export Method (kg/yr)	Loading Method (kg/yr)
Vermont Portion	178951	89509	91223
Quebec Portion	131519	51571	56272

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