Vermont Water Resources and Lake Studies Center Annual Technical Report FY 2003

Introduction

Attached is the Fiscal Year 2003 Annual Report for the Vermont Water Resources and Lake Studies Center. The grant, awarded under the State Water Resources Research Institute Program, is numbered 1434-HG-96-GR-02702.

Research Program

The 2004 Vermont Water Resources and Lake Studies program has featured two research projects. "Water quantity and quality dynamics in high-elevation watersheds: developing a scientific approach to understanding ski area impacts in Vermont" by Wemple et al. has used a paired watershed approach on the eastern slopes of Mt. Mansfield. Team scientists have detected a distinct difference in runoff volume and water quality between developed and undeveloped watersheds. Empirical relationships between discharge and solute concentrations have been established in order to estimate annual loads. The team has also used principal components analysis to explore the variability among the full suite of solutes and to explore the seasonal chemical signals associated with runoff events. Research results will be useful to state regulators responsible for maintaining the quality of Vermont’s high elevation streams. This project is being completed.

In "Detection of cyanobacterial blooms using remote sensing," Levine et al. are experimenting with the use of satellite imagery to detect the presence and extent of blooms of blue-green algae in Lake Champlain and other Vermont lakes. Researchers are using images taken by the commercial European satellite SPOT to detect and characterize algal blooms from space. In addition the European satellite ENVISAT with its MERIS detector is being used for smaller lakes and bays. This research is funded for an additional year, with continued ground-truthing of images planned.

In addition to the oversight of these two projects, the Water Center continues to publish its newsletter in collaboration with the university’s Sea Grant program. It also continues to play a leadership role in evolving strategies for managing watersheds and storm water runoff in Vermont. The Director hosted an October 2003 workshop focused on engaging communities in storm water issues and is administering a USEPA-funded project on storm water runoff in the local area.

Water quantity and quality dynamics in high-elevation watersheds: Developing a scientific approach to understanding ski area impacts in Vermont

Basic Information

Title:	Water quantity and quality dynamics in high-elevation watersheds: Developing a scientific approach to understanding ski area impacts in Vermont
Project Number:	2002VT1B
Start Date:	3/1/2002
End Date:	2/28/2004
Funding Source:	104B
Congressional District:	First
Research Category:	Not Applicable
Focus Category:	Hydrology, Water Quality, Models
Descriptors:	
Principal Investigators:	Beverley Wemple, Donald Ross, James Shanley

Publication

1. Wemple, B. C. 2003. Water quality and quantity in high-elevation watersheds: developing a scientific approach to understanding ski area impacts in Vermont. Vermont Water Resources and Lake Studies Center, Annual Meeting, October, Burlington, VT.
2. Wemple, B. C., J. B. Shanley, and S. Waichler, 2003. Forest disturbance through alpine ski area development: results of a paired watershed study in the Northeastern U.S. American Geophysical Union, Fall Meeting, December, San Francisco, CA.
3. Wemple, B., J. Shanley, and J. Denner. 2004. Effects of an alpine ski resort on hydrology and water quality in the Northeastern U.S.: preliminary findings from a field study (poster). Vermont EPSCoR Program, Annual Meeting, March, Burlington, VT.
4. Mills, K. 2004. Understanding the spatial variability of snow water equivalent on Mt. Mansfield, Stowe, VT. Vermont Geological Society Spring Meeting, April, Middlebury, VT.
5. Zinni, B., B. Wemple, J. Shanley, and A. Lini. 2004. Using streamwater chemistry in flowpath analysis of large-scale forested watersheds near Stowe, VT. American Geophysical Union, Spring Meeting, May, Montreal, Quebec, Canada.
6. Mills, K. 2004. Understanding the spatial variability of snow water equivalent on Mount Mansfield,

Stowe, Vermont. Unpublished senior research project, Dept. of Geography, University of Vermont.

Water quantity and quality dynamics in high-elevation watersheds:
Developing a scientific approach to understanding ski area impacts in Vermont

Annual Progress Report for the period

March 2003 – March 2004

Submitted to:
Vermont Water Resources and Lake Studies Center
University of Vermont
Burlington, VT 05405

by:
Beverley C. Wemple, Principal Investigator
Dept. of Geography
University of Vermont
Burlington, VT 05405

Introduction and Project Objectives

Activities associated with the development and operation of alpine ski areas, including forest clearing, development of impervious surfaces, and snowmaking, represent distinct impacts in the mountain environment. Cleared and impervious surfaces alter the quantity and quality of runoff reaching stream channels. Snowmaking operations reduce instream flows and alter the dynamics of snow accumulation and melt. The nature of land development activities associated with alpine resort operations and the temporal persistence of their effects may differ from those imposed by traditional forest harvesting operations, which have been the subject of substantial scientific research. Despite the rather widespread persistence of this land use activity -- roughly 326 U. S. alpine ski resorts belong to the National Ski Areas Association (NSAA, 2003) -- few scientific studies have examined the effects of alpine ski area development and operations on water quality and quantity. This project seeks to combine the approaches of paired-watershed studies and simulation modeling to assess the impacts of ski area operations on watershed processes in two high-elevation watersheds in Vermont. The objectives of the research include:

1. To collect baseline data on streamflow, sediment transport and water quality, using a paired-watershed approach, to examine current and potential future effects of ski area development and operations.

2. To use simulation modeling to assess the impacts of existing operations and proposed future development on the magnitude and timing of runoff from the study watersheds.

Approach

Our approach combines the use of empirical data analysis of a paired-watershed study with simulation modeling to evaluate the effects of ski area operations. Our study area includes the West Branch and Ranch Brook watersheds, tributaries to the Little River in northwestern Vermont (Table 1). The watersheds drain the eastern slopes of Mt. Mansfield, Vermont's highest peak, and have similar characteristics with respect to geology, soils, vegetation and relief. The West Branch watershed encompasses an entire alpine ski resort, which occupies roughly 15% of the basin area. The Ranch Brook watershed is undisturbed except for a network of cross-country ski trails. A paired-watershed study, initiated in the Fall of 2000 and funded jointly by the U.S. Geological Survey and the Vermont Monitoring Cooperative, established stream gaging stations in both watersheds. Automated ISCO water samplers allow collection of water samples. Funding provided through this grant supports the analysis of total suspended solids, common cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, Fe^{3+}, and Mn^{2+}), inorganic anions (Cl^{-}, NO_3^{-} and SO_4^{2-}), total nitrogen and total phosphorus.

Watershed modeling is accomplished using the Distributed Hydrology Soil Vegetation Model (DHSVM), a process-based, distributed parameter rainfall-runoff simulation model. Specification of vegetation and soil types occurs at the resolution of the digital elevation model (DEM). Elevation data of the DEM are used to simulate topographic controls on absorbed shortwave radiation, precipitation, air temperature and downslope water movement. The model simulates evaporation, transpiration, snow accumulation and melt, and runoff through vertical unsaturated flow, lateral saturated groundwater flow, and overland flow over surfaces or in channels (Wigmosta, 1994). Input to DHSVM includes grids of surface elevation, soil type and thickness, and vegetation; tables of soil and vegetation biophysical parameters, and time series of meteorological variables. The model is validated against existing streamflow data. We have obtained 30-meter DEM data for the study area from the Vermont Mapping Program. Vegetation and land cover data have been interpreted from high resolution remotely-sensed imagery. Soils data have been taken from GIS coverages and tables provided by the Natural Resource Conservation Service and distributed by the Vermont Center for Geographic Information (www.vcgi.org). Meteorological data have been provided by the Vermont Monitoring Cooperative and the U.S. Geological Survey (USGS). Stream flow data for the West Branch and Ranch Brook basins have been provided by the USGS.

Progress to Date

Research activities during Year 2 of the project have focused on (1) evaluating water quality data and (2) continued model development. Our work has capitalized on using the existing three water years of data (10/01/00-9/30/01, 10/01/01-9/30/02, 10/01/02-9/30/03) to develop an improved understanding of runoff processes and the behavior of chemical solutes in streamflow. Analysis of water quality data has involved establishing empirical relationships between discharge and solute concentrations in order to estimate annual loads. We have also used principal components analysis to explore variability among the full suite of solutes and to explore the seasonal chemical signals associated with runoff events. Model development during year 2 of the project has progressed from developing input (spatial and time series) data to implementing initial runs and assessing model performance.

Presentations and publications from the project include one peer-reviewed publication, several presentations at professional meetings, and a number of papers prepared by students involved in the project. One graduate student is funded by the project and we continue to attract undergraduate students who assist with data collection and analysis. Dissemination of results to the management community has occurred through presentations at meetings of the Vermont Monitoring Cooperative, the Vermont Water Resources and Lake Studies Center, and the Vermont EPSCoR program. In January 2004, we submitted a grant proposal to the USDA NRI competitive grants program.

Results

Analysis of water quality data for WY ‘01 ‘02 and ’03 indicates distinct seasonal signals in solute concentrations and suggests some effects of watershed management. Most of the variation in solute chemistry can be explained by fluctuations in weathering solutes (Ca, Mg, Si, K) and nitrate, and this signal exhibited distinct seasonal patterns (Figure 1). Nitrate peaked near 70 ueq L-1 in both basins during snowmelt, but generally remained somewhat higher at West Branch (Figure 2). Salting of parking lots and roadways within the West Branch basin resulted in elevated chloride concentrations year round (up to 700 ueq L-1 during snowmelt). These concentrations remained high in samples collected during summer and fall months (Figure 3).

Our initial, uncalibrated model simulations indicate some success in capturing the magnitude of and timing of hydrologic response in the watersheds; however, some work remains to improve model performance (Figure 4). Annual runoff at both basins peaks during the snowmelt period in April. Our initial simulations have focused on matching this snowmelt peak with relatively good success; however, fall and summer peaks are overpredicted in our simulations. These results highlight the importance of model validation against observed streamflow records, which have previously not been available for high-elevation watersheds in Vermont. Our future efforts will involve calibration of the model for WY02 and validation of the model for WY03 and WY 04 in both basins.

Sources Cited

Wigmosta, M. S., L. W. Vail, and D. P. Lettenmeier, 1994. A distributed hydrology- vegetation model for complex terrain, Water Resources Research 30, 1665-1679.

Table 1: Characteristics of the study basins

	West Branch	Ranch Brook
Watershed Area (km^2)	11.7	9.6
Watershed area in		
• ski trails (%)	11.60	0.38
• impervious surfaces* (%)	2.17	0.01
• exposed bedrock (%)	3.16	0.63
Land use	Alpine skiing	State forest, Nordic skiing

* includes buildings and paved or gravel roads and parking lots

Table 1: Results of the principal components analysis of solute chemistry for samples collected in WY 01, 02, and 03. Note that 80% of the variation in solute chemistry can be explained by two components in West Branch and by three components in Ranch Brook. The first component is related to weathering solute (Na, Ca, K, Mg, and Si) concentrations in both basins. The second component is related to nitrate concentrations in both basins.

	Initial Eigenvalues					
	West Branch			Ranch Brook		
Component	Total	% variance	Cumulative %	Total	% variance	Cumulative %
1	4.64	58.0	58.0	4.3	53.2	53.2
2	1.74	21.8	79.8	1.4	17.6	70.7
3	0.91	11.4	91.2	1.0	12.6	83.4
4	0.36	4.4	95.6	0.8	10.3	93.7
5	0.19	2.4	98.0	0.3	3.4	97.1

Figure 1: Plot of factor scores from the principal components analysis for water samples collected at West Branch in WY 01, 02, and 03. Note separation of the chemical signature of samples by season when plotted against the first two principal components.

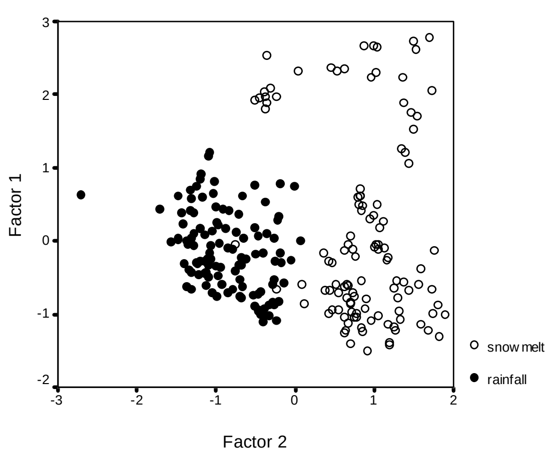


Figure 2: Hydrographs for 2001 spring snowmelt and nitrate concentrations

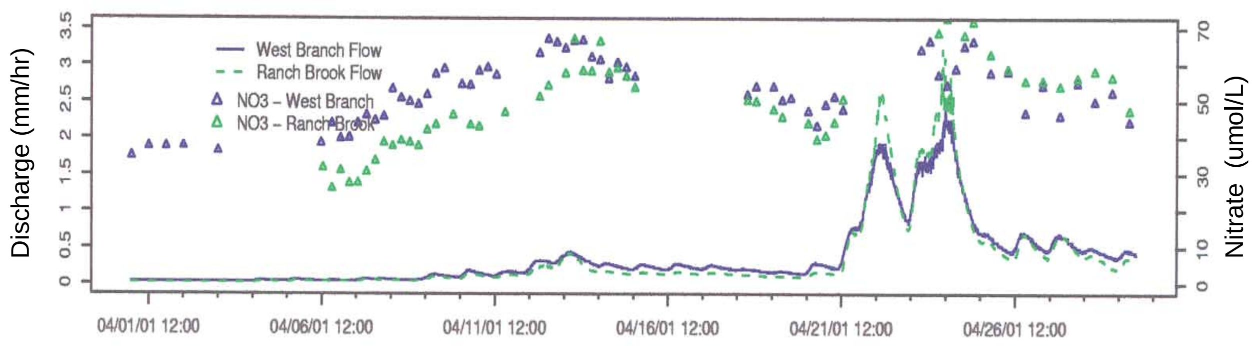
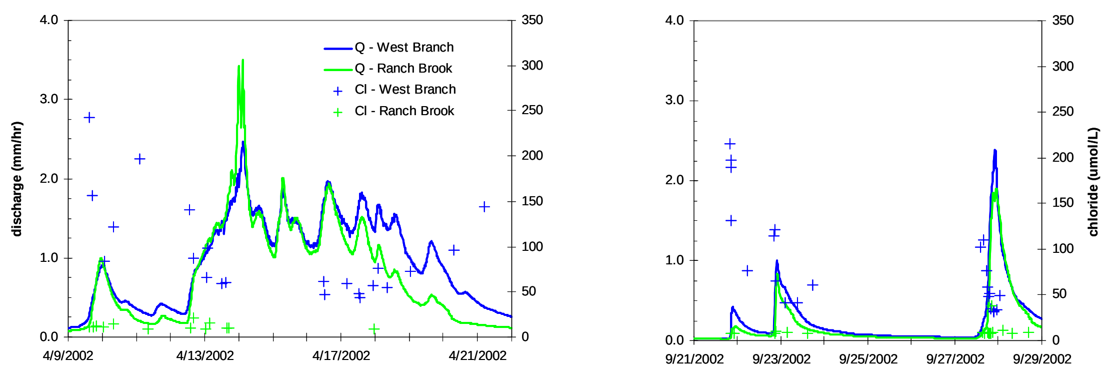


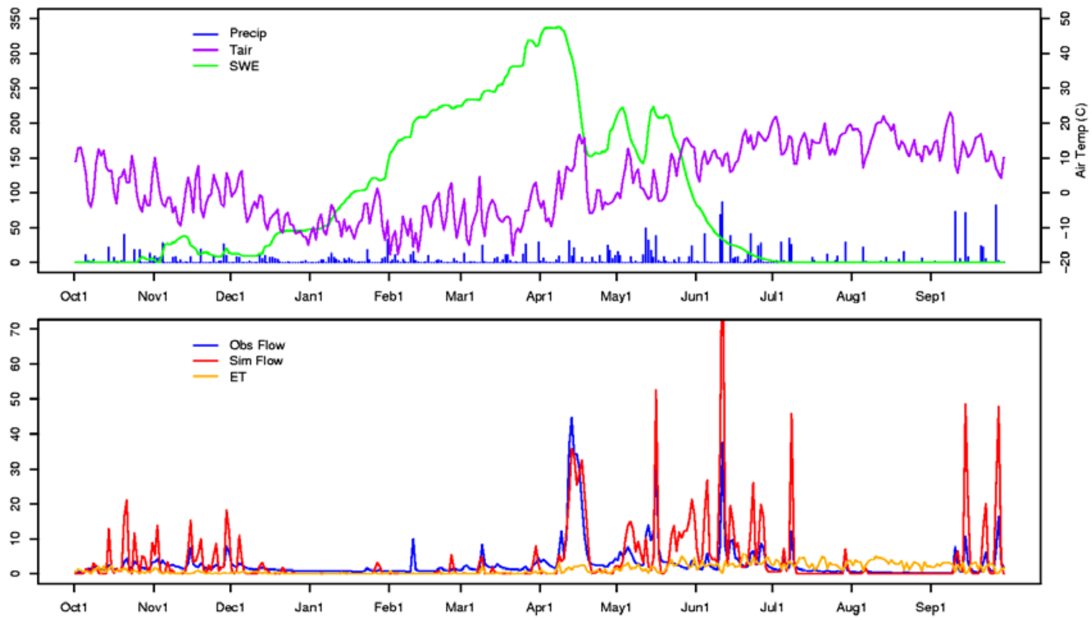
Figure 3: Hydrographs for spring and fall runoff events at West Branch and Ranch Brook with chloride concentrations.



Snowmelt 2002

Fall 2002

Figure 4: Uncalibrated model simulation results for Ranch Brook for WY 2002. Top panel shows basin average precipitation, air temperature, and snow water equivalent. Bottom panel shows observed and simulated streamflow and simulated evapotranspiration. Note that the April snowmelt event is captured by model simulations but smaller events in fall and late spring are overpredicted by simulations.



Detection of cyanobacterial blooms using remote sensing

Basic Information

Title:	Detection of cyanobacterial blooms using remote sensing
Project Number:	2002VT5B
Start Date:	3/1/2003
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	First
Research Category:	None
Focus Category:	Water Quality, Methods, Toxic Substances
Descriptors:	None
Principal Investigators:	Suzanne Levine, Gerald Livingston, Leslie Morrissey

Publication

Detection of cyanobacterial blooms using remote sensing

Suzanne N. Levine and Leslie A. Morrissey (Principal investigators)
Sarah Wheeler (Graduate Student)
Rubenstein School of Environment and Natural Resources, University of Vermont, Burlington, VT 05405

The goal of this two-year study is to assess the feasibility of tracking and quantifying cyanobacterial blooms in Lake Champlain and small Vermont lakes using remote sensing. During 2003-2004, specific project objectives included: 1) investigation of the spectral and spatial capabilities of existing satellites (literature research and consultation); 2) development of "groundtruthing" methodology (means of describing bloom pattern and intensity across image pixels); 3) simultaneous satellite image acquisition and field assessment of blooms in Lake Champlain; and 4) development of algorithms that relate spectral parameters measured by the satellites to cyanobacteria biomass in the lake (assessed by pigment analysis and transmissivity data, the latter an indicator of particle concentration).

The Landsat 7 detector Thematic Mapper (TM) was identified as the most appropriate instrument for detecting blooms in Vermont's modestly sized lakes and bays. TM has 30m spatial resolution and spectral bands that relate well to algal biomass (although they are not specific to cyanobacteria). A TM image of Lake Champlain from August 2002 was analyzed for chlorophyll and revealed detailed patterns of algal distribution not apparent from routine field sampling (see last year's report). A shortcoming of Landsat is its infrequent flyovers (12 day orbit frequency). Consequently, we chose to investigate use of the European satellite ENVISAT with its detector MERIS as well. MERIS has a return time of about 3 days and although its spatial resolution is coarse (300 m pixel width), it has appropriate spectral band positioning for examining phytoplankton. Phycocyanin, a pigment specific to cyanobacteria, can be distinguished from other pigments and quantified by this detector. MERIS might be used to flag small lakes or bays of Lake Champlain with algal problems that might subsequently be analyzed through use of satellites with greater spectral resolution or field sampling. The ENVISAT program is still in exploratory mode; only principal investigators on approved projects may order images. We obtained images through a Canadian collaborator, Warwick Vincent (Laval University, Quebec City). Dr. Vincent is tracking North American lakes between 70 and 75° W longitude, including Lake Champlain, to detect possible responses to climate change.

In May 2003, the scan line corrector on Landsat 7 failed and could not be recovered. This happened a few days before our first scheduled Landsat image collection. Consequently the Landsat component of the study had to be abandoned. We arranged instead to have images taken by the commercial European satellite SPOT. SPOT has a spatial resolution of 10 m that allows for excellent examination of detail within lakes and bays. However, this sensor also has broad spectral bands that can lead to sediment interference with chlorophyll assessment. This interference does not seem to be a serious problem in waters with high biomass levels such as those present in the bays of Lake Champlain. Two SPOT images of the north end of Lake Champlain were obtained in August 2003. Because

SPOT images cost $4400 per frame, we were able to afford acquisition of only half of a frame centered over St. Albans Bay. (Additional sections may be purchased this year.) Three MERIS images of the entire lake (and surrounding small lakes) were obtained in September. Groundtruthing was conducted during all image collection events (in either St. Albans or Missisquoi Bays during MERIS flyovers).

For field assessment, water was pumped through a train of probes that measured fluorescence of phycocyanin and chlorophyll *a* along with transmissivity (a proxy for particle content). Water was collected from the front of the boat from a depth of approximately 10 cm and continuous measurements were made as our boat traversed a long transect at each field site. Transects were defined based on collecting the greatest variation of algae concentration. Transects usually began in deep, clear waters and ended in shallow areas within the bay with high concentrations of cyanobacteria. A Garmin GPS unit was used to track the exact time and location of the boat along each transect at 1-second intervals. Water samples were collected at several points along transects to permit analysis of extracted phycocyanin and chlorophyll, and thus calibration of the fluorescence data to pigment concentrations. In addition, phytoplankton samples were taken to determine species composition and cyanobacterial biomass.

Algorithm development for the satellite imagery is in progress. Initial processing techniques for our SPOT image were conducted based on research published by Chacon-Torres et al. (1992). Principal components analysis (PCA) was performed on the SPOT image and a correlation was made between SPOT PCA band 1 and field chlorophyll data. Based on the derived algorithm, a map of chlorophyll *a* concentrations in St. Albans Bay on August 18 was produced (Figure 1). Wind piling of algae along shorelines is apparent. Clearly this image better represents conditions in the Bay than the single site sampling normally carried out by the Vermont Department of Environmental Conservation.

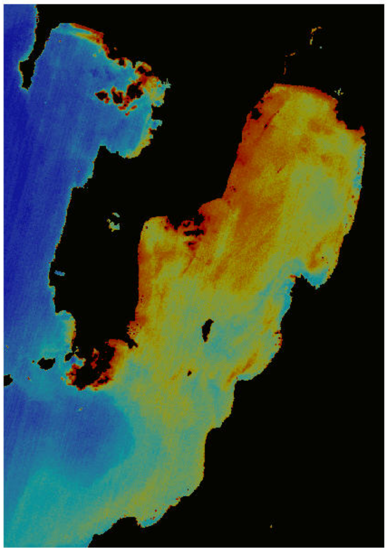


Figure 1. Relative chlorophyll content displayed from red (high concentrations) to blue (low concentrations). Predictions are based on principal components analysis of SPOT satellite imagery collected over St. Alban's Bay on August 18^{th}, 2003.

For the MERIS images we have begun initial digital processing; however, we have not yet formulated algorithms. Analysis will focus on the relationship between band ratios and pigment concentrations. Figure 2a shows the large size of the MERIS frames; not only the entire lake but also many small lakes in Vermont and the Adirondack are covered by a single image. Figure 2b is a close-up of the north end of Lake Champlain. The green color in Missisquoi and St. Albans Bays represents algal presence at bloom densities.

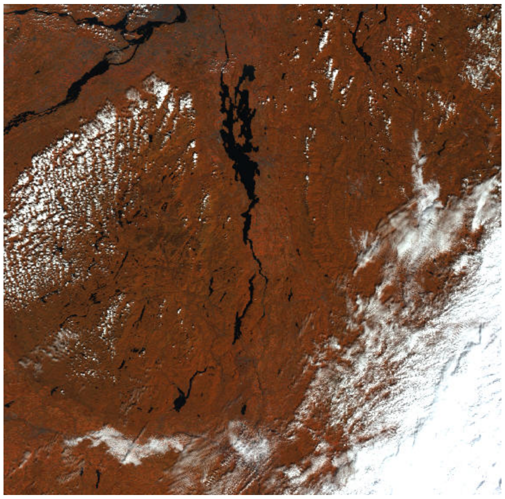


Figure 2a. Full scene of Lake Champlain taken from ENVISAT Meris on September 26th, 2003.

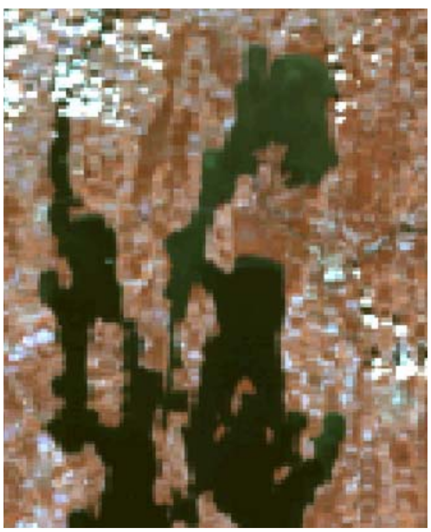


Figure 2b. ENVISAT Meris image of Mississquoi Bay and St. Albans Bay collected on September 26th, 2003.

During 2004-2005, additional MERIS images will be obtained. Most of these will be used to improve algorithm development, but at least one will be used to validate the equations developed from the other samplings. While there are no plans to acquire SPOT images in 2004, the second image taken in August 2003 may be purchased. We also may have the opportunity to obtain a Quickbird image (resolution 5 m).

References

Chacon-Torres, A., Ross, L.G., Beveridge, M.C.M., Watson, A.I. (1992). The application of SPOT multispectral imagery for the assessment of water quality in Lake Patzcuaro, Mexico. *International Journal of Remote Sensing*, **13**, 587-603.

Information Transfer Program

Student Support

Student Support					
Category	Section 104 Base Grant	Section 104 RCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	3	0	0	0	3
Masters	2	0	0	0	2
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	5	0	0	0	5

Notable Awards and Achievements

Publications from Prior Projects

None