# Vermont Water Resources and Lake Studies Center
# Annual Technical Report
# FY 2001

## Introduction

Attached is the Fiscal Year 2001 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

# Lagrangian Drifters Within Lake Champlain Feasibility Study

## Basic Information

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| **Title:** | Lagrangian Drifters Within Lake Champlain Feasibility Study |
| **Project Number:** | 2001VT641B |
| **Start Date:** | 3/1/2001 |
| **End Date:** | 2/28/2002 |
| **Research Category:** | |
| **Focus Category:** | Water Quality, Climatological Processes, None |
| **Descriptors:** | Water Quality, Atmospheric Forcing, Lagrangian Drifters, RAFOS,Hydrodynamics |
| **Principal Investigators:** | Thomas O. Manley , Jean Claude Gascard |

## Publication

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| **State:** | Vermont |
| **Project Number:** | VT641 |
| **Title:** | Lagrangian Drifters Within Lake Champlain Feasibility Study |
| **Project Type:** | Research Project |
| **Focus Category:** | Water Quality, Climatological Processes |
| **Keywords:** | Water Quality, Atmospheric Forcing, Lagrangian Drifters, RAFOS,Hydrodynamics |
| **Start Date:** | 03/01/2001 |
| **End Date:** | 02/28/2002 |
| **Congressional District:** | First |
| **PI:** | Thomas O. Manley<br>Professor, Middlebury College<br><br>Jean Claude Gascard<br>Associate Professor, Universite Perre et Marie Curie |


## Abstract

An understanding of the hydrodynamics of Lake Champlain is critical to our ability to accurately model and predict the movement and eventual disposition of contaminants within the water column. Although our knowledge of lake circulation has increased dramatically over the past, it is nevertheless based entirely upon Eulerian observations at a few selected sites within the lake. By their very nature. Eulerian measurements (observations made at a fixed location over time) possess intrinsic limitations in their ability to map complicated flow dynamics within large regions. Specifically for Lake Champlain, large oscillatory currents created by the internal seiche mask our ability to define average flow conditions due to low average values bounded by high standard deviations.

Additionally, documenting circulation throughout the entire lake using existing techniques is cost prohibitive. This proposal seeks to test the practicality of using a Lagrangian mapping technique known as RAFOS to define complicated flow trajectories of fluid parcels at different levels within the water column over time. While this technique has been used within the oceans over the past several decades to look at oceanographic problems ranging over a wide spectrum of temporal and spatial scales, it has never been employed, to our knowledge, in any lake environment. This project is a feasibility study using acoustically traced, neutrally buoyant, free-drifting subsurface floats within Lake Champlain. If successful, both Eulerian and Lagrangian measurements could be coupled to produce the next significant level of understanding of circulation dynamics within Lake Champlain.

# Lagrangian Drifters Within Lake Champlain Feasibility Study

## Statement of Critical Regional or State Water Problems.

The understanding of hydrodynamics of Lake Champlain is critical to our ability to accurately model and therefore predict the movement and eventual disposition of contaminants within the water column. Although our knowledge of lake circulation has increased dramatically over the past seven years, it is nevertheless based entirely upon Eulerian observations at a few selected sites within the lake. By their very nature, Eulerian measurements, observations made at a fixed location over time, possess intrinsic limitations in their ability to map complicated flow dynamics within large regions. Specifically, for Lake Champlain, large oscillatory currents created by the internal seiche mask our ability to define average flow conditions due to low average values bounded by high standard deviations. Additionally, to describe circulation throughout the entire lake would be cost prohibitive. This proposal seeks to test the practicality of using a Lagrangian mapping technique, known as RAFOS, to define complicated flow trajectories of fluid parcels at different levels within the water column (over time). While this technique has been used within the oceans over the past several decades to look at oceanographic problems ranging over a wide spectrum of temporal and spatial scales, it has never been employed, to our knowledge, in any lake environment. What is proposed is a feasibility study using acoustically tracked, neutrally buoyant, free drifting subsurface floats within Lake Champlain. If successful, both Eulerian and Lagrangian measurements could be coupled to produce the next significant level of understanding of circulation dynamics within Lake Champlain.

## Statement of Results or Benefits.

The results of employing such a coupled program would be immediately realized in the fields of numerical modeling, toxic transport, sediment transport, vertical fluxes and mixing, mean circulation, topographic control of currents, wintertime convection, fall and spring turnover dynamics, effluent transport, water quality, atmosphere-lake interactions, large-scale and mesoscale dynamics, nonlinear dynamics of the internal seiche, and nutrient fluxes from hypolimnion to epilimnion. For example, imagine the utility of such a system that could accurately define the movement of water contaminated by PCB particulates after leaving Cumberland Bay, or determine where the final deposition sites for sediments being eroded at depths of 200 to 300 feet are. Presently, these answers are beyond the scope of our instrumentation and models.

Beyond these initial impacts, it is just as likely that newer, important and unforeseen lake dynamics could be brought into light as were countless oceanographic phenomena over the past 20 years. Whatever the benefits brought about by this coupling of Eulerian and Lagrangian techniques towards the deciphering of the very complex internal dynamics of Lake Champlain, the final benefit would be that of verifying an improved atmospherically forced, hydrodynamic model representing this lake. It is in this field that some of the most exciting results will be found, both for the researcher as well as management.

As can be observed in any major scientific research program, there exists a symbiotic relationship between observational and modeling components. Typically, observations force the verification and subsequent improvement of analytical and numerical based models representing a specific system. Once these models produce acceptable results, they are often used to show where knowledge of specific properties needs to be improved, identify dynamics that have not been observed before and/or locate regions that are more critical than others and, hence, require further more detailed investigations. It has been suggested by Myer and Gruendling (1979), as well as by one of the earliest models by ASA, that smaller-scale circulation cells may exist within the large-scale dynamics of Lake Champlain. These small-scale cells, as of yet, have not been observed over the past seven years through the use of Eulerian measurements. Similarly, long-term moorings have provided new information about internal surges (Hunkins et al., 1998), gravity currents (Saylor et al., 1999), vertical convection cells (Manley et al., 1999) and thermal anisotropic conditions during fall turnover (Manley et al., 1999) existing within the Main Lake of Lake Champlain. Presently, numerical models of Lake Champlain are under revision (ASA modeling improvements submitted to the Lake Champlain Basin Program in 1999) or are being modified to incorporate these new findings (Drs. Jim Saylor and Ken Hunkins, personal communications). Only with constant improvement of these analytical and numerical models will they be able to provide us with more realistic information that can be related to management issues. As stated earlier, it is the intent of this proposal to gather and test new information that will significantly improve our knowledge of circulation within Lake Champlain, and, hence, improve our modeling capability with better management results.

## Results from the Year 2000 Field Program

During late May, ballasting and stability calculations of the RAFOS floats were completed at WHOI by Pierre Tillier and Jean-Claude Gascard. Shortly thereafter, the equipment was transported from WHOI to the *Melosira* for immediate testing in Lake Champlain. This phase of a program lasted until mid-June and was primarily devoted to verifying sound propagation characteristics within the Main Lake. Unfortunately it was discovered during the stability testing of the RAFOS floats at WHOI that they would not be stable at the very shallow depths of Lake Champlain. The reason for this was not only surprising to us but to the other researchers who frequently use these floats in the deep ocean. Apparently, the soft components of the RAFOS float (which consist of o-rings and the rubber coated transducer) displayed high compressibility within the 0-100 meter range. The glass enclosure, on the other hand, is highly incompressible and therefore has very stable characteristics for ballasting at specific depths. The compressibility of the "soft" components change the volume of the instrument enough so that it cannot be ballasted for a specific depth. As a result, these floats would be stable only drifting at the surface or sitting on the bottom of Lake Champlain.

While this initially appeared to be a serious problem, we will shift our attention to another instrument that was recently created at WHOI and Scripps Institute of Oceanography that could be successfully utilized within Lake Champlain (i.e., the SOLO float). These specific profiling instruments are free drifters (similar to the RAFOS float), however, they are designed to profile vertically within the water column and therefore have their own internal ballasting mechanism. For the Lake Champlain pilot study, we do not need such a large and sophisticated device as the SOLO float. Rather, a smaller, less expensive unit, which we refer to as the Lake Champlain Profiler (LCP), can be created utilizing this technology. Unfortunately, none of these specific "SOLO" floats have been available for testing in Lake Champlain on such a short notice.

Additionally, verification of sound propagation in Lake Champlain still had to be completed. As a result, the program was slightly modified from its original version to that of more active field-driven research that utilized both the sound sources and RAFOS floats that were within our possession.

Approximately one week prior to the arrival of the equipment for trial in Lake Champlain, discussion among several members of the SCUBA diving community prompted us to slightly modify our research program. While not believed to be a problem from a theoretical acoustic standpoint, we were requested by several members of the diving community to verify the intensity level of the sound sources at varying distances for safety considerations. In response to this request, one day was spent within Shelburne Bay focusing on this specific issue. The *Melosira* and the Middlebury College *R/V Baldwin* provided range testing for SCUBA divers at various distances from one of the sound sources suspended from the *Melosira*. This particular sound source was set up so that it could be manually controlled to transmit its standard output signal at any given time. The conclusions from this testing phase were that at a distance of approximately 30 feet, the intensity of the emitted sound signal was very tolerable to the divers. As a matter of fact, divers could barely hear the signal when they were within approximately 200 feet of the sound source. Since all of these sound sources are deployed in regions of the Main Lake that are well distant (over two miles) from any recreational diving sites and in deep water where diving activity is highly unlikely, these sound sources represent no hazard to divers.

On the following day, our planned program of deploying the four 780 Hz sound sources commenced. From the *Melosira*, the sources were positioned within the Main Lake as shown in Figure 1. The sources were programmed to transmit their signals on a rotational sequence of 0, 10, 20, and 30 minutes past the hour, every hour of the day. For example, Valcour Island would always transmit on the hour, while Thompson's Point would only transmit 30 minutes past the hour. In this way, we could verify which sound source created the observed signal. With sufficient observations, signal strength vs. distance and location away from any given source could then be created. Shortly after deployment, the sound source located near Valcour Island stopped transmitting due to the failure of a component on the power conditioning board. Still, with three active sources within the region, we were able to gain sufficient information on sound propagation within the Main Lake to define the next field season program.

After the deployment of the 4 sound sources within the Main Lake, the *RV Baldwin* was utilized over the following ten days to observe signal strength from these various sound sources over a wide range of locations. This type of testing utilized a tethered receiver containing the same acoustic equipment found in the RAFOS floats. This tethered receiver was lowered from the *RV Baldwin* at various depths throughout the lake to gain specific information on the correlated signal strength from each of the sound sources. It should be noted that each sound source transmitted a swept (frequency-varying) signal over a period of 90 seconds. The electronics and software within the receiving unit compare the original signal to that of signals observed within the water column over a five minute period.  If the system can match the original signal to that of any section of the five minute underwater recording, then it will assign a correlation strength that is relative to the original sound source signal.  It is this capability of the RAFOS system that permits it to transmit at relatively low power, yet have relatively high correlation strengths at great distances. From shipboard operations, it was discovered that typical listening distances that were reasonably correlated varied from 10-20 kilometers.  Sound shadow zones were also observed behind islands (example, Four Brothers) or relatively large, shallow bathymetric features (reefs or shoals). By their very nature, observations from ships produce degraded range values because of the noise generated by the engine or other components on the vessel. Therefore, the values that were obtained represent worst-case conditions.

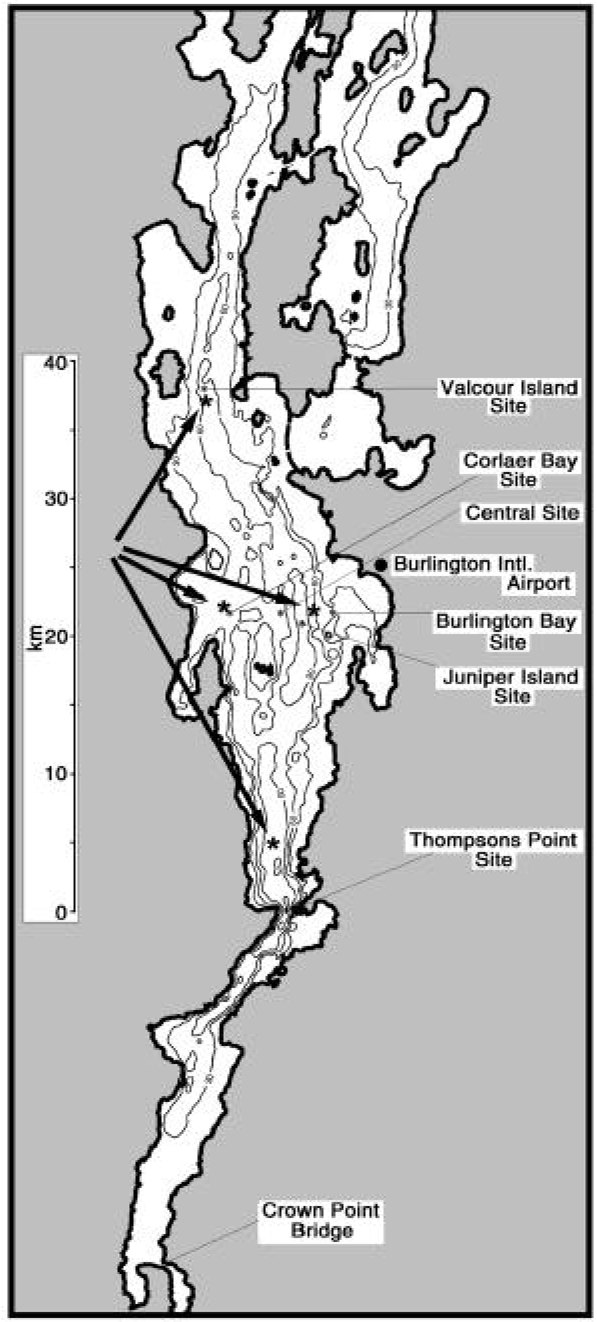


Figure 1. Positions of the four sound sources within the Main Lake during the summer 2000 field program. These are defined by the four arrows originating from the left-hand side of the diagram. Previous sites where Eulerian measurements (i.e. subsurface moorings) had been taken during the past seven years are also shown (with their names) on the right-hand side of the diagram.

To test more realistic conditions, where receivers would be distant from any vessel, the tethered receiver system was converted to internal recording and allowed to free-drift at the surface with several marker buoys. Additionally, a RAFOS float was suspended beneath it at a depth of approximately 100 feet. This system was allowed to drift within the central region of the Main Lake for approximately 5 hours. As expected, data from the two free-drifting units indicated stronger correlation values over the same distances that had been covered using the *RV Baldwin*.

A longer deployment of the same system was made the following Thursday; the system was designed to free-drift until the following Monday. Unfortunately, by Friday evening, it had grounded out near the Four Brothers Islands at an isobath of proximally 150 feet (the depth at which the weight was located). Jean-Claude Gascard and Dick Furbush picked up the instrument string Saturday morning and re-deployed it farther to the east, where it continued drifting to the south until it was picked up north of Thompson's Point Monday afternoon. The drift-track of the instrument string was constantly monitored by Jean-Claude through the Argos data telemetry system. Positional information could be gained with as little as a one hour delay. Data from this longer drifting system suggested that maximum correlatable distances were closer to the 25-30 kilometers range. This was indeed a significant improvement over our initial estimate of 10-20 kilometers from the *RV Baldwin*.

From this field program, we are confident in stating the following conclusions:

1) The 780 Hz system is too large for Lake Champlain. In essence, this type of system should have easily transmitted well over 100 kilometers. The reason that we are not observing these distances is not due to the frequency or the power of the system, but, rather, the decorrelation of the signal due to multipath reflections off the lake surface and bottom bathymetry. As a result, the smaller and cheaper 1560 Hz system could be used just as effectively.

2) With the observed bottom bathymetry and correlation distances within the Main Lake, it would take approximately 8 separate sound sources to completely "insonify" the main sector of the lake from Valcour Island to Thompson's Point.

3) The "SOLO" float would offer the best solution in creating a free-drifting neutrally-buoyant float for Lake Champlain. The units that would be created are estimated to be cheaper and lighter than their oceanic counterparts.

4) A Lagrangian drifters program within Lake Champlain has an even higher probability of success than our first estimate.

5) The RAFOS floats that were initially purchased for this program were obtained by Jean-Claude Gascard for utilization in some of his deep ocean research. Only the expendables such as batteries, ballasting, and shipping would be paid for by this contract.

**Program Direction for the Next Year**

Our initial plan was to continue on a slow and very directed testing program of the various components needed to assure success within Lake Champlain. Specifically, this would be to create the first LCP and complete a very rigorous buoyancy (depth stability) checkout of the device in Lake Champlain. Furthermore, we would purchase only enough sound sources (1-3) to carry out the testing of this specific drifter. Unfortunately, due to the accounting policies of the USGS, no no-cost extensions will be permitted for any contracts for the current fiscal year, since they are closing all of their contract accounts. As a result, we cannot judiciously hold any money in reserve as the program continues to verify all components within the system.

Because we must expend all of our funds prior to February 1, 2001, we will accelerate our timetable. As a result, we will purchase as many components as possible in order to satisfy our needs for next year. Thus, all remaining funds from our first year contract will be spent for the purchase of at least 1 Lake Champlain Profiler (LCP) and as many 1560 Hz sound sources as possible.

During the second year, funds will be expended in order to gain a total of 4 or more sound sources and a total of 4 LCPs. Jean-Claude Gascard was not available for consultation, since he has been out on a research cruise for the past several months and, therefore, there may be modifications in the final budget.

With regard to personnel, Tom Manley, Jean-Claude Gascard, and Pierre Tillier will be present for most, if not all, of the 2000-2001 field program. Pierre Tillier is the owner of *SeaScan,* the company which designs and manufactures both sound sources and RAFOS floats for central ocean programs. All of us are extremely interested in this pilot program since it represents a completely new branch of acoustic technology that can be opened to a wide body of researchers throughout the world if successful. As such, Jean-Claude and Pierre are essential to the successful completion of this program.

## References


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# Identification of Candidate Parcels for Riparian Buffers: Reducing Fecal Contamination of Vermont Surface Waters

## Basic Information

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|---|---|
| **Title:** | Identification of Candidate Parcels for Riparian Buffers: Reducing Fecal Contamination of Vermont Surface Waters |
| **Project Number:** | 2001VT661B |
| **Start Date:** | 3/1/2001 |
| **End Date:** | 2/28/2002 |
| **Research Category:** | |
| **Focus Category:** | Non Point Pollution, Surface Water, Agriculture |
| **Descriptors:** | water quality, fecal contamination, nonpoint source pollution, GIS, remote sensing, agriculture, surface water |
| **Principal Investigators:** | Leslie A. Morrissey |

## Publication

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| **State:** | Vermont |
| **Project Number:** | VT661 |
| **Title:** | Identification of Candidate Parcels for Riparian Buffers: Reducing Fecal Contamination of Vermont Surface Waters |
| **Project Type:** | Research Project |
| **Focus Category:** | Non Point Pollution, Surface Water, Agriculture |
| **Keywords:** | water quality, fecal contamination, nonpoint source pollution, GIS, remote sensing, agriculture, surface water |
| **Start Date:** | 03/01/2001 |
| **End Date:** | 02/28/2002 |
| **Congressional District:** | First |
| **PI:** | Leslie A. Morrissey<br>Associate Professor, The University of Vermont |


## Abstract

Fecal contamination of surface waters in both agricultural and urban watersheds is a major environmental concern in the state of Vermont. Conservation practices are needed that will significantly reduce bacterial contamination of Vermont's surface waters. One effective approach to reduce contamination in runoff from adjacent agricultural fields to streams and rivers involves the construction of buffer zones and filter strips along streams and rivers. With limited resources, identification and prioritization of land parcels for riparian buffer zone implementation constitute a critical need for water quality programs. The research proposed here focuses on the development of a suitability model to identify and prioritize candidate land parcels for riparian buffer zone implementation utilizing Geographic Information Systems (GIS) and state-of-the-art remote sensing technologies. Suitability modeling will incorporate environmental parameters that are readily available, can be derived from available data, or can be mapped using soon-to-be-available high-resolution (1m) satellite data. The proposed study is focused on the Mad River watershed in northern Vermont and, if successful, this methodology could be extended to watersheds throughout the Northeast U.S.

**Identification of Candidate Parcels for Riparian Buffers: Reducing Fecal Contamination of Vermont Surface Waters**

**Focus categories:** **NPP, SW, AG**

**Keywords: water quality, fecal contamination, nonpoint source pollution, GIS, remote sensing, agriculture, surface water**

**Duration:** 3/1/01 - 2/28/02

| | Total | Direct | Indirect |
|---|---|---|---|
| **Fiscal Year Funds:** | | | |
| | $ 25,000 | $ 25,000 | $ 0 |
| **Non-Federal Funds:** | Total | Direct | Indirect |
| | $ 39,827 | $ 17,932 | $ 21,895 |

**Principal Investigator:** Leslie A. Morrissey, University of Vermont

**Congressional District:** 1st District, State of Vermont

**Abstract:** Fecal contamination of surface waters in both agricultural and urban watersheds is a major environmental concern in the state of Vermont. Conservation practices are needed that will significantly reduce bacterial contamination of Vermont's surface waters. One effective approach to reduce contamination in runoff from adjacent agricultural fields to streams and rivers involves the construction of buffer zones and filter strips along streams and rivers. With limited resources, identification and prioritization of land parcels for riparian buffer zone implementation constitute a critical need for water quality programs. The research proposed here focuses on the development of a suitability model to identify and prioritize candidate land parcels for riparian buffer zone implementation utilizing Geographic Information Systems (GIS) and state-of-the-art remote sensing technologies. Suitability modeling will incorporate environmental parameters that are readily available, can be derived from available data, or can be mapped using soon-to-be-available high-resolution (1m) satellite data. The proposed study is focused on the Mad River watershed in northern Vermont and, if successful, this methodology could be extended to watersheds throughout the Northeast U.S.

## Significance of Proposed Research

Fecal contamination of surface waters is a growing concern in agricultural and wildland areas throughout the U.S. (Crane et al., 1983). Runoff from agricultural lands carrying microorganisms from livestock manure can contaminate water supplies and pose a serious risk to human health. Animal feeding operations, fecal waste storage and application, and grazing pastures are all potential sources of bacterial contamination of nearby waters. Manure and sludge applied to cropland soils and grazing by domestic livestock in pastures are important sources of animal waste carried into adjacent streams during or following precipitation events in rural Vermont. Even in pastures where cows have been removed, elevated bacterial levels may persist for months (Jawson et al., 1982, Tiedemann et al., 1988). To decrease fecal contamination of streams from these sources, both state and federal conservation practices, including the construction of riparian buffer zones, have been adopted.

The construction of buffer zones and filter strips along streams and rivers has been shown to be an effective conservation practice that reduces bacterial contamination of surface waters in agricultural environments (Dickey and Vanderholm, 1981; Doyle et al., 1977; Meals, 1996, Young et al., 1980; Coyne and Blevins, 1995). A riparian buffer is typically defined as an area of trees and shrubs immediately adjacent to streams, lakes, ponds, or wetlands that is managed to enhance and protect aquatic resources. Filter strips refer to comparable grass covered areas. Riparian buffers and filter strips reduce *E. coli* counts in waterways by reducing the volume and velocity of runoff and increasing adhesion onto soil particles and vegetation (Palone and Todd, 1997). Riparian buffers (and filter strips) are most effective when bacterial concentrations are high (Moore et al., 1988) and may intercept up to 95% of the pathogens in surface runoff from manured fields if of sufficient width and properly managed (Coyne and Blevins, 1995). At the local level, pilot studies in two Vermont watersheds have also had modest success (Meals, 1996).

In an attempt to improve water quality at state levels, federal cost share programs were implemented to encourage the use of riparian buffers and filter strips by agricultural landowners. These programs, however, have not been widely adopted by landowners in the state of Vermont. As a consequence, the NRCS, in collaboration with the Vermont Agency of Natural Resources, Non-Game and Natural Heritage Program, and USDA Farm Service Agency, initiated a program in 1999 to provide economic incentives to landowners to develop riparian buffers within the Mad River watershed. With limited resources, *the identification and prioritization of land parcels for riparian buffer zone implementation are thus a critical need for this and other water quality programs.* The research proposed herein will focus primarily on the identification and prioritization of candidate land parcels that could benefit from the development of riparian buffers and filter strips for the purpose of reducing fecal contamination of surface waters in the Mad River watershed. If this research is successful, the methodology could be extended to watersheds elsewhere.

The effectiveness of riparian buffers and filter strips is affected by a number of environmental factors, including soil type, soil moisture, vegetation type, slope and dimensions of the buffer. Organic and clay particles in soil are very effective at trapping *E. coli* bacteria (Mawdsley et al., 1995). Mortality of microorganisms entrapped within the soil is subsequently hastened if soils are well drained (Rosen, in prep.). Soil saturation and its role in overland flow are major factors in transporting microorganisms. *E. coli* were found to move as much as 1.5m/hr through saturated hillside slopes in Oregon (Rahe et al., 1978). The length, width, slope, and type of vegetation in a buffer also impact bacterial transport. Glenne (1984) found that steeper slopes are most effective at moving water, sediment, and *E. coli* downslope and, as a result, typically require wider buffers to reduce input into adjacent streams. Widths up to 30m or more may be necessary on steeper slopes and less permeable soils (Schultz et al., 1995). Although trees and woody shrubs are more effective at reducing erosion and thus stabilizing streambanks, grass filter strips are more effective at reducing fecal contamination inputs (and other pollutants) into nearby streams (Schultz et al., 1995). Ideally, therefore, buffer zones should be defined based on the specific setting to limit both erosion and agricultural runoff. In summary, any practice that reduces runoff and sediment transport will simultaneously reduce pathogen transport to nearby waters (Rosen, in press).

Geographic Information Systems (GIS) and digital remote sensing are technologies well suited to aid identification and prioritization of candidate land parcels in need of a riparian buffer. High-resolution digital orthophotography (1:5000; 0.5m pixels) and satellite imagery (1m pixels) can be used to characterize riparian zones by determining the presence or absence of a buffer, the length, width, dominant vegetation type of existing buffers, and adjacent land use/land cover. Remote sensing can also provide information on drainage channels that directly circumvent the beneficial effects of riparian buffers and thus represent a potentially direct source of contaminants entering streams. These drainage channels are expected to be visible on both digital orthophotography and satellite imagery but are not otherwise currently mapped. Available digital topographic data can be used to derive slope and length measures of fields adjacent to streams. Using these methods, state and federal conservation programs could prioritize their limited resources to maximize returns in terms of improved water quality. With the recent launch of high resolution IKONOS satellite data in September of 1999, mapping of areas adjacent to streams can be based on multispectral digital image processing and classification techniques rather than manual interpretation of panchromatic photography. This newest generation of satellite data records information in the visible and near infrared wavelengths, and is thus ideally suited for mapping vegetation. These satellite data are expected to easily surpass digital orthophotography (which is based on black and white aerial photography flown in 1992) in value. By utilizing remotely sensed data to map the environmental characteristics of riparian zones, land parcels can be prioritized for buffer implementation based on a combination of environmental factors analyzed within a GIS framework. For instance, a streambank without a riparian buffer adjacent to a pasture would receive a high rank with regard to the need for riparian buffer or filter strip development.

*Escherichia coli* (*E. coli)* is the most reliable indicator of bacterial contamination of surface waters in the U.S., according to water quality standards promulgated by the U.S. Environmental Protection Agency. Although *E. coli* are not pathogenic in and of themselves, U.S. EPA standards are based on an epidemiological study by Dufour (1984) which demonstrated that *E. coli* was a better predictor of swimming-associated gastrointestinal illness than fecal coliform concentration (Francy et al., 1993). The standards are defined as an indicator concentration where the health risk from waterborne illness is unacceptably high. Water quality standards adopted by the State of Vermont set the *E. coli* limit at 77 organisms/100ml for class B recreational waters (e.g. swimming holes) suitable for direct contact (Vermont Water Resources Board, 1996).

**Scope and Objectives of this Research**

The goal of this proposed research is to develop and assess the GIS and remote sensing technologies required to identify and prioritize candidate parcels within the Mad River watershed for riparian buffer or filter strip development. Candidate land parcels will be identified based on their probable fecal contribution to adjacent waters as modeled using environmental parameters that are readily available or directly measured. For example, land parcels with commodity crops and manure spreading, as well as pastures for livestock grazing adjacent to streams and rivers on steeper slopes with saturated clay and organic soils, would be identified as the most critical candidate parcels. State-of-the-art digital processing of high resolution IKONOS satellite data will provide a new method for: 1) identifying and characterizing riparian zones, 2) mapping adjacent land parcels by current land use, and 3) determining the density of drainage channels. If successful, this satellite-based methodology could be used to extrapolate the results generated and tested in the Mad River watershed to the entire Winooski River watershed. This proposed research effort will be conducted in collaboration with state and federal agencies and local citizen volunteer groups. On-going and collaborative efforts by Friends of the Mad River, Mad RiverWatch, Natural Resources Conservation Service, and Vermont Farm Bureau will complement this proposed project.

Finally, dissemination of the results of this and other *E. coli* measurement programs is needed to increase public awareness of water quality issues and on-going research efforts. We propose to use the WWW for disseminating our results. We are sensitive to representations of water quality indicators (i.e. *E. coli*) on the Web that may be misconstrued or misinterpreted by the public, and we will use extreme care in presenting the data.

The objectives of this proposed research are to:

- Identify and prioritize candidate land parcels within the Mad River watershed for riparian buffer development using a spatially explicit (GIS-based) suitability model

- Assess the utility of high resolution satellite data for mapping and monitoring riparian buffers along streams and rivers
    - panchromatic digital orthophotography (DOQ) vs. multispectral satellite magery

- Disseminate information to the public on fecal contamination of streams and lakes using a WWW Page listing *E. coli* measurements for this study, state and municipal beaches, and River Watch groups

**Study Area**

The Mad River has been named one of Vermont's best swimming resources, having 19 of the 210 best swimming holes in the state (Mad River Valley Planning District, 1995). The scenic Mad River flows 42 km north from the Granville Wilderness area to the Winooski River in central Vermont. Land cover and land use within the watershed (370 $km^2$) are dominated by forest and agricultural use. The watershed encompasses the towns of Granville, Warren, Waitsfield, Fayston, Duxbury, and Moretown. The southern end of the watershed is relatively undeveloped and covered primarily with forests. Development and agricultural farmland increase northward. The Sugarbush Ski Resort is also located within the watershed. Although a major resort area in the state, Mad River was identified on the 1998 Vermont Impaired Waters list. Moreover, a local volunteer group, Mad River Watch, found that of the 38 sites sampled in 1995, 19 violated the water quality standard for class B recreational waters 50% or more of the time (Mad River Program Annual Report, 1995). Fecal contamination in the Mad River watershed has been attributed to agricultural runoff and inadequate septic treatment of human waste. With seven years of water sampling data by River Watch and an on-going riparian conservation program by the NRCS, the Mad River watershed provides an ideal environment for water quality studies.

**Methods, Procedures, and Facilities**

<u>GIS Database Development and Modeling</u>: Candidate land parcels for riparian buffer development will be identified through the development of a suitability model. Suitability models are used commonly in GIS to identify the best locations for some particular activity. In a broad sense, suitability models provide a framework to systematically organize and synthesize a number of complex environmental variables
(e.g., soils, slope, land use/land cover). The goal of this proposed project is to identify and rank locations for riparian zones in critical need of buffers or filter strips. Interval measures of suitability for each environmental data class will be combined with a weighting factor to create ratio measures of suitability. The modeling effort will be based on the incorporation of existing GIS data layers, derivation of new layers, and careful weighting of environmental factors based on suitability for riparian buffers. Major tasks required to meet the objectives of this proposed research include:

- Mapping areas in riparian zone
    presence or absence of riparian buffers and filter strips along the Mad River
    if present, document buffer width, length, and vegetative type
        (shrub/grass, shrub/forest, forest)

- Mapping land areas adjacent to riparian zone
    - land use/land cover (forest, agriculture, residential)
    - commodity crop or livestock pasture
    - slope of field adjacent to stream/river
    - density of drainage channels (indicator of runoff)
    - hydrologic modeling of flow and accumulation, drainage area and outlet

- Develop suitability model for buffer development
    - identify candidate land parcels
    - prioritize candidate parcels

Existing GIS data layers

- Property parcels
- Stream network
- Soil drainage class in fields adjacent to stream/river
- Digital topographic data (DEM)
- Digital orthophotography
- Satellite imagery

GIS Derivatives

- Slope gradient in adjacent field
- Hydrologic flow and accumulation downslope, drainage area delineation and location of outlets

Mapping

- Adjacent land use/land cover to stream/river
  - Commodity cropland
  - Grazing pastures
- Density of drainage channels/area
- Riparian buffer width, length, and vegetative type

One might assume that land located adjacent to a riparian buffer would be filtered by that buffer. In reality, the slope gradient, aspect, and shape determine which downhill path water will take. Hydrologic modeling can be used to trace the path of water (raindrops) down a slope to a specific outlet. Using ESRI's ArcView and Arc/INFO software, flow direction and accumulation, drainage area, and outlet will be derived from 1:5,000 digital elevation data.

Image Processing: Analysis of the satellite data will include image classification and enhancement. Digital classification of land use and land cover in parcels adjacent to the river will be performed using a contextual classifier. Image enhancement (edge enhancement) will be utilized to map drainage channels. Screen digitizing of digital orthophotography and satellite imagery will locate existing riparian buffers and quantify each by width, length, and vegetative type.

The Spatial Analysis Lab (SAL) at the School of Natural Resources will provide all of the computer resources required to meet the GIS and image processing needs of this project. The SAL consists of 6 SGI Unix and 2 NT workstations, CD writer, color plotter, color printers, Exabyte tape drive, CD reader/writer - a fully equipped facility for image processing and GIS. The SAL has site licenses for ESRI's suite of GIS software (ArcView and extensions, Arc/INFO, GRID, etc.) and ERDAS Imagine Image Processing software. A system manager maintains the facility, which is supported solely by research dollars.

## Evaluation of the Candidate Parcels

Evaluation of candidate parcels will require both site specific visits and collaboration with on-going efforts by federal and state agencies and citizen Riverwatch groups. For example, as part of a collaborative two-year study begun in August of 1999, NRCS will inventory riparian corridors adjacent to 51 commodity crop fields in the Mad River Valley. One evaluation, therefore, will compare the independent rankings of parcels for riparian buffer development for those reaches of the Mad River where the NRCS and this study overlap. In addition, *E. coli* measurements collected by the Mad River Watch group will be compared to the ranking of the adjacent and immediately upstream stream corridor based on the suitability model. We realize that the locations of the River Watch sites may not be optimally located to fully test the results of the suitability model.

## Statement of Potential Benefits

The anticipated outcomes of this proposed research include:

- Identification of the location, length and area of adequate inadequate stream buffers
- Development of satellite-derived mapping techniques within a GIS framework that, if successful, can be used to map to the entire Winooski River watershed
- Development of spatially explicit (GIS-based) methodology for identifying candidate land parcels for development of riparian buffers and filter strips
- Development of a publicly available Web page documenting on-going *E. coli* measurement programs within the state of Vermont, including this proposed study, state and municipal beaches, and River Watch watersheds
- GIS database and map products will be provided to NRCS, ANR, and local River Watch organizations

If successful, the use of state-of-the-art high resolution satellite data and GIS for mapping riparian buffers will provide a reliable and accurate method which could be adopted throughout the state of Vermont, across the Northeast, and will be relevant to similar studies throughout the U.S. The development of computer-based techniques in the Mad River watershed that can be extrapolated to the Winooski River watershed could provide cost effective and accurate inventories of water quality parameters such as fecal contamination. Finally, dissemination of the results of this study and other *E. coli* measurement programs in the state on the WWW will heighten public awareness of water quality issues within the state of Vermont.

## Investigators Qualifications

Leslie Morrissey, the Principal Investigator, is an Associate Professor in the School of Natural Resources. With twenty years experience and expertise in remote sensing, GIS, and ecology, she is an investigator in three NASA-funded research projects utilizing recently launched satellite data (POLDER and RADARSAT) for mapping wetlands. She is also an International Investigator for the soon to be launched European satellite ENVISAT. To date, she has published 38 refereed journal articles, conference proceedings, and technical reports. She currently mentors six graduate students whose research address issues regarding water quality, wetlands, and human health. Her curriculum vitae can be found in the Appendix.

**Training Potential**

Two graduate students from the University of Vermont will take part in this project. The first, Deborah Sargent, was involved in water sampling in the Mad River last year. She will complete her thesis by the spring of 2001. We will utilize her expertise in lab processing of water samples, GIS database development, and WWW page design. A second student, Jarlath O'Neil-Dunne, is participating in the proposed research. Undergraduate students will also be recruited to participate in water sampling, GIS database development, and WWW design as part of the School of Natural Resource's internship or honors programs.

**Proposed Schedule**

- GIS database development
  - Satellite data acquisition
- Mapping of riparian zones
  - Presence, absence of riparian buffers
  - Buffer width, length, and vegetative type
  - Mapping of drainage channels
- GIS suitability modeling of candidate parcels
- Preliminary evaluation of model

**Dissemination of Results**

The results of this proposed research effort will be disseminated in the form of one or more refereed articles in scientific journals or conference proceedings. A Web page will also be created to provide a broader outlet for dissemination to the public sector. The graduate students involved in the research will give a seminar at the University of Vermont detailing their analyses and results. The GIS database developed as part of this project will be made available through the Vermont Center for Geographic Information (GIS archive for the state).

**Results to Date**

To date, we have developed a GIS database of existing data layers (streams, land cover, soils, and DEM), generated the required derivative layers (slope, aspect, and hydrology), and mapped riparian zones and adjacent fields with digital orthophotography. Based on these efforts, we have concluded that panchromatic digital orthophotography (even with 0.5m resolution) acquired during leaf off stage is inadequate for mapping vegetative characteristics and distinguishing field crops. Therefore, digital band-sharpening techniques that are used to merge high-resolution panchromatic data (VT DOQs) with satellite data acquired in the near infrared region of the spectrum would be needed. Since IKONOS satellite data have not been acquired for the study region due to cloud cover and acquisition scheduling conflicts, we will acquire Enhanced Thematic Mapper (ETM+) multispectral satellite data for this purpose. We shall incorporate IKONOS 4m data if they become available for this study area.

A Web Page incorporating data from VT River Watch volunteer groups throughout the state, public state beaches, and our own on-going research efforts has been constructed with more than 70 pages of information on *E. coli* and recreational water quality in Vermont.  In the month of October, 2000, this web page received 1283 hits!

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**RECENT REFEREED PUBLICATIONS**

Vanderbilt, V. C., G. L. Perry, G. P. Livingston, S. L. Ustin, M, C. Diaz Barrios, F. M. Breon, M. M. Leroy, J. Y. Balois, L. A. Morrissey, S. T. Shewchuk, J. A. Stearn, S. E. Zedler, J. L. Syder, S. Bouffies, M. Herman, Wetlands Discrimination using Sun Glint, *IEEE Transactions on Geoscience and Remote Sensing*, in press.

Morrissey, L.A., G. P. Livingston and S. C. Zoltai. Influences of Fire and Climate on Patterns of Carbon Emissions in Boreal Peatlands, Chapter in *Fir, Climate Change, and Carbon Cycling in the Boreal Forest* (eds. E. Kasischke and B. Stocks), John Wiley and Sons, New York, 2000, pg. 423-439.

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# Information Transfer Program

# Student Support

| Student Support | | | | | |
|---|---|---|---|---|---|
| **Category** | **Section 104 Base Grant** | **Section 104 RCGP Award** | **NIWR-USGS Internship** | **Supplemental Awards** | **Total** |
| **Undergraduate** | 0 | 1 | 0 | 0 | 1 |
| **Masters** | 0 | 1 | 0 | 0 | 1 |
| **Ph.D.** | 0 | 0 | 0 | 0 | 0 |
| **Post-Doc.** | 0 | 0 | 0 | 0 | 0 |
| **Total** | 0 | 2 | 0 | 0 | 2 |

# Notable Awards and Achievements

None

# Publications from Prior Projects


1. Papadopoulou, M.P., G.F. Pinder, and G.P. Karatzas.1999. A Dynamic Approach to Groundwater Remediation Design. 8 pages