Vermont Water Resources and Lake Studies Center Annual Technical Report FY 2004

Introduction

The Annual Report for the Vermont Water Resources and Lake Studies Center for FY2004 is attached. The grant awarded under the State Water Resources Research Institute Program is 01HQGR0115.

Research Program

The Vermont Water Resources and Lake Studies Center supported two major research projects during FY2004. The Center supported a project entitled Detection of cyanobacterial blooms using remote sensing which was lead by Drs. Suzanne N. Levine and Leslie A. Morrissey. Cyanobacterial (blue-green algal) blooms have recently become a major nuisance and potential health threat in Lake Champlain. Some species of cyanobacteria produce neurotoxins that may cause serious illness and even death in humans. So far there have been no incidents of human health problems associated with cyanobacterial blooms, but several years ago two pet dogs died from drinking water heavily infested with cyanobacterial. Since that time cyanobacterial cell numbers have been monitored seasonally and a plan has been developed to monitor the toxin levels in the water. However, the efficiency of sampling these blooms and developing timely management plans is hampered by their extremely patchy distributions in time and space. The primary goal of this project was to investigate whether remote sensing tools could be used to reliably identify cyanobacterial blooms in the lake. The project participants assessed a variety of potential remote sensing platforms and products, acquired several test images, developed and tested algorithms to predict cyanobacterial abundance from the imagery and verified the remote sensing predictions through a groundtruthing protocol. The results of the project suggest that remote sensing can be successfully employed to identify cyanobacterial blooms. Some continued refinement of the algorithms is on-going. The project has supported one MS graduate student (Sarah Wheeler) and has produced two symposium presentation and one published paper.

The Center also supported a project entitled A Comparison of Fecal Concentrations in Streams: a Paired Watershed Study lead by Dr. Leslie A. Morrissey. FY2004 was the first year for this project. This project is a complement to an ongoing paired watershed that is focused on the effects of ski development on water quality. The ski industry is important in Vermont. There are numerous ski developments in the state that exert pressures through associated developments. These developments are expanding in Vermont and there is concern that continued development might impair these healthy streams. Fieldwork completed in the first year of this project shows that fecal bacteria are not abundant in streams during baseflow. However, during storm events levels of fecal coliform bacteria in excess of the state standards were detected in stream water draining both the developed and undeveloped watershed. The sources of this contamination are currently not known. Work will continue this coming year on land use/land cover classification using remotely sensed data to help identify and assess the risks of fecal contamination from various sources. This project is supporting one MS graduate student (Mathew Bruhns).

In addition to oversight of these two projects the Water Center continues to publish its newsletter in collaboration with the University of Vermont Sea Grant Program. It also continues to play a leadership role in evolving strategies of land and water management in Vermont. In particular, the Water Center has been instrumental in leveraging new funds from Federal (EPA) and state (Agency of Natural Resources) sources for research that is urgently needed to support management decisions about urban stormwater management in rapidly developing areas in Vermont. These projects include efforts to identify impairments to ecosystem functions in stormwater impacted streams, a project to identify key indicators of geomorphic change in urban streams, a project to find ways to better involve citizen stakeholders in decisions about local stormwater management, a project to develop new hydrological and GIS based tools to prioritize stormwater permitting activities, and a project to identify whether and how neighborhood types influence stream health. All of these projects are relevant to key policy and management needs identified by local stakeholders. The Vermont Water Resources and Lake Studies Center continues to be a visible and trusted source of data and knowledge about these issues.

Detection of cyanobacterial blooms using remote sensing

Basic Information

Title:	Detection of cyanobacterial blooms using remote sensing
Project Number:	2002VT5B
Start Date:	3/1/2004
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	First
Research Category:	Not Applicable
Focus Category:	Water Quality, Methods, Toxic Substances
Descriptors:	
Principal Investigators:	Suzanne Levine, Leslie A. Morrissey

Publication

1. Wheeler, S., L. Morrissey, S. Levine, and W. Vincent, 2005, Mapping Cyanobacteria Blooms in Lake Champlain at Multiple Scales: A Comparison of Three Satellites, Ecological Society of American 90th Annual Meeting, August 7 12, Montreal, Canada. Morrissey to present.
2. Wheeler, S., S. Levine, L. Morrissey, and W. Vincent, 2005, A Comparison of Satellite Sensors for Mapping Cyanobacteria in Lake Champlain, USA/CAN, American Society of Limnology and Oceanography Annual Summer Meeting, June 19-24, Santiago de Compostela, Spain.
3. Wheeler, S.M, S.N. Levine, L.A. Morrissey, and W.F. Vincent. 2005. A COMPARISON OF SATELLITE SENSORS FOR MAPPING CYANOBACTERIA IN LAKE CHAMPLAIN. ASLO Meeting, June 19-24, Santiago de Compostela, Spain
4. Wheeler, S.M, L.A. Morrissey, S.N. Levine and W.F. Vincent. 2005. Mapping cyanobacteria blooms in Lake Champlain at multiple scales: A comparision of three satellites. Abstracts. ESA INTECOL Joint Meeting, August 7-12, Montreal, Canada.

Detection of cyanobacterial blooms using remote sensing

Suzanne N. Levine and Leslie A. Morrissey (Principal investigators)
Sarah Wheeler (Graduate Student)
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The goal of this two-year study is to assess the feasibility of tracking and quantifying cyanobacterial blooms in Lake Champlain using remote sensing. Throughout this study, the 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) develop a local bio-optical model that relates 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). We investigated the usefulness of three operational satellites for mapping and quantifying cyanbacterial biomass in Lake Champlain. The three satellite sensors examined included SPOT, Envisat MERIS and QuickBird. The spatial and spectral resolution of each satellite along with the cost and frequency of image acquisition were considered while evaluating the utility of each system.

In the summer of 2003, we acquired two images from the commercial European satellite SPOT. SPOT has a spatial resolution of 10 m that allows for examination of spatial 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. One scene was acquired (Aug 18th, 2003) coincident with field data collection.

Two cloudless MERIS images were acquired in September of 2003, in addition to 4 images in the summer of 2004. Groundtruthing was conducted for four of the dates of image collection (in either St. Albans or Missisquoi Bays during MERIS flyovers). MERIS is a sensor on the European satellite Envisat and has a return time of about 3 days. Although its spatial resolution is coarse (300 m pixel width), spectral band positioning is optimized for examining phytoplankton. The 15 spectral bands of this satellite allow for bio-optical modeling which is not possible with the other two satellites examined for this study. 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. ENVISAT is considered an experimental satellite; 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.

A single QuickBird image was collected in August of 2004. QuickBird is a commercial satellite launched by the company, DigitalGlobe, based out of Colorado. This satellite has 2.4-meter spatial resolution and spectral resolution similar to SPOT. Although QuickBird imagery is not practical from a monitoring perspective due to high cost, the high resolution imagery provides an excellent opportunity to study spatial detail of phytoplankton distributions.

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 continues. 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 (r^2=0.57; n=415). 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 much better than the single site sampling normally carried out by the Vermont Department of Environmental Conservation.

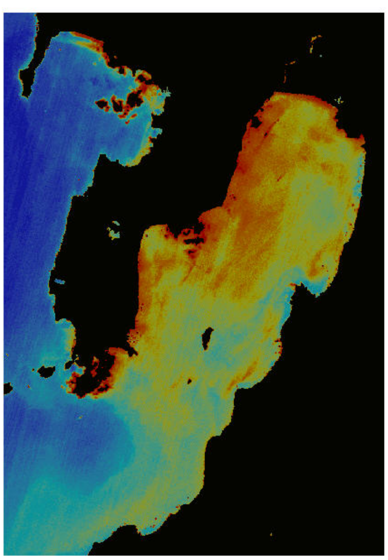

Figure 1. Relative chlorophyll content displayed from red (high concentrations) to blue (low concentrations). Predictions are based on principal components analysis of SPOT satellite imagery collected over St. Alban's Bay on August 18th, 2003.

The positioning of QuickBird spectral bands are similar to those of SPOT and therefore, PCA analysis is also being conducted on the QuickBird image. The derived algorithm from the analyses will be used to extrapolate chlorophyll *a* and phycocyanin concentrations for all of Missisquoi Bay. The high resolution imagery should allow for detailed examination of cyanobacteria distribution in the Northern portions of Lake Champlain.

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.

Results to date will be presented this June at the American Society for Limnology and Oceanography (ASLO) conference in Santiago de Compostela, Spain as well as at the Ecological Society of America conference this August in Montreal.

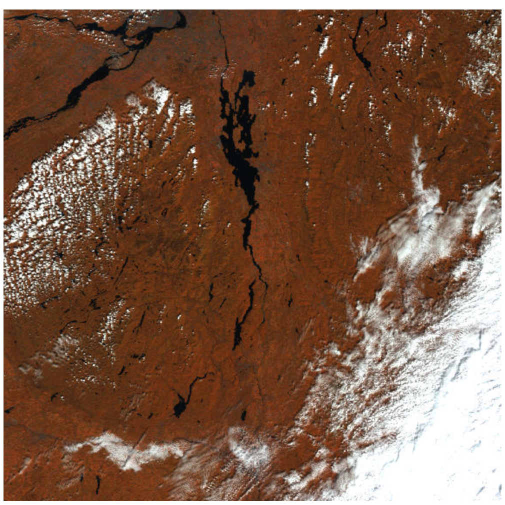

Figure 2a. Full scene of Lake Champlain taken from ENVISAT Meris on September 26th, 2003.

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

Conference Abstracts

Wheeler, S., L. Morrissey, S. Levine, and W. Vincent, Mapping Cyanobacteria Blooms in Lake Champlain at Multiple Scales: A Comparison of Three Satellites, Ecological Society of American 90th Annual Meeting, August 7 – 12, 2005, Montreal, Canada. Morrissey to present.

Wheeler, S., S. Levine, L. Morrissey, and W. Vincent, A Comparison of Satellite Sensors for Mapping Cyanobacteria in Lake Champlain, USA/CAN, American Society of Limnology and Oceanography Annual Summer Meeting, June 19-24, 2005, Santiago de Compostela, Spain.

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.

A Comparison of Bacterial Concentrations in Streams: a Paired Watershed Study

Basic Information

Title:	A Comparison of Bacterial Concentrations in Streams: a Paired Watershed Study
Project Number:	2004VT16B
Start Date:	3/1/2004
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	First
Research Category:	None
Focus Category:	Water Quality, Non Point Pollution, Surface Water
Descriptors:	None
Principal Investigators:	Leslie Morrissey

Publication

1. Title: A Comparison of Bacterial Concentrations in Streams: a Paired Watershed Study

2. Project Type: Research

3. Focus Categories: WQL, NPP, SW, HYDROL

4. Keywords: fecal contamination, *E. coli*, coliform, stream discharge, water quality, watersheds, remote sensing, GIS

5. Start Date: March 1, 2004

6. End Date: February 28, 2006

7. Principal Investigator: Leslie A. Morrissey, Associate Professor, University of Vermont, 802 656-2695

8. Congressional District: 1st District, State of Vermont

9. Abstract:

Throughout the U.S., high-elevation forested watersheds are facing the pressures of development for increased housing, year-round recreational use, water management, and timber. Towards improving our understanding of how development-related disturbances may affect these highly sensitive ecosystems, the proposed research will address fecal contamination in relation to hydrologic and sediment loading responses in paired undeveloped and developed watersheds within a northeastern high-elevation forest.

Runoff from residential, agricultural, and forested lands carrying microorganisms from fecal sources can pose a serious risk to human health through contamination of drinking and recreational waters. Uncertainties in the relative importance of these fecal sources, however, have constrained federal and state agency efforts to understand and manage water quality. In particular, although bacteria levels in streams are strongly correlated with development and agricultural runoff, there is considerable debate regarding the contribution of undeveloped areas (which in the northeastern U.S. often are represented by higher elevation forested lands). Limited observations, however, suggest that fecal bacteria in streams draining undeveloped forest lands may significantly contribute to downstream concentrations and may exceed water quality standards during storm events. To date, however, no studies have addressed bacterial contamination in streams draining high-elevation forested watersheds in the northeastern U.S.

The proposed study offers a unique opportunity to address these uncertainties by quantifying stream bacteria levels in paired, forested watersheds on Mt. Mansfield in northern Vermont. The overall goal of this research is to assess the contribution of developed and undeveloped forested lands to bacterial contamination of adjacent streams, providing improved understanding of downstream water quality and a baseline for planned future development of the study area. Access to near-real-time meteorological and stream gage data will further allow quantification of the relationship between stream discharge, sediment loading, and bacteria concentrations. Such information is critical if we are to understand the factors contributing to water quality in northeastern forested regions and to assess current and proposed changes to the Vermont water quality standards. The proposed analyses will combine *in situ* water sampling of *E. coli* (a fecal indicator), stream gage data, analysis of land use/land cover updated with high resolution satellite imagery, and hydrological modeling within a GIS framework. Collaboration with recently initiated efforts by Drs. J. Shanley (USGS) and B. Wemple (University of Vermont) will facilitate an integrated and cross-disciplinary assessment of how ski-area development may affect the hydrology, and environmental and water quality of these ecosystems.

12. Title: A Comparison of Bacterial Concentrations in Streams: a Paired Watershed Study

13. Statement of critical regional or state water problem:

Fecal contamination of surface waters is a major concern across Vermont and throughout the northeastern U.S. (Crane et al., 1983; Smith et al., 1987; Vermont Water Resources Board, 1996; Meals, 1996). Runoff from residential, agricultural, and forest lands carrying microorganisms from fecal sources can pose a serious risk to human health through contamination of drinking and recreational waters (Francey et al., 1993; Tiedemann et al.; 1988; Rosen, 2001). Increasingly frequent beach closures and warnings regarding use of recreational waters are a source of public frustration and confrontation between various stakeholders and an indication of an increasing water quality management problem. In turn, the lack of water quality data on fecal bacteria has fueled recent debate regarding revision of the state's Water Quality Standards for recreational waters, delayed implementation of state legislation designed to regulate septic systems of seasonal homes, and impacted efforts by local communities and environmental action groups to seek solutions to the water quality issues related to fecal contamination.

Although fecal bacteria levels in streams are often strongly correlated with the amount of developed land and impervious area within a watershed (Mallin et al., 2000), isolated studies also report bacterial contamination in streams draining "pristine" areas that exceed federal and state water quality standards (Bohn and Buckhouse; 1985, Niemi and Niemi; 1991, Edwards et al., 1997). To date, however, only a single (and yet unpublished) study in Vermont has documented the contribution of streams to fecal bacteria levels in undeveloped watersheds and this was limited in scope to two small streams (Sargent, 2001). Moreover, there are no data on fecal contamination in high-elevation watersheds in the Northeast, although these ecosystems are facing intense development pressures and are highly sensitive to disturbance.

To address these issues, studies are needed to assess the background contribution of undeveloped forested watersheds, the impacts of ski resort development on water quality, and the relationship between stream discharge, sediment loading, and fecal bacteria concentrations. To meet these objectives, this proposed study will compare stream water quality in two high-elevation, forested watersheds in northern Vermont to quantify the contribution of an undeveloped and developed watershed to fecal bacteria levels in adjacent streams. These data will also serve as a baseline against which the impacts of significant planned development in the study area over the next several years may be compared. These data are particularly needed because the Water Quality Management Plan in effect for the planned development does not address bacterial monitoring (J. Shanley, USGS, pers. comm.).

14. Statement of results or benefits:

The results of this study will contribute to the resolution of discussions at regional, state and local levels regarding the relative contribution of fecal bacteria from undeveloped forested watersheds to downstream water quality. Additionally, this effort will provide a baseline against which the impacts of present and planned housing, recreational and water management developments within the study area on fecal bacteria can be assessed in relation to hydrologic and sediment loading responses, thus either verifying the effectiveness or demonstrating the limitations of current and planned water quality management efforts. Together with an improved understanding of the relationship between stream discharge and fecal bacteria, this information will aid communities, developers, and water quality managers (particularly in high-elevation forested environments) in deciding how best to address their water quality management needs. Such information is critical to both understanding the factors contributing to bacterial contamination of surface waters and to assessing current and proposed state water quality standards.

An additional product of this effort will be a Geographic Information System (GIS) database integrating georeferenced land use/land cover information (e.g., the areal representation of impervious surfaces, forests, cleared ski trails, and other lands derived from analysis of high spatial resolution satellite imagery) with available data on topography, roads, streams, etc. to characterize the respective watersheds. These data will directly support not only this study but also collaborative hydrologic and sediment loading projects led by USGS and UVM investigators in return for near-real-time meteorological and stream discharge data. The resultant GIS database in turn will be made available to the public through the Lamoille County Planning Commission and Vermont Center for Geographic Information (VCGI) to aid regional planning and flood water management efforts within the encompassing Lamoille River watershed.

The results of this proposed research effort will be disseminated in one or more refereed journal article(s) or conference proceeding(s) and posted on the Internet to an existing water quality site developed and managed by the Principal Investigator to provide public access to fecal bacteria monitoring results across the state (*Recreational Water Quality in Vermont*, http://www.uvm.edu/~envnr/sal/ecoli/index.htm).

15. Nature, scope, and objectives of the project, including a timeline of activities:

Focused on the northeastern U.S., the proposed research addresses whether undeveloped high-elevation forested watersheds are a significant source of fecal contaminants to downstream surface waters and the relative impact of existing and planned development within these high-elevation watersheds on stream water fecal concentrations. The specific objectives of the proposed research are to:

- Characterize the concentration and temporal variability of fecal contaminants in the surface waters draining separate undeveloped and developed, high-elevation, forested watersheds
    - Characterize the existing land use/land cover within each watershed and assess the impact of development on stream bacteria concentrations
    - Establish a baseline of fecal bacteria concentrations against which the impacts of planned housing, recreational, and water management developments over the next several years can be compared

- Quantify the relationship between stream discharge, sediment loading, and *E. coli* concentrations within the undeveloped and developed watersheds during base flow and storm events

To meet these objectives, our approach will be based on three specific tasks: monitoring of fecal bacteria concentrations, satellite image analysis and GIS development, and hydrological modeling. We will monitor fecal bacteria levels in Ranch Brook (undeveloped watershed) and West Branch (developed watershed) streams located on the eastern slope of Mt. Mansfield in northern Vermont to address uncertainties in our current understanding of the contribution of developed and undeveloped watersheds to downstream bacterial water quality. Specifically, levels of *E. coli* and fecal coliforms will be monitored in the paired watersheds throughout two growing seasons (from just before snowmelt until freeze up) on both systematic (weekly) and storm-event bases.

Study Area: The two watersheds proposed for study are located on the eastern slope of Mt. Mansfield in northern Vermont and are both within the Lake Champlain basin. These drainages were selected in a recently initiated collaboration between USGS (J. Shanley) and UVM (B. Wemple) investigators to specifically address the potential impacts of development on high-elevation forested watersheds. From an ecosystem perspective, the study area is representative of the northern forest ecosystem that characterizes the northeastern U.S. and of the Green Mountain forest ecosystem of Vermont. The Ranch Brook watershed (10.5 km^2) occupies a nearly pristine forested basin, while West Branch Little River (12.0 km^2) encompasses two ski resorts (Mt. Mansfield Ski Resort and Stowe Mountain), associated development (roads, buildings, ski lifts, trails) and is bisected by Vermont State Highway 108. The West Branch drainage also is the site for extensive expansion of the Stowe Mountain Ski Resort over the next several years that will include a planned residential community, extensive expansion of recreational activities and lands, and the implementation of extensive snow making facilities. The two watersheds share similar geology, size, elevation, slope, soils, and forest cover; the principal difference is land use.

It is anticipated that development in the West Branch watershed may augment surface runoff and stream flow and thus potentially impact stream discharge and fecal bacteria levels in the watershed. Monitoring of bacteria levels in these streams prior to expansion of development will provide a much needed baseline for this assessment. This is particularly important because the Stowe Water Quality Management Plan does not include bacterial monitoring as part of its water quality measurement program (J. Shanley, USGS, per. comm.).

Timeline: Weekly and storm event-based water sampling will be carried out from April through September in both 2004 and 2005.

Year one: Hydrologic modeling to define drainage areas will be conducted in collaboration with USGS and UVM investigators early in the first year to assist in defining drainage areas within the two watersheds. Field sampling protocols will be defined and amended as required early in the first field season to best meet the project objectives but will be fixed in year two. IKONOS or Quickbird satellite imagery will be scheduled for acquisition during the summer of 2004 and analyzed that fall. Acquisition and integration of GIS data layers and preliminary analyses of the water data will also occur over the first year.

Year two: Validation and refinement of the resultant land use/land cover mapping and related GIS data layers will be completed early in the second year and incorporated into the USGS/UVM hydrologic model to aid analyses following completion of the field season. Statistical analyses of the 2004 water data will be completed early in 2005; analyses of 2005 water samples will be completed during and immediately following the field season. Preparation of manuscript and conference materials (comparison of bacterial levels in paired watersheds and relationship between stream discharge, sediment load, and bacterial levels) will begin immediately following the second field season. Resultant land use/land cover and other GIS data will be provided to the Regional Planning Commission and VCGI within 6 months of completion of this project. Water quality data will be posted to the Internet for public review also within this timeframe.

16. Methods, procedures, and facilities:

The proposed research will involve *in situ* water sampling of *E. coli* and fecal coliform bacteria, analysis of land use/land cover within each watershed (updated with high resolution satellite data), development of a GIS based on available and derived data layers, and hydrologic modeling to determine subwatershed drainage areas. This effort will complement on-going hydrology, sediment, and stream water chemistry studies by USGS and UVM investigators within the study area and thus will benefit from existing cooperative agreements, infrastructural support, and the mutual exchange of data.

Site Characterization and Environmental Monitoring: All water samples will be collected at the two gaging station locations. Drainage catchments within each of the West Branch and Ranch Brook watersheds will be delineated using VT 1:5,000 scale digital elevation model (DEM) data and ArcGIS in collaboration with B. Wemple (UVM). Land use and topographic descriptions for each watershed will be summarized based on select GIS data layers, 1:5,000 digital orthophotography, 1:5,000 E911 data layers (buildings, roads, driveways), soils and field reconnaissance. Since the digital orthophotography and derivatives (E911 data layers) are based on imagery acquired in 1994, high resolution satellite imagery will be analyzed to update land use and land cover data in the two watersheds. Real-time stream discharge data will be provided by the USGS gaging station within each watershed and made available via the World Wide Web. Hourly to daily meteorological observations (including precipitation) within each watershed and from the nearby eastern slope of Mt. Mansfield (summit and MMW stations) are archived and will be made available on a weekly to seasonal basis depending upon the location of the instruments.

Water Sampling and Analysis**:** *In situ* water samples (with replicates) will be collected at each gaging station within each watershed on a weekly basis from April through September in 2004 and 2005. Additional storm-event based observations will supplement the weekly samples to clarify the contribution of storm events to seasonal fecal bacteria loadings. Sampling frequency (~2 hrs) for four selected storm events will be timed as possible using local weather forecasts and the USGS stream gage data to represent stream bacteria levels immediately prior to and at each stage of the storm hydrograph. Storm water sampling protocols will be defined to ensure both the safety of the field personnel and the integrity of the samples.

Water samples will be collected and handled following established EPA protocols and will be analyzed in the Principal Investigator's laboratory at UVM. Additionally, because fecal materials are known to readily adsorb onto suspended sediments in surface runoff and stream waters, we will coordinate sampling and subsequent correlation of fecal and sediment stream loadings with UVM investigators. Sediment analyses will be performed by B. Wemple (UVM) as part of an independent investigation. Fecal analyses will be based on replicate water samples (r = 2) collected in sterile polypropylene bottles directly from the stream, stored on ice, and processed within 6 hours. *E. coli* and fecal coliform analyses will follow EPA protocol (USEPA, 1985) using the EPA-approved IDEXX Quantitray 2000 analyzer and Colisure reagent. Following initial processing, samples will be incubated at 35° C for a period of 24-48 hours prior to reading.

Current Water Quality Standards adopted by Vermont are based on a single sample *E. coli* limit of 77 colonies/100ml water for Class B recreational waters suitable for direct contact, such as swimming (Vermont Resources Board, 1996). While water quality standards at the federal and state levels are based on an indicator *E. coli* concentration above which the human health risk from waterborne illness is unacceptably high, this approach does not account for the amount of water present. Normalizing the concentrations by stream discharge, in contrast, does provide a true measure of the delivery rate of bacteria to downstream waters per unit time (load). Our analyses will include both *E. coli* concentrations and load.

Since bacterial counts are often exponential in distribution, data summaries and analyses will be based on log transformed data as needed. Resultant bacterial concentrations will be normalized by stream discharge at the time of sampling so that data from different streams and time periods can be compared. Fecal concentration and loading data will be analyzed using appropriate repeated measures for time series data. Time plots will show trends, seasonality, and outliers. Analysis of the relationship between *E. coli* concentrations and total suspended sediment or stream discharge will be analyzed using a bivariate cross-correlation function based on paired watershed observations over time.

<u>GIS Database Development:</u> Water sampling site selection, characterization and subsequent analyses require the acquisition and integration of several GIS data layers, analysis of satellite imagery, and the results of laboratory water sample analyses. Initial efforts will focus on delineating sub-watershed drainage areas using 1:5,000 scale digital elevation model data to aid site selection and characterization, and analysis of high spatial resolution satellite imagery to map land use/land cover (particularly impervious and forested areas) within each watershed. Subsequent analyses will incorporate data layers for land use/land cover, slope, soils, and distance from drainages. Land use attributes such as road density, number of structures, type of structures, etc. will be summarized along with forest cover for each watershed and water sampling site drainage area. Most data are available at a scale of 1:5,000. All analyses will be performed using ESRI's commercial software, ArcGIS. A tentative list of the GIS data layers and derivatives to be incorporated in support of this proposed research include:

Available data layers and source

- Stream network; VCGI
- Digital topographic data (DEM); VT Mapping Program
- Digital orthophotography; VT Mapping Program
- High spatial resolution satellite data; IKONOS (4m multispectral, 1m panchromatic) or Quickbird (2.5m multispectral, 0.6m panchromatic)
- E911 structures and roads; VCGI

Data layers to be derived

- Sub-watershed drainage area delineation
- Detailed land use/land cover e.g., impervious surface, forested areas, etc.

Image Processing: One scene of either IKONOS or Quickbird multi-spectral and panchromatic imagery will be acquired during the summer (leaf on) of 2004 for use in deriving land use/land cover. A search of both satellite data archives indicate that imagery for the study area is not currently available and thus will have to be ordered. We will request the basic product to which radiometric and first order geometric corrections have been applied. Upon delivery, we will further preprocess the imagery by rectifying it to an appropriate map projection and apply a correction for topographic shadowing. Digital classification of land use and land cover within each watershed will be performed using the commercial image processing software eCognition™ and ERDAS Imagine™. eCognition is an object oriented "smart" classifier developed specifically for high resolution digital imagery that utilizes spectral, contextual, and textural information in the classification process. We will also explore using the higher spatial resolution panchromatic data to subsequently band-sharpen the multispectral data to improve definition of edges. Our experience in mapping urban impervious surfaces has demonstrated this technique performs well. The land cover mapping will quantify the fraction of forested, impervious and other important land covers within each watershed. Additionally, we will apply image enhancement techniques to update features not shown on the E911 data layers, such as residences and roads that have been constructed since the creation of the original E911 data layers. Validation of mapping efforts will be conducted through field verification and comparison with existing GIS data layers and available aerial photography and/or orthophotography.

Facilities: Analysis of the water samples for *E. coli* and fecal coliforms will be conducted in the PI's laboratory in the School of Natural Resources (UVM). Available laboratory equipment and supplies include an IDEXX Quanti-Tray 2000, Colilsure reagent, incubator, and glassware, de-ionized water, pipettes, etc.. The IDEXX Quanti-Tray/2000 provides semi-automated quantification methods for coliforms and *E. coli* with counts from one to 2,419/100 ml. Colisure is a US EPA-approved reagent for fecal testing and is outlined in *Standard Methods for Examination of Water and Wastewater*.

GIS and image analyses will be performed using the computational facilities of the Spatial Analysis Lab (SAL), School of Natural Resources. The SAL is a research facility dedicated specifically to digital image processing and GIS analyses. The SAL houses several high end PCs and associated peripherals (CD/DVD reader/writer, color plotter, color printer, Exabyte tape drive). The SAL has site licenses for ESRI's suite of GIS software (ArcGIS), eCognition, and ERDAS Imagine software for image processing. Morrissey contributes to and assists in the management of SNR's Spatial Analysis Laboratory and thus has access to those restricted facilities.

17. Related research:

Bacterial concentrations in streams draining undeveloped watersheds: While forested watersheds generally have better bacterial water quality than that of other land uses (Kunkle and Meiman 1967, Kunkle 1970, Skinner et al. 1974, Doran and Linn 1979, Tiedmann et al. 1987, Niemi and Niemi 1991, Sargent 2001), these watersheds can nevertheless be important contributors to fecal contamination downstream. Several studies have documented the existence of fecal bacteria in "pristine" environments, even under non-storm conditions. Morrison and Fair (1966) reported fecal coliforms in "clean" streams in Colorado. Early studies by Kunkle and Meiman (1967) and Skinner et al. (1974) of natural areas essentially free of human impact, identified low maximum fecal coliforms counts in the range of 20-25/100mL. At times, the results have been much higher than expected during non-storm events. A study of 3 small watersheds in Utah that had been protected from fire, domestic livestock, and timber cutting for 45 years yielded fecal coliforms concentrations that ranged to maxima of 183 organisms/100 mL (Doty and Hookano, 1974). Ongerth et al. (1995) documented levels of fecal coliforms higher than 100 organisms/100 mL in a pristine forested watershed, while Tiedmann et al. (1987) reported fecal coliforms in excess of 500 organisms/100 mL in forested areas of eastern Oregon that supported no domestic grazing. More recently, Moir and Morrissey (in. prep.) found that up to 50% of the water samples collected in undeveloped, forested watersheds of the Mad River violated Vermont Water Quality Standards during storms.

Stream fecal bacteria levels related to land use: Most studies quantifying the relationship between land use and water quality have been focused on sediment and nutrient loading, particularly phosphorus and nitrogen, and contamination by metals or toxic chemicals, but the spatial framework also applies to the study of bacterial water quality. Since watersheds integrate surface and subsurface flow of water above a sample point, they are appropriate spatial units for the study of nonpoint source stream pollutants like fecal bacteria (Omernik and Bailey, 1997). Cumulative impact studies have compared changes in water quality to changes in land use by locating sampling stations consecutively downstream. In the Appalachian Mountains of North Carolina, fecal coliform counts increased downstream as land use changed from forested to suburban (Bolstad and Swank, 1997). Osborne and Wiley (1988) used a cumulative impact analysis of the effect of land use on water quality in the Salt Fork, Illinois watershed to show that phosphorus and nitrogen stream concentrations were primarily due to urbanization. In a comparison of stream fecal coliform concentrations monitored above and below rural municipalities, the municipalities were found to contribute a significant amount of fecal bacteria to surface waters (Farrell-Poe et al., 1997). In contrast, Sargent (2001) found no difference between *E. coli* measurements above and below a Vermont village. However, she did find a significant negative relationship between watershed forest cover and *E. coli* concentrations in streams in the Mad River valley. Relating bacterial levels in streams to land use can be improved by aggregating and analyzing data within watersheds and drainage areas.

Streambed sediments as a reservoir of fecal bacteria: Studies measuring the amount of bacteria found in streambed sediments and comparing it with levels in the overlying water column have documented that streambed sediments represent a significant reservoir of fecal bacteria. The phenomenon of deposition was demonstrated by a dye study conducted by Gannon et al. (1983), in which fecal coliform concentrations in bottom sediments were shown to increase in an upper area of the study lake while fecal coliforms in the water column were decreasing simultaneously. Gannon concluded that sedimentation of fecal coliforms attached to solid particles accounted for the high fecal coliform disappearance in that area of the lake. Van Donsel and Geldreich (1971) discovered approximately a 100-1000 fold increase in fecal coliforms in stream sediments as compared to the overlying water. Stephenson and Rychert (1982) confirmed this finding with their own observations that *E. coli* concentrations in bottom sediment were 20-760 times that of the water. Both Crabill et al. (1999) and Buckley et al. (1998) observed fecal coliform sediment to water ratios of greater than 2000:1. There have also been several studies that did not directly sample the sediment, but instead used disturbance methods like raking to simulate the resuspension of the sediment and its associated bacteria such as would occur during recreational use or high stream flows. Sherer et al. (1988) found that manual disturbance of stream bottom sediments increased bacterial water concentrations an average of 17.5 times. Moir and Morrissey (in prep.) found that high storm flows are particularly effective in resuspending most of the fecal-bound sediments during a storm event. Thus recontamination of surface water can occur long after and at a considerable distance from the point of original fecal input to the stream.

18. Training potential: One full time graduate student will be recruited to conduct this research as part of his/her graduate thesis research. As a result, he/she will receive training in water sampling and analysis, GIS and image processing of satellite data.

19. Investigators qualifications: Leslie Morrissey, the Principal Investigator, is an Associate Professor in the Rubenstein School of Environment and Natural Resources. L. Morrissey has extensive experience using satellite remote sensing and GIS in terrestrial, wetland and aquatic ecosystems. In addition, over the past 7 years, she has conducted four water quality related research projects (graduate student theses) focusing on fecal contamination of Vermont streams and rivers. She has published 38 refereed journal articles, conference proceedings, and technical reports.

Collaboration with Drs. B. Wemple and J. Shanley will also contribute to the success of this effort by providing hydrologic and water quality data. Water sampling, quality control, and analyses will be conducted under the direction of the P. I. and in collaboration with project leaders J. Shanley (USGS) and B. Wemple (UVM). Since stream discharge data will be utilized in calculation of fecal load data, data sharing will be coordinated with J. Shanley (USGS). Hydrologic modeling and water sediment sampling will be coordinated with B. Wemple (UVM).

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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	0	0	0	0
Masters	2	0	0	0	2
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	2	0	0	0	2

Notable Awards and Achievements

Publications from Prior Projects

1. 2000VT21N ("Stable Isotope Analysis of the Contribution of N2 Fixation to Phytoplankton Nutrition, Lake Nitrogen Budgets and Lake Eutrophication") - Articles in Refereed Scientific Journals - Ferber, L.R., S.N. Levine, A. Lini and G.P. Livingston, 2004, Do cyanobacteria dominate in eutrophic lakes because they fix atmospheric nitrogen? Freshwater Biology 49: 690-708.