Report for 2002VT1B: Water quantity and quality dynamics in high-elevation watersheds: Developing a scientific approach to understanding ski area impacts in Vermont

- Conference Proceedings:
  - Wemple, B., J. Shanley, and J. Denner. "Effects of an Alpine Ski Resort on Hydrology and Water Quality in the Northeastern U.S.: Preliminary Findings from a Field Study," American Geophysical Union Fall Meeting, San Francisco, CA. December 2002.
- Other Publications:
  - Shanley, J.B. and B. Wemple, 2002. Water Quality and Quantity in the Mountain Environment. Vermont Law Review (Special issue - Mountain Resorts: Ecology and the Law), 26(3):717-751.
  - Mussleman, K. Analysis of Spatial Variability of Precipitation on Mt. Mansfield, Stowe, VT. Vermont Geological Society Spring Meeting, Middlebury, VT. April 2002.
  - Denner, J., J. Shanley, and B. Wemple, 2001. Comparison of Runoff from a Ski Resort and Adjacent Undeveloped Watershed in Northern Vermont. Eastern Snow Conference, Stowe, VT. June 2001.
  - Mussleman, K. 2002. Analysis of Spatial Variability of Precipitation and Snow Accumulation on Mount Mansfield, Stowe, Vermont. Unpublished senior research project, Dept. of Geology, University of Vermont.
  - Muth, M. and L. Pascale. 2001. Runoff from Paved and Unpaved Parking Lots at the Spruce Peak Parking Area, Stowe Mountain Resort, Stowe, Vermont. Unpublished student research paper.
  - White, M. 2002. Total Suspended Solids and Runoff Analysis for the Big Spruce and Mansfield Tributaries in the West Branch Watershed, Stowe, Vermont. Unpublished student research paper.

Report Follows:

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

Annual Progress Report for the period

March 2002 – March 2003

Submitted to:
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Introduction and Project Objectives

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

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

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

Approach

Our approach combines the use of empirical data analysis of a paired-watershed study with simulation modeling to evaluate the effects of ski area operations. Our study area includes the West Branch (11.7 km^2) and Ranch Brook (9.6 km^2) watersheds, tributaries to the Little River in northwestern Vermont. The watersheds drain the eastern slopes of Mt. Mansfield, Vermont's highest peak, and have similar characteristics with respect to geology, soils, vegetation and relief. The West Branch watershed encompasses an entire alpine ski resort, which occupies roughly 15% of the basin area. The Ranch Brook watershed is undisturbed except for a network of cross-country ski trails. A paired-watershed study, initiated in the fall of 2000 and funded jointly by the U.S. Geological Survey and the Vermont Monitoring Cooperative, established stream gaging stations on both watersheds. Automated ISCO water samplers allow collection of water samples. Funding provided through this grant supports the analysis of total suspended solids, common cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, Fe^{3+}, and Mn^{2+}), inorganic anions (Cl^{-}, NO_3^{-} and SO_4^{2-}), total nitrogen and total phosphorus.

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

Progress to Date

Activities during Year 1 of the project have focused on data collection and analysis of water quality and quantity from the study watersheds. We have collected and processed over 300 samples for total suspended solids (TSS), common cations and inorganic anions. In addition, we have processed 35 samples from spring snowmelt and summer storms for total nitrogen (TN) and total phosphorus (TP). Our analysis involves establishing correlations between streamflow and water quality constituents (TSS, cations, anions, TN, TP) in order to estimate basin yields. We have also conducted empirical analyses of hydrograph data to compare water yields, peak flows and low flows between the two watersheds.

Modeling activities during Year 1 have focused on land cover analysis and data compilation for model parameterization. We have used a combination of manual interpretation of 1:5000 digital orthophotos and an unsupervised classification of satellite imagery to interpret land cover conditions for the watersheds (Table 1). We have also compiled and formatted GIS datalayers to represent elevation, soils, and vegetation for model input. Model parameterization is underway, with initial modeling results expected by September 2003.

Table 1: Characteristics of the study watersheds

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

* includes buildings and paved or gravel roads and parking lots

Results

Runoff analysis for the two basins indicates that flow is synchronized in time but distinctly different in peak magnitude and water yield (Figure 1). In WY 2001 and 2002, 80% of all paired peak flow events occurred within 1 hour of each other at the two basins. Unit area peak discharge at West Branch is higher than at Ranch Brook for summer and fall storms, but lower for winter and spring storms (Figure 2), suggesting that development increases peak runoff during rain events but reduces snowmelt peaks by storing and slowly releasing water from ski trails. This seasonal difference was statistically significant ($p = 0.04$) in WY 2001, when prodigious natural snow was available, but not in WY 2002 ($p = 0.16$), a drought year with little natural snowpack. Annual water yield for WY 2001 at West Branch was over 40% higher than at Ranch Brook, and exceeded water yield at other mountainous basins in the region (Figure 3). Differences in water yield between West Branch and Ranch Brook are larger than can be reasonably explained by land cover differences or basin hypsometry (Table 1, Figure 4) and appear to be due to large differences in measured streamflow during low and moderate flow periods (Figure 5). We are currently investigating whether a high precipitation anomaly exists in West Branch basin (Mussleman, 2003).

Our preliminary data analysis indicates that development in the West Branch basin affects key water quality parameters. Concentrations of TSS are higher, and they are flushed earlier in West Branch than the Ranch Brook basin (Figure 1). TSS concentrations are related to discharge, but concentrations peak in advance of the runoff peak (Figure 1b), leading to considerable scatter in the TSS vs. discharge rating curve (Figure 6). Yield of TSS also varies seasonally, with higher concentrations in both basins during spring/summer storms, presumably due to the lack of snowcover protection. Deicing salts applied to ski area parking lots cause a sharp chloride spike in streamwater at the onset of snowmelt (Figure 3a). The chloride concentration falls off rapidly but the signal persists year round, remaining several times higher than at Ranch Brook in late summer storms (Figure 1b)

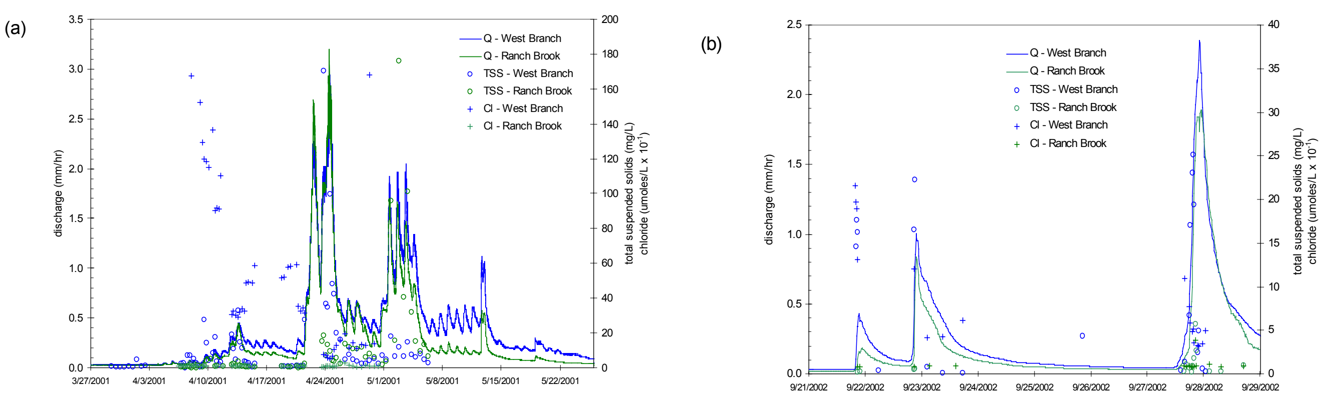

Figure 1: Hydrographs and concentrations of total suspended solids and chloride for (a) spring snowmelt 2001 and (b) a summer storm in 2002.

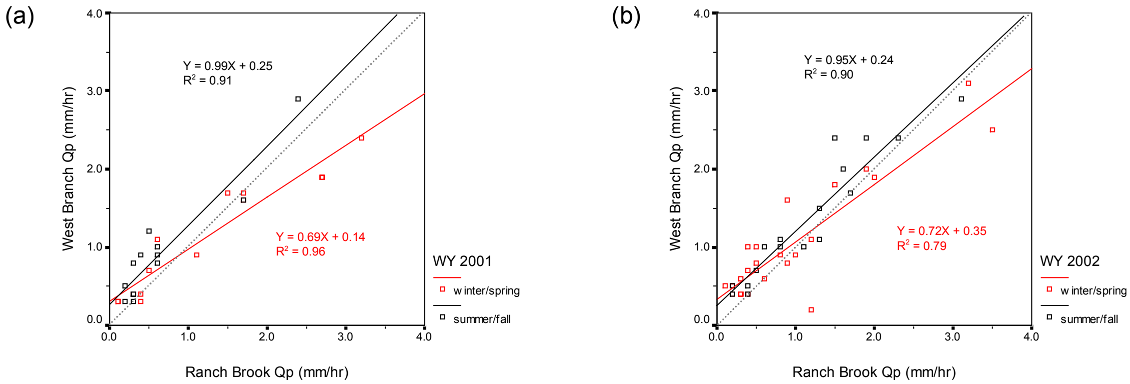

Figure 2: Scatterplots of peak discharge at West Branch vs. Ranch Brook basin for (a) WY 2001 and (b) WY 2002. Regression lines for seasonal effects are statistically different for WY 2001 but not for WY 2002. Dotted line is 1:1.

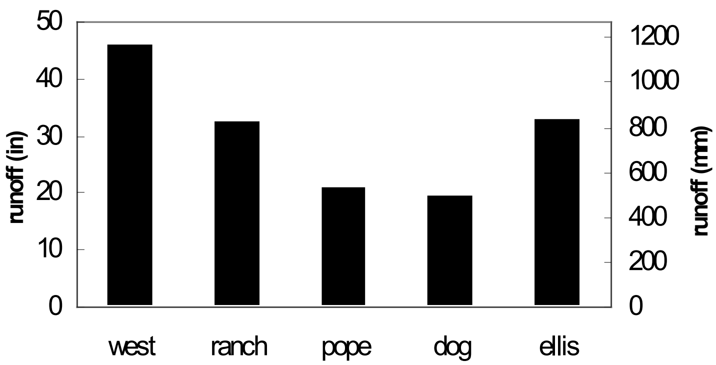

Figure 3: Annual water yield for WY 2001 at West Branch, Ranch Brook and three other basins in the region. Comparative basins are Ellis River (USGS Station #01064300), Pope Brook (USGS Station #01135150), and Dog River (USGS Station #04287000)..

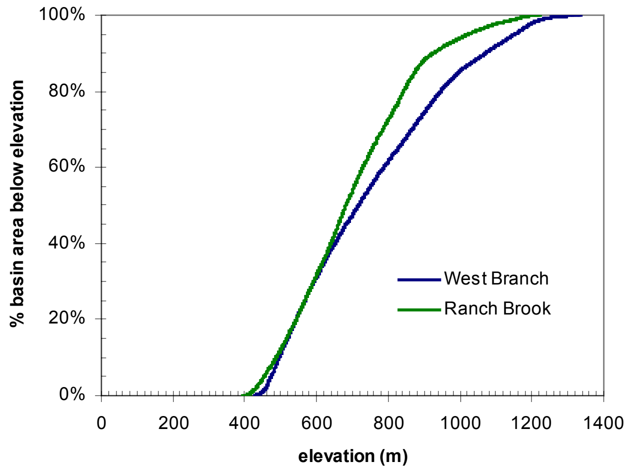

Figure 4: Basin hypsometry.

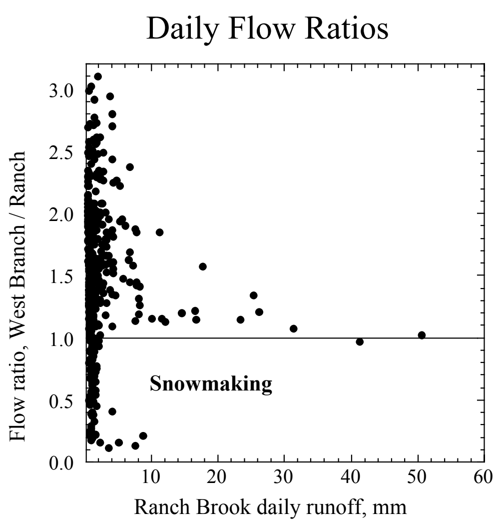

Figure 5: Ratio of West Branch to Ranch Brook average daily flow vs. Ranch Brook average daily flow (WY 2001).

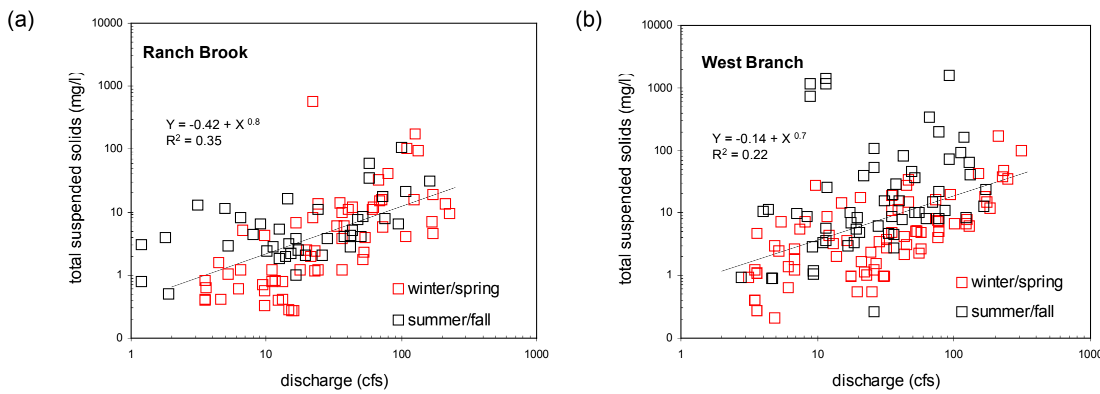

Figure 6: Scatterplots of total suspended solids vs. discharge at (a) Ranch Brook and (b) West Branch for WY 2001. Regression line is for all points (samples from winter/spring and summer/fall flows). The regression intercept is greater for West Branch than for Ranch Brook, suggesting slightly higher sediment yields in the managed basin; however, regression lines for the two basins are not statistically different. Seasonal effects are statistically significant in both basins, indicating that total suspended sediment concentrations are lower for winter/spring flows than for summer/fall flows.

Research Products

Peer-reviewed publications

Shanley, J. B. and B Wemple, 2002. Water Quality and Quantity in the Mountain Environment. Vermont Law Review (Special issue – Mountain Resorts: Ecology and the Law), 26(3): 717-751.

Presentations at Scientific Meetings

Wemple, B., J. Shanley, and J. Denner. "Effects of an Alpine Ski Resort on Hydrology and Water Quality in the Northeastern U.S.: Preliminary Findings from a Field Study," American Geophysical Union Fall Meeting, San Francisco, CA. December 2002.

Mussleman, K. Analysis of Spatial Variability of Precipitation on Mt. Mansfield, Stowe, VT. Vermont Geological Society Spring Meeting, Middlebury, VT. April 2002.

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Student research papers

Mussleman, K. 2002. Analysis of Spatial Variability of Precipitation and Snow Accumulation on Mount Mansfield, Stowe, Vermont. Unpublished senior research project, Dept. of Geology, University of Vermont.

Muth, M. and L. Pascale. 2001. Runoff from Paved and Unpaved Parking Lots at the Spruce Peak Parking Area, Stowe Mountain Resort, Stowe, Vermont. Unpublished student research

paper, prepared for Geol 151, available at http://geology.uvm.edu/morphwww/classes/morph/2001/projects/PROJ2001.html, accessed June 17, 2003.

White, M. 2002. Total Suspended Solids and Runoff Analysis for the Big Spruce and Mansfield Tributaries in the West Branch Watershed, Stowe, Vermont. Unpublished student research paper, prepared for Geol 198.

Students supported by the grant (* funded research assistant, ** unfunded student collaborators)

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Sources Cited

Mussleman, K. 2002. Analysis of Spatial Variability of Precipitation and Snow Accumulation on Mount Mansfield, Stowe, Vermont. Unpublished senior research project, Dept. of Geology, University of Vermont.

National Ski Areas Association (NSAA), 2003. About NSAA – Working together for the future of skiing and snowboarding. Available at http://www.nsaa.org/nsaa2002/_home.asp, accessed June 17, 2003.

Waichler, S. R., M. S. Wigmosta, and B. C. Wemple (in review). Simulation of water balance and forest treatment effects at the H. J. Andrews Experimental Forest, submitted to *Hydrological Processes.*

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