Effects of an Alpine Ski Resort on Hydrology and Water Quality in the Northeastern U.S.: Preliminary Findings from a Field Study

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Abstract

High elevation, forested watersheds are particularly vulnerable to stresses from development. Steep slopes and thin soils rapidly transmit water, nutrients and sediment when disturbed by logging, road construction or other activities associated with development. The effects of forest harvesting practices on streamflow and water quality in high-elevation, forested watersheds have been well studied and provide relevant information about the susceptibility of these ecosystems to anthropogenic disturbance. Few studies have directly addressed the hydrologic or water quality effects of ski resort development on mountain streams, and these studies draw almost entirely from western U.S. examples. Ski resorts in the eastern U.S. face particular development pressures. Transient and unpredictable snow conditions generate extensive need for snowmaking. Competitive economic pressure has motivated plans for slope-side village development and summer recreation facilities at many eastern U.S. ski resorts.

Here, we report preliminary findings of a recently initiated paired-watershed study to examine the effects of alpine ski area development on water quantity and quality. Our study area is located on the eastern slope of Mt. Mansfield, Vermont, and includes the basins of Ranch Brook and West Branch (Figures 1, 2; Table 1). Ranch Brook is undeveloped, except for a network of cross-country ski trails and unsurfaced access roads, and serves as our control watershed. West Branch encompasses nearly an entire major ski resort, with an extensive network of alpine ski lifts and trails, day lodges, snowmaking facilities, and vacation homes. A major expansion of resort facilities and ski trails has recently received state approval. Our preliminary analysis indicates distinct differences in runoff and water quality between the two basins. Differences in basin hydrographs suggest that ski trails alter the magnitude of runoff, particularly during spring snowmelt. Elevated concentrations of total suspended solids in West Branch streamwater suggest that exposed surfaces (trails, parking lots) may be important sources of sediment in the ski resort basin. Streamwater chemistry at West Branch also indicates contamination by deicing salts. Variability in summer low flows between the two basins indicates unexplained differences in precipitation capture or groundwater loss in the basins and must be resolved in future analysis. These findings provide important baseline information for ski area management in the eastern U.S., where field studies have been sparse. Our future plans include hydrologic modeling to assess the effects of current development and various future development scenarios on streamflow and water quality.

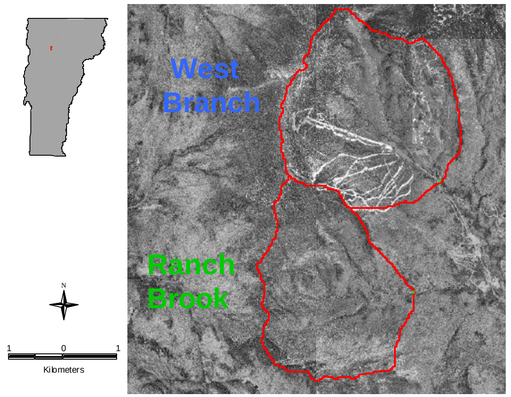

Figure 1: Study area

Table 1: Comparison of of watershed characteristics

	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

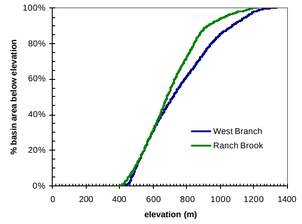

Figure 2: Basin hypsometry

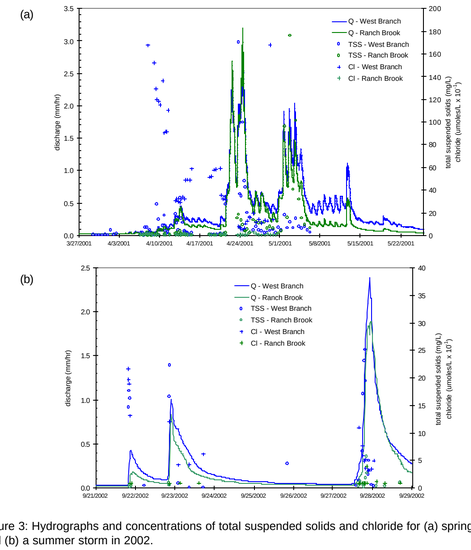

Figure 3: Hydrographs and concentrations of total suspended solids and chloride for (a) spring snowmelt 2001 and (b) a summer storm in 2002.

Hydrology

Runoff analysis for the two basins indicates that flow is synchronized in time but distinctly different in peak magnitude and water yield. 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, suggesting that development increases peak runoff during rain events but reduces snowmelt peaks by storing and slowly releasing water from ski trails (Figure 4). This seasonal difference is 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 exceeds water yield at other mountainous basins in the region (Figure 5). Differences in water yield between West Branch and Ranch Brook are larger than can be reasonably explained by land cover differences or basin hypsometry (Figure 2, Table 1) and appear to be due to large differences in measured streamflow during low and moderate flow periods (Figure 6). We are currently investigating whether a high precipitation anomaly exists in West Branch basin.

Water Quality

Our preliminary data analysis indicates that development in the West Branch basin affects water quality. Concentrations of total suspended solids (TSS) are higher and are flushed earlier in West Branch compared to the Ranch Brook basin (Figure 3). TSS concentrations are related to discharge, but concentrations peak in advance of the runoff peak (Figure 3b), leading to considerable scatter in the TSS vs. discharge rating curve (Figure 7). 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 3b)

Conclusions

- Timing of runoff response is similar in the two basins with 80% of all paired peak flows occurring within one hour of each other.
- Development appears to increase peak runoff for summer and fall storms but reduces peak runoff during snowmelt.
- Sediment and chloride concentrations are higher in the developed basin, relative to the undeveloped basin.
- Water yield is 40% higher in the developed basin and exceeds annual water yield at other regional basins, indicating unresolved differences in precipitation capture or groundwater contributions.
- Elevated chloride concentrations apparent in summer flows suggest an important groundwater contribution in West Branch.

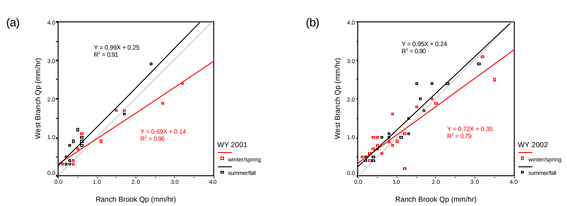

Figure 4: Scatterplots of peak discharge at West Branch vs. Ranch Brook basin for (a) WY 2001 and (b) WY 2002. Regression lines for seasonal effects are statistically different for WY 2001 but not for WY 2002. Dotted line is 1:1.

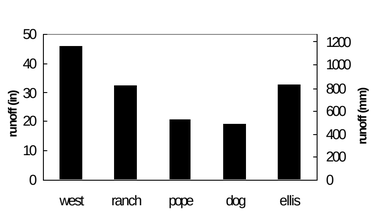

Figure 5: Annual water yield for WY 2001 at West Branch, Ranch Brook and three other basins in the region. Comparative basins are Ellis River (USGS Station #01064300), Pope Brook (USGS Station #01135150), and Dog River (USGS Station #04287000).

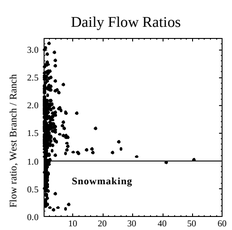

Figure 6: Ratio of West Branch to Ranch Brook average daily flow vs. Ranch Brook average daily flow (WY 2001).

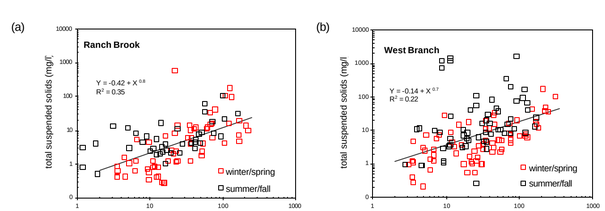

Figure 7: Scatterplots of total suspended solids vs. discharge at (a) Ranch Brook and (b) West Branch for WY 2001. Regression line is for all points (samples from winter/spring and summer/fall flows). The regression intercept is greater for West Branch than for Ranch Brook, suggesting slightly higher 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.