Application of the Distributed Soil Hydrology Vegetation Model (DHSVM) to the case of forest landcover change and alpine development.

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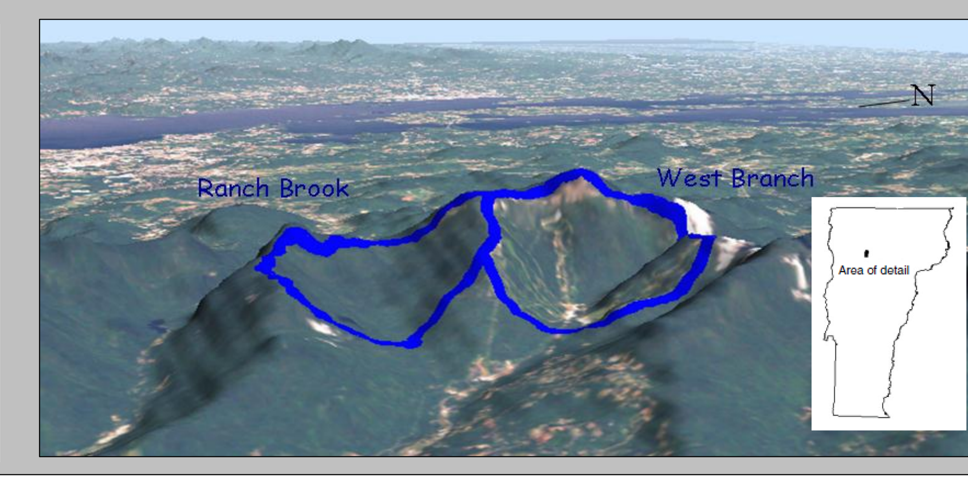
Abstract

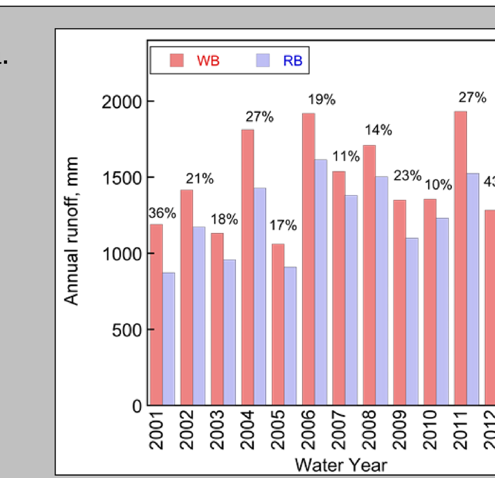
Forest cover in the North East is changing due to both natural disturbances and anthropogenic influences. These changes in forest cover are likely to affect watershed hydrology, including precipitation interception, infiltration and stream flow. Understanding the interaction between forest cover and hydrologic processes is important as they provide critical ecosystem services to the region. Our research focuses on alpine development in high-elevation, forested watersheds, in particular how ski runs and base village development influence runoff production. Our study area includes a forested control watershed and a watershed managed as an alpine ski area in northwestern Vermont. Empirical results show substantial differences (10-31%) in annual water yield between the watersheds over the 11-year period of record (2000-2011). This water yield differential is correlated with maximum seasonal snow depth (R^2 = .47), with larger differences occurring in years with abundant winter snowpack. Field infiltration measurements show a significant difference between ski trail and forested soils (t=2.65, p<.05) with the average infiltration measured on ski trails nearly an order of magnitude slower. We suggest that enhanced routing of water from the compact soils found on ski trails and differences in watershed storage are responsible for the observed difference in runoff. Using the Distributed Soil Hydrology Vegetation Model (DHSVM), we developed simulations for snow accumulation, melt and streamflow in both watersheds. Preliminary model runs show high model skill in simulating observed hourly flows (NE = .78). Model simulations support the hypothesis that slower infiltration results in an enhanced routing of runoff. This water transport mechanism should be integrated into future development designs in order to moderate environmental impacts. Next steps involve testing alternative development scenarios and the effects of variable winter climate conditions on streamflow dynamics.

Background - The Mt. Mansfield paired-watershed study

The Mt. Mansfield paired-watershed study was initiated in October 2000 as a joint monitoring effort supported by the U.S. Geological Survey and the Vermont Monitoring Cooperative. The study is situated in the West Branch (11.7 km²) watershed, site of the Stowe Mountain Resort alpine ski area, and the adjacent Ranch Brook (9.6 km²) watershed, which lies on state forest land and serves as our reference watershed. Over the period of record to date, annual water yields (a) in West Branch exceed those in Ranch Brook by 152-385mm (average difference = 243 mm). Water yield differentials are correlated with annual maximum snowpack depth (b) and cumulative runoff plots show that differences emerge during the snowmelt season and continue to differ through periods of high evapotranspiration (c). This finding has motivated further study of the hydrology of these watersheds.



a.



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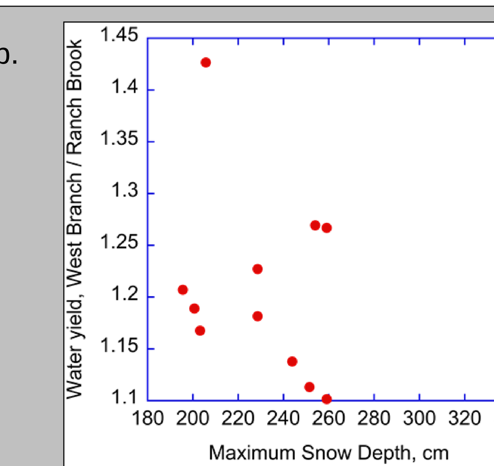

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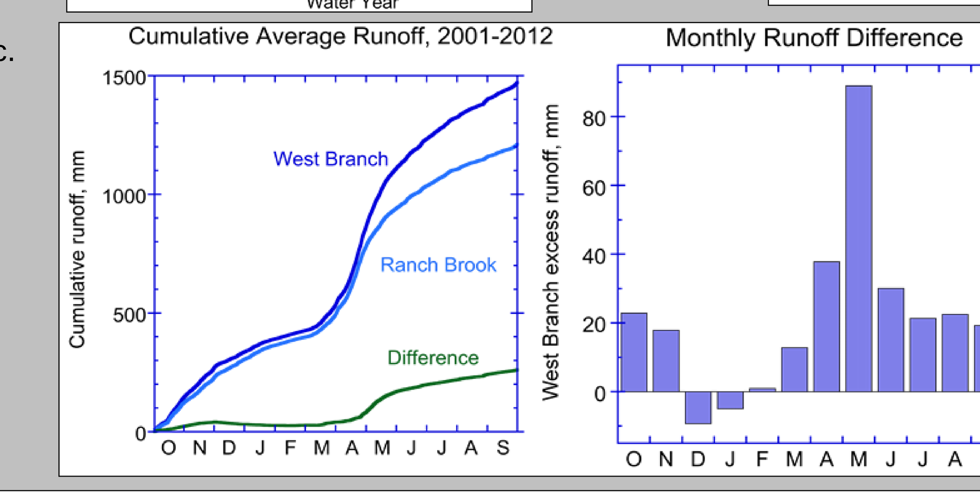
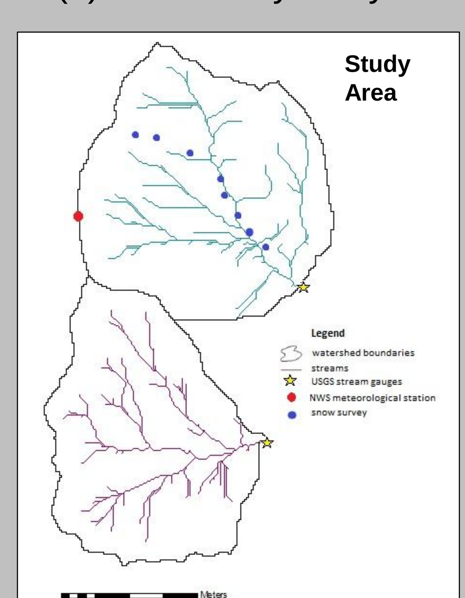


Model Development

We used the Distributed Hydrology Soil Vegetation Model (DHSVM, Wigmosta et al.1994) to simulate runoff and snowpack dynamics in our study watersheds. Meteorological forcing data are taken from a heated tipping bucket rain gage at the base of West Branch and a nearby meteorological station operated by Vermont Monitoring Cooperation (VMC) (a). Model parameter values for vegetation (b) and soil classes (c) are taken from a combination of field measurements, past model applications and from published empirical studies conducted in the region. Field measurements include infiltration measurements on forests and ski trails (d) and hemispherical photographs for determining Leaf Area Index (e). Sensitivity analysis shows the model to be sensitive to a small subset of parameters (f).

a



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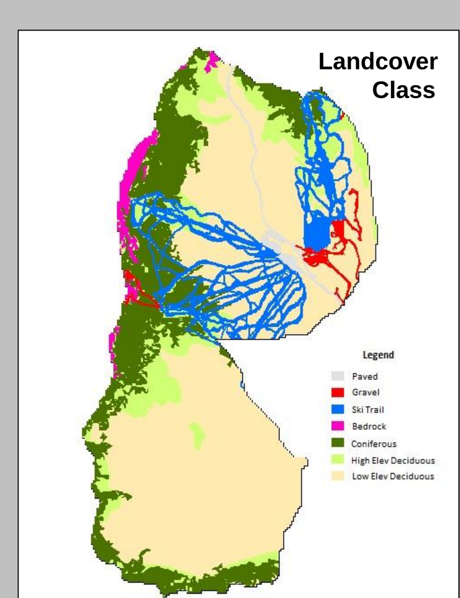

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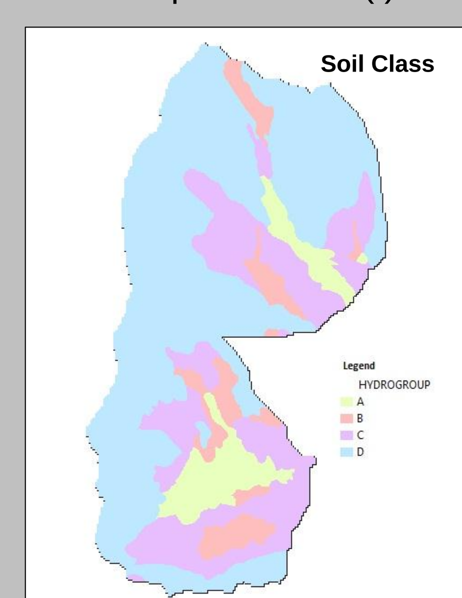
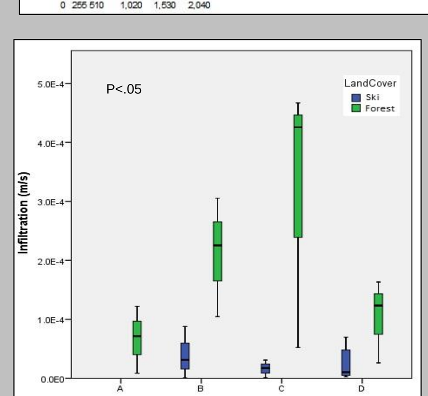
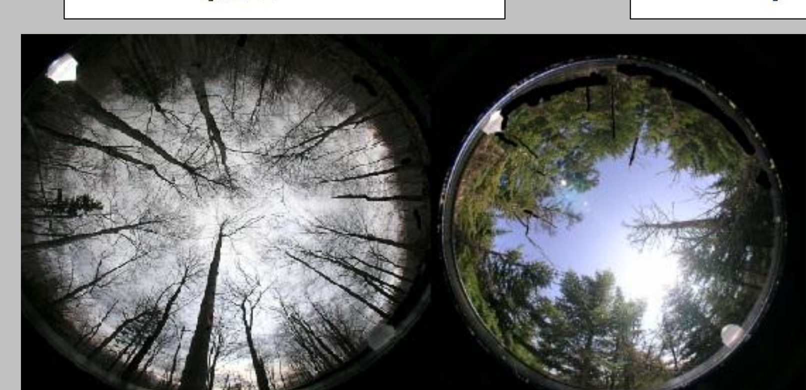


d

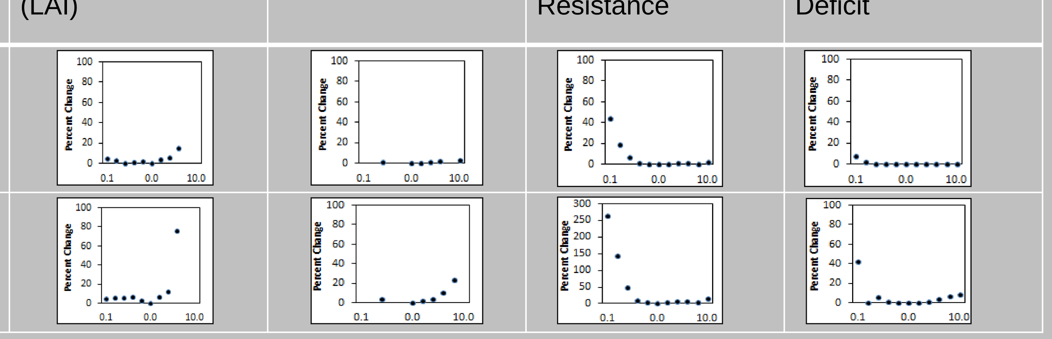


e

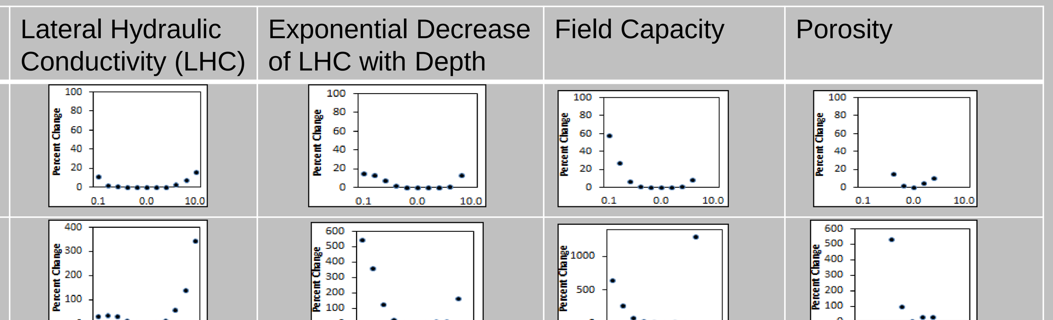


f. Note: Y-axis indicates the percent change in efficiency index and x-axis gives the value which base parameter value was multiplied by.

		Leaf Area Index (LAI)	Rooting Depth	Stomatal Resistance	Vapor Pressure Deficit
Vegetation	Nash-Sutcliffe Efficiency (E)				
	Nash-Sutcliffe of log(values) (Elog)				



		Lateral Hydraulic Conductivity (LHC)	Exponential Decrease of LHC with Depth	Field Capacity	Porosity
Soils	Nash-Sutcliffe Efficiency (E)				
	Nash-Sutcliffe of log(values) (Elog)				



Model Performance

DHSVM produced reasonable simulations for water year 2002, 2003 and 2008 (a). WY2002 was calibrated and 2003 and 2008 were reserved for validating performance. The model was able to capture the annual hydrologic balance with high accuracy (b) and simulated runoff in Ranch Brook was reasonable at both annual and storm scales (c). Distributed snow measurements taken during 2008 allowed us to internally validate the models ability to reproduce the distribution of SWE across the watershed. Model shows good simulations of snow pack dynamics along an elevational transect (d).

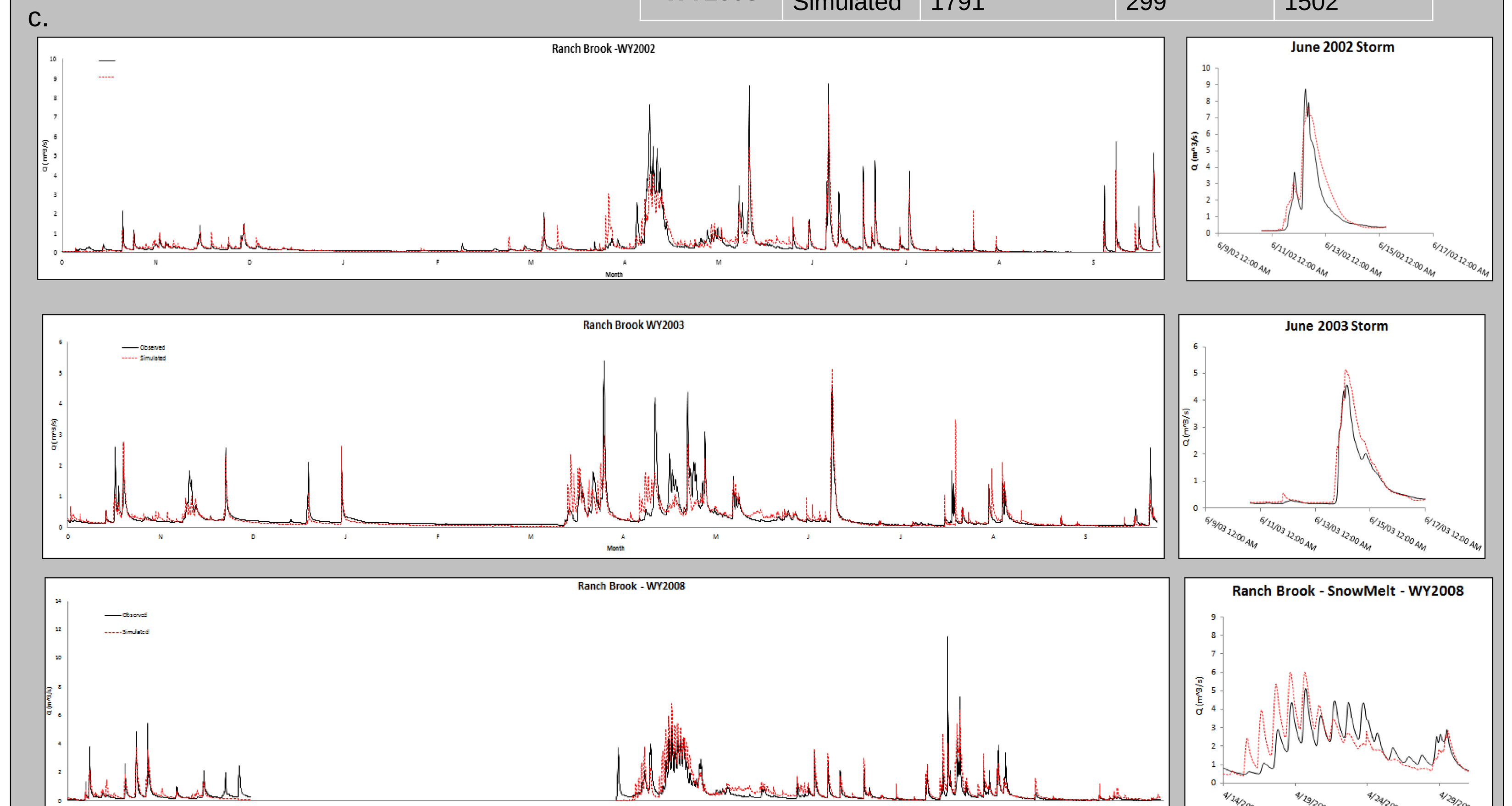
a.

	NE	NElog	r^2
WY2002	0.78	0.74	0.78
WY2003	0.64	0.67	0.64
WY2008	0.65	0.67	0.68

b.

Ranch Brook		Precipitation (mm)	ET (mm)	Runoff (mm)
WY2002	Observed	1613	440	1173
	Simulated	1604	370	1217
WY2003	Observed	1318	236	958
	Simulated	1270	354	930
WY2008	Observed	1771	324	1447
	Simulated	1791	299	1502

c.



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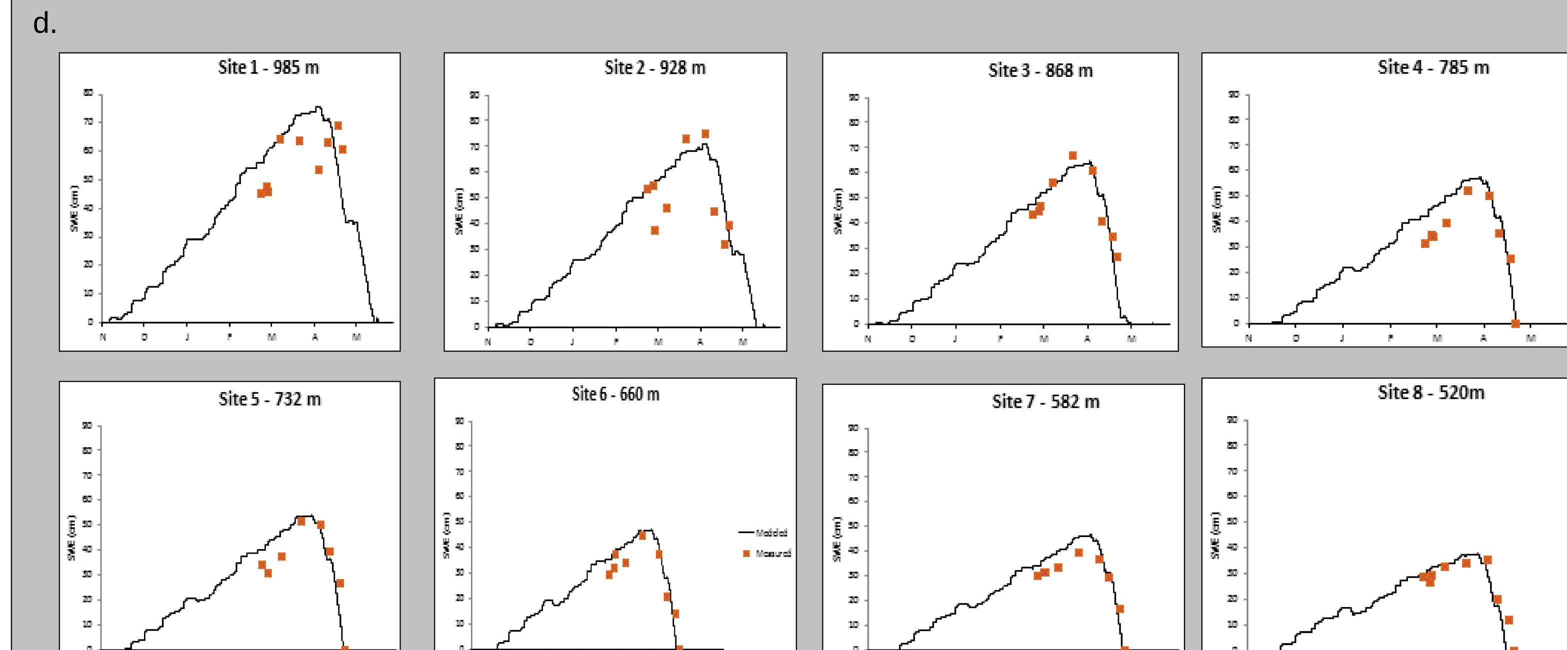
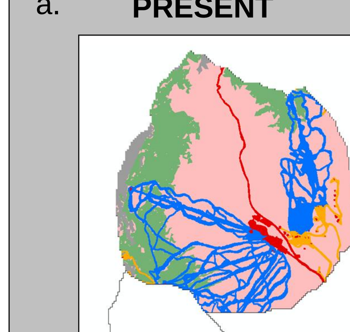


Ski Area Development Scenarios

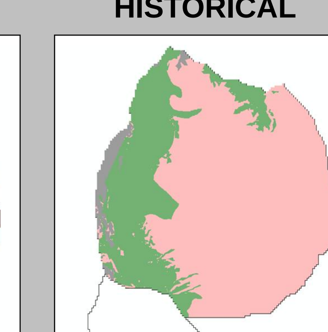
SCENARIO 1

High model performance in the Ranch Brook watershed provided confidence to simulate West Branch using the same parameter set under historical land cover conditions (without development)(a). Under this scenario the model predicts a 73% increase in annual ET for WY2002 (b). Cumulative runoff plots show similar pattern to the paired-watershed study with the water yield differential emerging during the snowmelt season (b).

a. **PRESENT**



HISTORICAL



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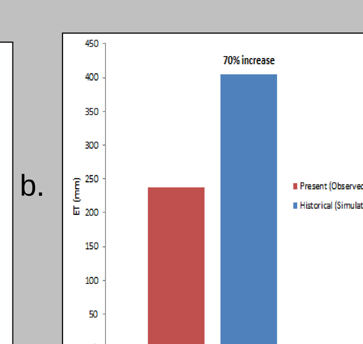

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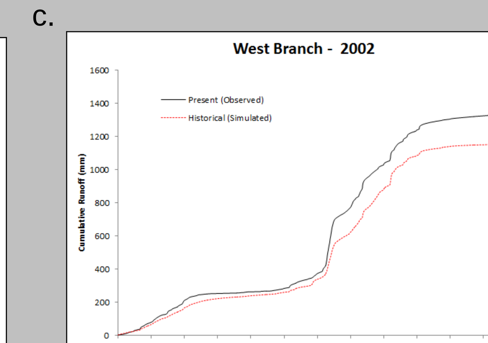
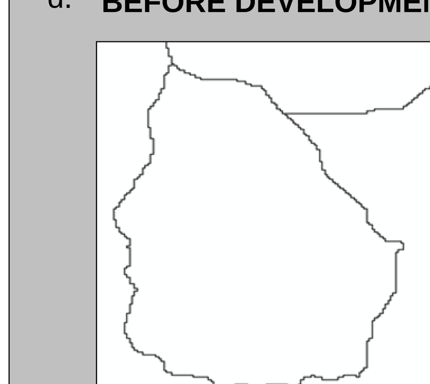


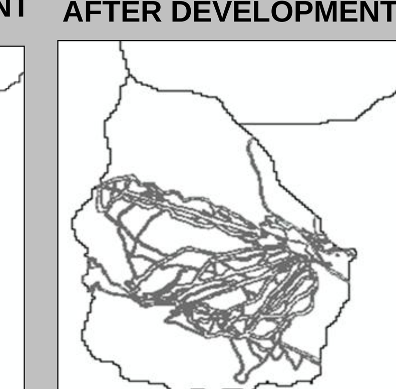
SCENARIO 2

A theoretical ski area was developed in Ranch Brook by removing 22% of the overstory, reducing the infiltration on ski trails by an order of magnitude, and adding snowmaking(d). These changes in watershed characteristics resulted in changes in both annual ET and runoff (e). These changes also produced marked differences in peakflows (f).

d. **BEFORE DEVELOPMENT**



AFTER DEVELOPMENT



e.

	Veg Removal	Veg Removal + Soil Compaction	Veg Removal + Soil Compaction + Snowmaking
Annual ET	7.5 % decrease	13% decrease	13% decrease
Annual Runoff	2.4 % increase	5.1 % increase	10% increase

Acknowledgements

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