Analysis of Changing Climate and Hydrology in the Winooski River Basin, Vermont

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Abstract

Analysis of more than seventy years (1936 to 2008) of daily discharge and weather data in the 2,704 km^2 Winooski River Basin of northern Vermont shows statistically significant increases in both precipitation and river discharge. We analyzed data from six discharge stations, both on the Winooski River and on its major tributaries, as well as nine weather stations at five locations within the basin (Figure 1). Analysis of historical datasets is of particular value as concern over climate change heightens and questions surrounding the behavior of climate and hydrology (and how they interact) become more pressing.
At all five weather stations average annual precipitation is increasing. At a 95% confidence level, this trend was significant at three of the five locations. Similarly, each of the six discharge stations showed an increasing trend in total annual discharge; half of these were significant at a 95% confidence level. Lowest annual daily flows increased significantly at all stations. In contrast, highest daily discharges for each year increased at some stations while decreasing at others. This inconsistent trend between stations could be evidence of the factors associated with changing landuse, which affects the way the sub-basins respond to storm events. In addition to the overall trends in the data, a linear spline has revealed a ~10-year cyclicity in total annual precipitation and discharge data that is well correlated with the behavior of the North Atlantic Oscillation (NAO).
The relationship between weather and discharge has also been changing on a monthly scale, with precipitation increasing significantly at three stations during March or April, while the discharge is trending downward during those same months. This trend may be indicative of the changing timing of seasonality. If spring comes earlier on average, the increases in precipitation could be buffered from the river by earlier leafing out of the trees, which transpire the added precipitation. It is also possible that earlier snowmelt is reducing spring flows.

Study Area

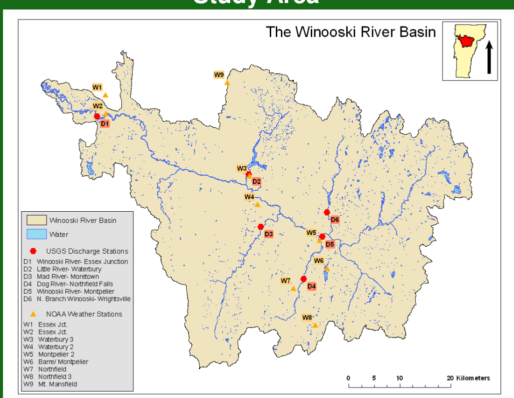
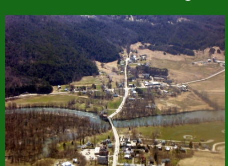


Figure 1. Winooski River Basin, northern Vermont. Water features represent the Winooski River and its tributaries (hydrography data acquired from VCGI). Symbols indicate USGS discharge stations (red) and NOAA weather stations (orange).



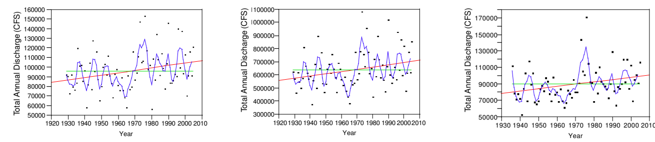
Richmond, VT and the Winooski River 2004 (left)

Winooski Gorge and the Winooski River, 1915-1930 (right)

Data Analysis

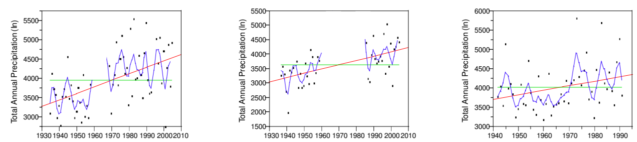
We analyzed discharge, precipitation, and temperature for annual, monthly and daily trends. For each category below, annual or monthly data were plotted with a green line (mean), red line (linear fit) and blue line (linear spline). The spline allows more flexibility than a traditional linear fit, allowing us to see patterns in the data. P values for each linear regression are noted below the plots.

Annual River Discharge



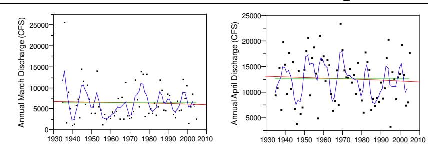
Mad River 1929-2005, p value= 0.016
Winooski River @ Essex Jct. 1929-2005, P value=0.018
Little River 1936-2005, p value= 0.017

Annual Precipitation



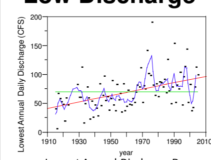
Northfield 1935-2005, P value= <0.0001
Essex Jct. 1937-2005, P value= <0.0001
Waterbury 1942-1991, P value= 0.046

Seasonal River Discharge



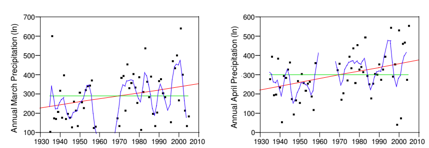
Dog River March Discharge 1935-2005, P value=0.707
Dog River April Discharge 1935-2005, P value=0.61

Low Discharge



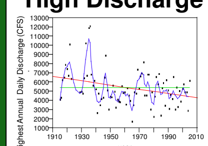
Lowest Annual Discharge Day
Winooski @ Montpelier 1915-2005
P value= <0.0001

Seasonal Precipitation



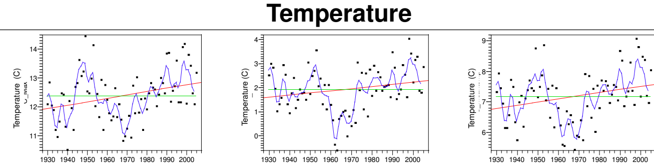
Dog River March Precipitation 1935-2005, P value=0.037
Dog River April Precipitation 1935-2005, P value=0.005

High Discharge



Highest Annual Discharge Day
Winooski @ Montpelier 1915-2005
P value= 0.003

Temperature



Annual Mean Daily Maximum Temperature 1930-2005, P value=0.007
Annual Mean Daily Minimum Temperature 1930-2005, P value=0.068
Annual Daily Mean Temperature 1930-2005, P value=0.017

Trends

The significance of trends for each weather/discharge station are listed below. Red P values indicate a significant trend at a 95% confidence level. Arrows for each value indicate whether flow/precipitation is trending upward or downward. The first sheet shows annual analyses while the second two address monthly analyses.

Annual Analyses

Category:		Dog River Northfield	Mad River Moretown	Little River Waterbury	Winooski River Wrightsville	Winooski River Montpelier	Winooski River Essex Jct.
Total annual discharge		↑ 0.124	↑ 0.016	↑ 0.017	↑ 0.166	↑ 0.063	↑ 0.018
Total annual precipitation		↑ <0.0001	N/A	↑ 0.046	N/A	↑ 0.455	↑ <0.0001
First, second, and third highest 24 hour period of discharge per year	1	↓ 0.221	↓ 0.344	↓ 0.166	↑ 0.225	↓ 0.014	↓ 0.163
	2	↓ 0.395	↑ 0.753	↓ 0.037	↑ 0.041	↓ 0.036	↓ 0.433
	3	↓ 0.851	↑ 0.494	↓ 0.006	↑ 0.009	↓ 0.105	▬ 0.936
First, second, and third lowest 24 hour period of discharge per year	1	↑ <0.0001	↑ <0.0001	↑ 0.0006	↑ 0.019	↑ <0.0001	↑ <0.0001
	2	↑ 0.0005	↑ <0.0001	↑ 0.0006	↑ 0.017	↑ 0.001	↑ <0.0001
	3	↑ 0.0006	↑ 0.0002	↑ 0.0005	↑ 0.016	↑ 0.005	↑ 0.0002
Intensity of largest annual precipitation in 24 hour period		↑ 0.183	N/A	↑ 0.884	N/A	↑ 0.793	↑ 0.589
Frequency of extreme precipitation events		↑ 0.004	N/A	↑ 0.105	N/A	↑ 0.356	↑ 0.062
20 largest precipitation events as a % of total annual precipitation		↓ 0.002	N/A	↓ 0.123	N/A	↑ 0.23	↓ 0.003

Monthly Precipitation

P Values Category: Monthly Precipitation	Dog River Northfield	Mad River Moretown	Little River Waterbury	Winooski River Wrightsville	Winooski River Montpelier	Winooski River Essex Jct.	# UP
January	↑ 0.068	N/A	↑ 0.145	N/A	↓ 0.464	↑ 0.063	3 of 4
February	↑ 0.54	N/A	▬ 0.991	N/A	↓ 0.009	↓ 0.874	1 of 4
March	↑ 0.037	N/A	↑ 0.053	N/A	↓ 0.184	↑ 0.016	2 of 4
April	↑ 0.005	N/A	↓ 0.77	N/A	↑ 0.802	↑ 0.125	3 of 4
May	↑ 0.275	N/A	↓ 0.921	N/A	↑ 0.583	↑ 0.714	3 of 4
June	↑ 0.275	N/A	↓ 0.787	N/A	↑ 0.715	↑ 0.519	3 of 4
July	↑ 0.462	N/A	↓ 0.875	N/A	↑ 0.718	↑ 0.129	3 of 4
August	↑ 0.013	N/A	↑ 0.028	N/A	↑ 0.089	↑ 0.162	3 of 4
September	↑ 0.488	N/A	↑ 0.233	N/A	↑ 0.321	↑ 0.205	4 of 4
October	↑ 0.021	N/A	↑ 0.816	N/A	↑ 0.268	↑ 0.088	4 of 4
November	↑ 0.201	N/A	↑ 0.41	N/A	↑ 0.635	↑ 0.27	4 of 4
December	↑ 0.055	N/A	↑ 0.28	N/A	↑ 0.881	↑ 0.4	4 of 4
	12 of 12		7 of 12		9 of 12	12 of 12	# UP

Monthly River Discharge

P Values Category: Monthly Discharge	Dog River Northfield	Mad River Moretown	Little River Waterbury	Winooski River Wrightsville	Winooski River Montpelier	Winooski River Essex Jct.	# UP
January	↑ 0.583	↑ 0.462	↑ 0.037	↑ 0.357	↑ 0.137	↑ 0.232	6 of 6
February	↑ 0.507	↑ 0.163	↓ 0.848	↑ 0.168	↑ 0.05	↑ 0.132	5 of 6
March	↓ 0.707	↑ 0.486	↓ 0.912	↑ 0.575	↓ 0.298	↑ 0.73	3 of 6
April	↓ 0.61	↓ 0.327	↑ 0.061	↓ 0.312	↓ 0.561	↓ 0.472	3 of 6
May	↓ 0.417	↓ 0.419	↓ 0.236	↓ 0.061	↑ 0.487	↓ 0.52	3 of 6
June	↑ 0.657	↑ 0.563	↑ 0.247	↑ 0.518	↑ 0.514	↑ 0.436	6 of 6
July	↑ 0.07	↑ 0.296	↑ 0.847	↑ 0.168	↑ 0.158	↑ 0.157	6 of 6
August	↑ 0.003	↑ 0.008	↓ 0.575	↑ 0.003	↑ 0.008	↑ 0.006	6 of 6
September	↑ 0.63	↑ 0.276	↓ 0.505	↑ 0.328	↑ 0.223	↑ 0.162	5 of 6
October	↑ 0.016	↑ 0.005	↑ 0.048	↑ 0.034	↑ 0.077	↑ 0.006	6 of 6
November	↑ 0.02	↑ 0.012	↑ <0.0001	↑ 0.155	↑ 0.015	↑ 0.008	6 of 6
December	↑ 0.093	↑ 0.019	↑ 0.003	↑ 0.185	↑ 0.025	↑ 0.006	6 of 6
	9 of 12	10 of 12	7 of 12	10 of 12	10 of 12	10 of 12	# UP

Conclusions

-Precipitation and discharge have increased at all stations in the Winooski Basin over the past seventy years.

-The intensity of discharge during the lowest flow days of each year has increased.

-Both frequency and intensity of the largest precipitation events per year have increased at varying levels of significance.

-Discharge has increased significantly at all stations during fall months along with increased fall precipitation. Discharge has decreased at all stations during some spring months despite increases in precipitation.

- A regular ~ 10 year cyclicity is apparent in the spline applied to discharge, temperature, and precipitation data.

Acknowledgements

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