Hydrology, Climate, and Land Use Change in The Winooski River Basin, Vermont

William Redin Hackett

Thesis Defense

Committee:
Paul R. Bierman
Donna M. Rizzo
Leslie Morrissey

The UNIVERSITY of VERMONT

Outline

-Statement of Problem

-New England Climate
    -IPCC Predictions
    -Recent Records

-Vermont History

-Study Area

-Methodology

-Results- Weather and Flow records

-Results- Landuse Analysis

-Interpretations and Conclusions

Has discharge in the Winooski River Basin changed over time and if so, why?

Importance of understanding

-Infrastructure designed using stationarity approach
- -More water
- -More storms

-Changing seasonality
- -Agricultural impacts
- -Precipitation timing

Human Population
- -More demand for water

-Ecosystems

Climate in New England

IPCC (2008) predictions for the region:

- -Increasing precipitation
  - -More storms
- -Increasing temperatures
  - -Increasing winter temperatures
  - -Earlier Spring melt
  - -More summer drying

New England Climate Records

-Sea Surface Temperatures

Friedland and Hare, 2007

-New England Temperatures

Trombulak and Wolfson, 2004

-New England Ice Out Dates

Hodgkins, 2005
IPCC, 2008

-New England Storms

Madsen and Figdor, 2007

Vermont Land Use History

-Post colonial settlement
  - -clearing for fuel

-Great Swarming Time
  - -Early 1700's

-Sheep Fever- 1810- 1840
  - -75% of New England cleared

-The Decline of Sheep- 1850

-The Age of Dairy

Vermont Land Use History

-Abandonment

-50% decrease in farms by 1850

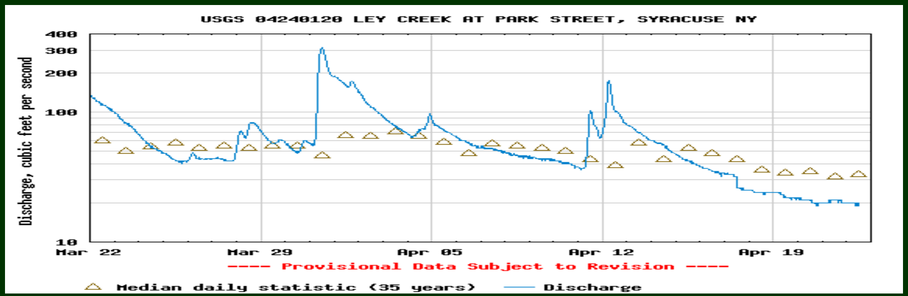
-Reforestation

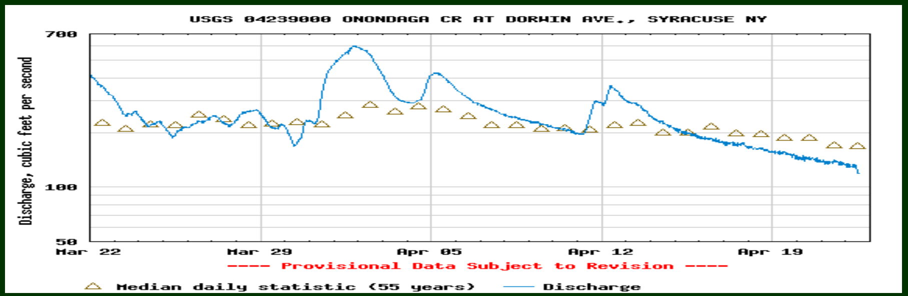
-Development

Potential Hydrologic Implications

-More Impervious Area
- -More runoff
- -Flashier discharge- floods

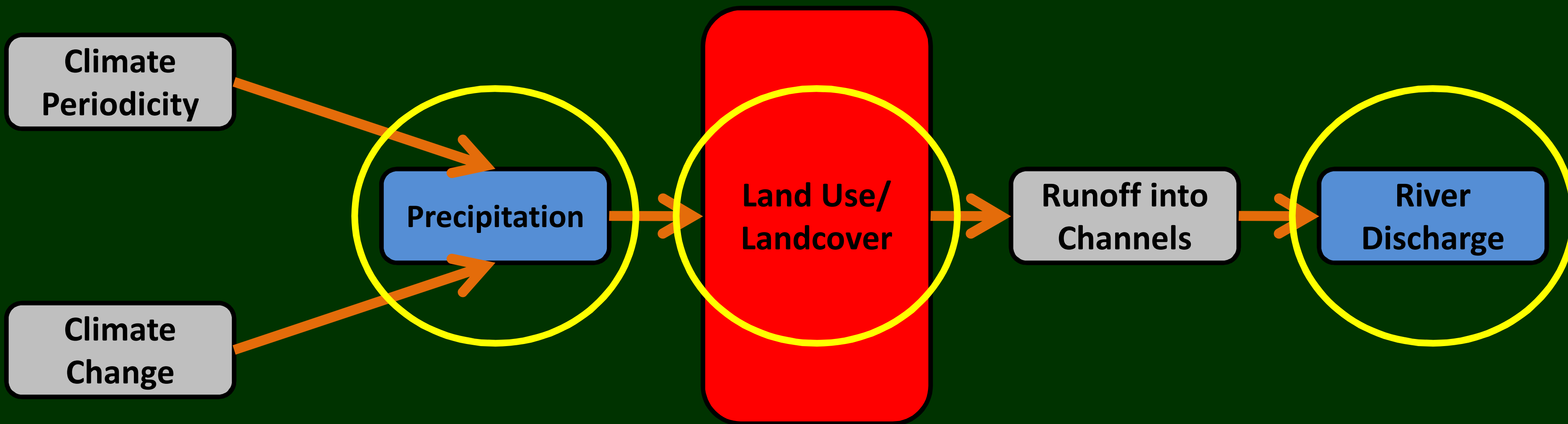
-More Reforestation-> More ET
- -Buffered basin response
- -Lower baseflows



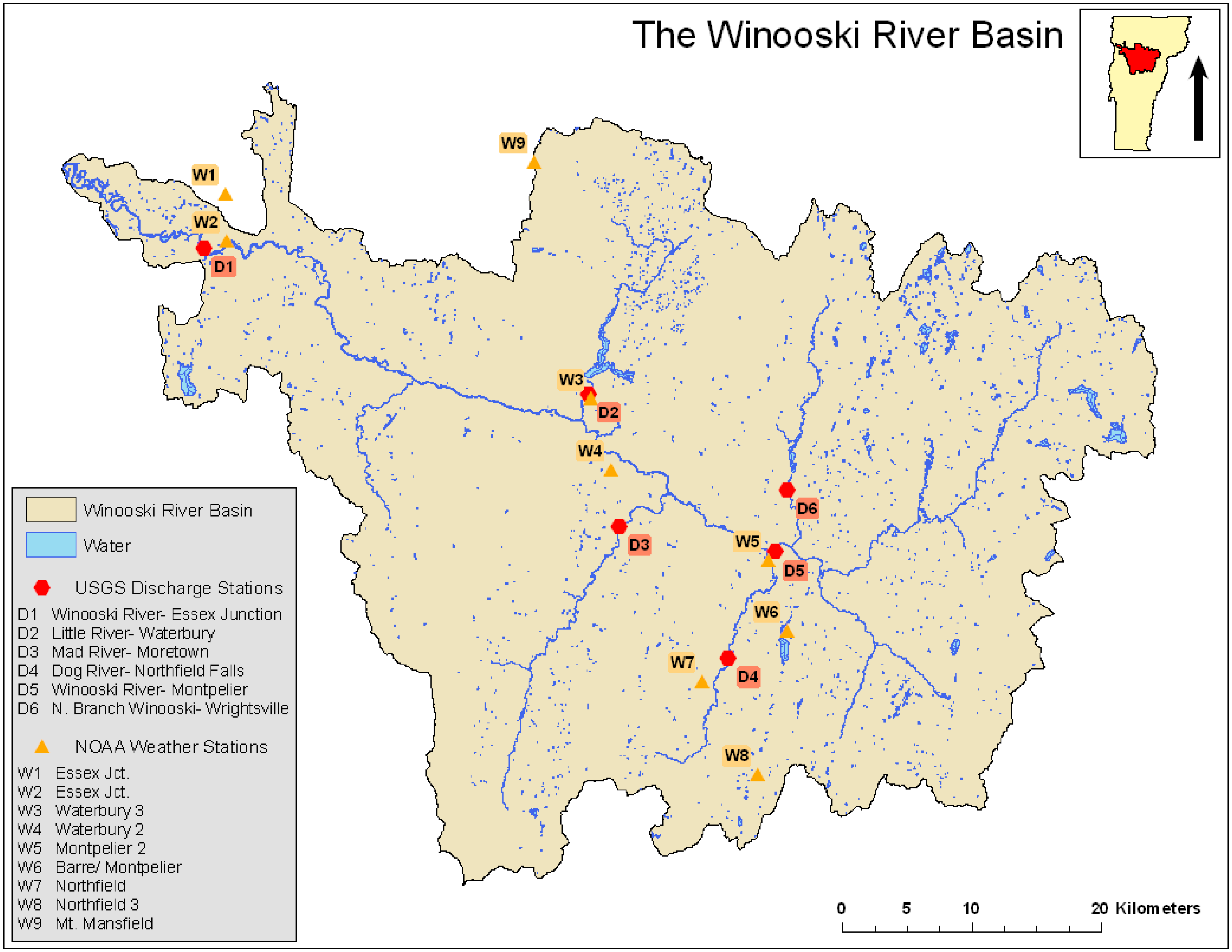


Winooski River Basin Fly Through

Has discharge in the Winooski River Basin changed over time and if so, why?

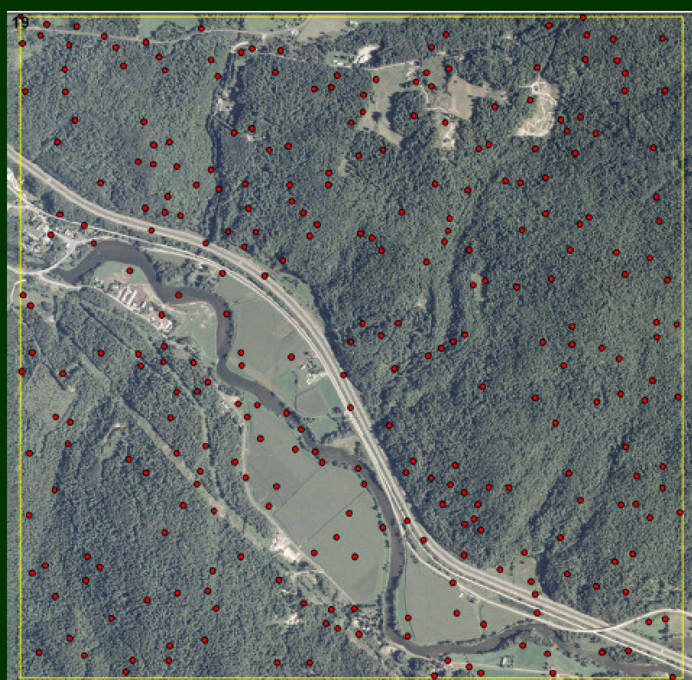


Study Area



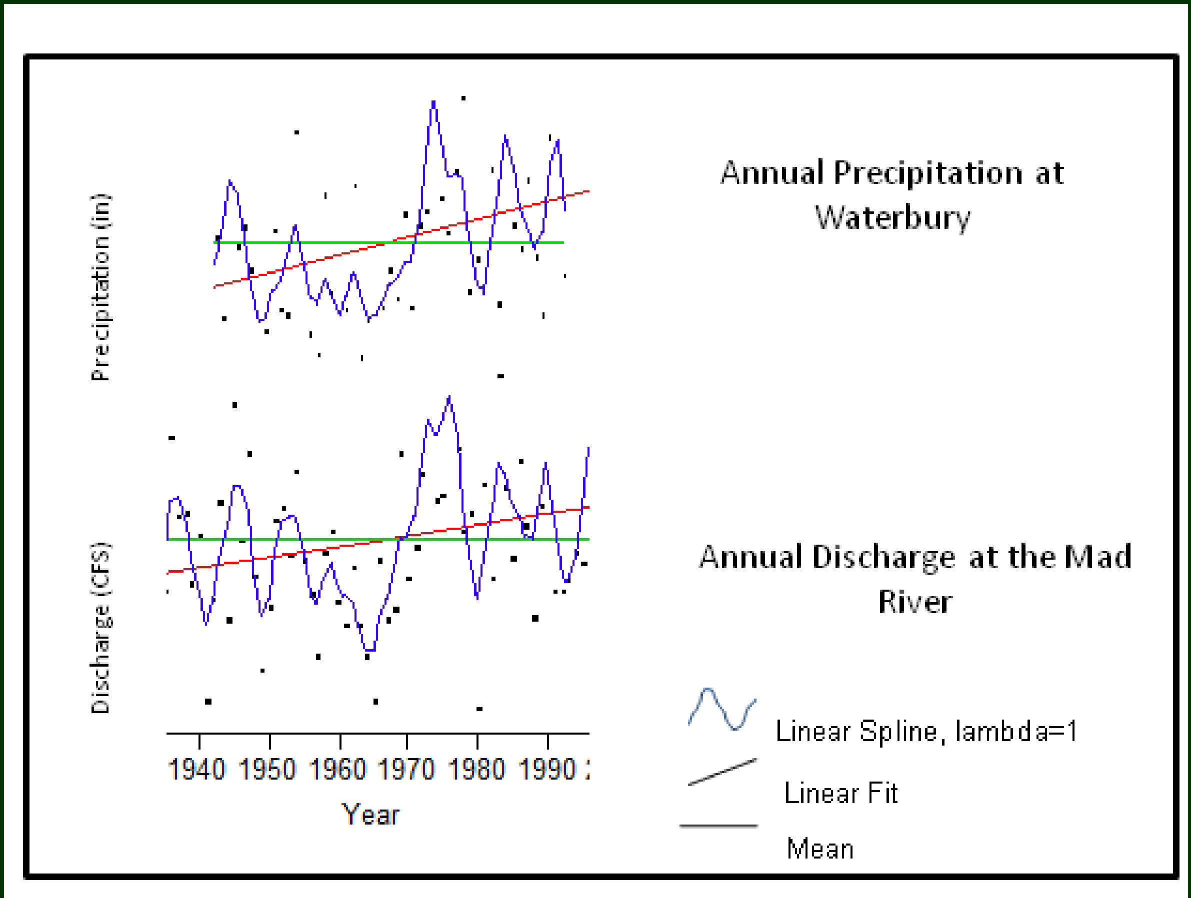
The Winooski River Basin
W1
W2
D1
W9
W3
D2
W4
D6
D3
W5
D5
W6
W7
D4
W8
Winooski River Basin
Water
USGS Discharge Stations
D1 Winooski River- Essex Junction
D2 Little River- Waterbury
D3 Mad River- Moretown
D4 Dog River- Northfield Falls
D5 Winooski River- Montpelier
D6 N. Branch Winooski- Wrightsville
NOAA Weather Stations
W1 Essex Jct.
W2 Essex Jct.
W3 Waterbury 3
W4 Waterbury 2
W5 Montpelier 2
W6 Barre/ Montpelier
W7 Northfield
W8 Northfield 3
W9 Mt. Mansfield
0 5 10 20 Kilometers

Weather Station	Years of Coverage	Elevation (m)
Essex Junction	1937-1960	104
Essex Junction	1971-2007	73
Waterbury 3	1941-1958	143
Waterbury 2	1958-1992	232
Montpelier 2	1999-2007	162
Barre Montpelier AP	1948-2007	343
Northfield	1923-1974, 1994-2007	204
Northfield 3	1974-1994	429
Mt. Mansfield	1954-2007	1204



Discharge Gage	Years of Coverage
Winooski River at Essex Jct.	1929-2005
Winooski River at Montpelier	1915-1922 & 1929-2005
Winooski River at Wrightsville	1934-2005
Little River at Waterbury	1936-2005
Mad River at Moretown	1929-2005
Dog River at Northfield Falls	1935-2005

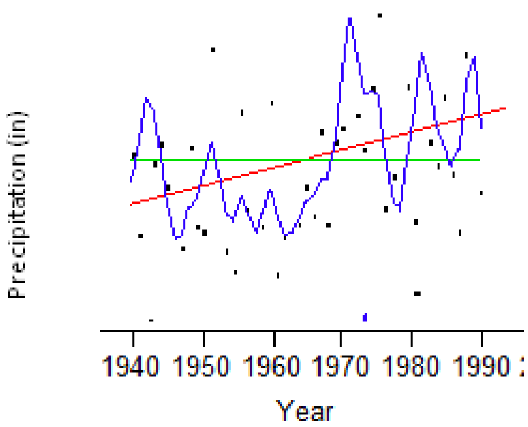
Methods- Weather and Discharge

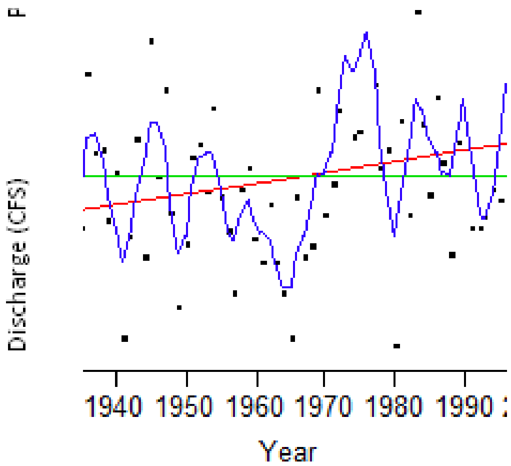


Results- Annual

Trends	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	⬆ 0.046	⬆ <0.0001

	Burlington Airport				Montpelier
Annual Mean	⬆ 0.068	⬆ 0.008	N/A	⬆ 0.017	Not Significant





Results- Monthly Precipitation

Monthly Precipitation	Dog River Northfield		Little River Waterbury	Winooski River Burlington Airport	Winooski River Montpelier	Winooski River Essex Jct.	# UP
January	↑ **0.068**		↑ 0.145	Not Significant	↓ 0.464	↑ **0.063**	3 of 5
February	Not Significant		Not Significant	Not Significant	↓ **0.009**	Not Significant	0 of 5
March	↑ **0.037**		↑ **0.053**	Not Significant	↓ 0.184	↑ **0.016**	3 of 4
April	↑ **0.005**		Not Significant	↑ 0.387	Not Significant	↑ 0.125	3 of 5
May	↑ 0.275		Not Significant	Not Significant	Not Significant	Not Significant	1 of 5
June	↑ 0.275		Not Significant	Not Significant	Not Significant	Not Significant	1 of 5
July	↑ 0.462		Not Significant	Not Significant	Not Significant	↑ 0.129	2 of 5
August	↑ **0.013**		↑ **0.028**	↑ **0.064**	↑ **0.089**	↑ 0.162	5 of 5
September	↑ 0.488		↑ 0.233	↑ 0.190	↑ 0.321	↑ 0.205	5 of 5
October	↑ **0.021**		Not Significant	↑ 0.394	↑ 0.268	↑ **0.088**	4 of 5
November	↑ 0.201		↑ 0.410	↑ **0.071**	Not Significant	↑ 0.270	4 of 5
December	↑ **0.055**		↑ 0.280	Not Significant	Not Significant	↑ 0.400	3 of 5
	11 of 12		6 of 12	5 of 12	3 of 12	9 of 12	# UP

Results- Monthly Discharge

	Dog River	Mad River	Little River	Winooski River	Winooski River	Winooski River	
Monthly Discharge	Northfield	Moretown	Waterbury	Wrightsville	Montpelier	Essex Jct.	**# UP**
January	Not Significant	↑ **0.462**	↑ **0.037**	↑ **0.357**	↑ 0.137	↑ 0.232	5 of 6
February	Not Significant	↑ 0.163	Not Significant	↑ **0.168**	↑ **0.050**	↑ 0.132	4 of 6
March	Not Significant	↑ 0.486	Not Significant	Not Significant	↓ 0.298	Not Significant	1 of 6
April	Not Significant	↓ 0.327	↑ **0.061**	↓ 0.312	Not Significant	↓ 0.472	1 of 6
May	↓ 0.417	↓ 0.419	↓ 0.236	↓ **0.061**	↑ 0.487	Not Significant	0 of 6
June	Not Significant	Not Significant	↑ **0.247**	Not Significant	Not Significant	↑ 0.436	2 of 6
July	↑ **0.070**	↑ 0.296	Not Significant	↑ 0.168	↑ 0.158	↑ 0.157	5of 6
August	↑ **0.003**	↑ **0.008**	Not Significant	↑ **0.003**	↑ **0.008**	↑ **0.006**	5 of 6
September	Not Significant	↑ 0.276	Not Significant	↑ 0.328	↑ 0.223	↑ 0.162	4 of 6
October	↑ **0.016**	↑ **0.005**	↑ **0.048**	↑ **0.034**	↑ **0.077**	↑ **0.006**	6 of 6
November	↑ **0.020**	↑ **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
	5 of 12	9 of 12	5 of 12	8 of 12	9 of 12	9 of 12	**# UP**

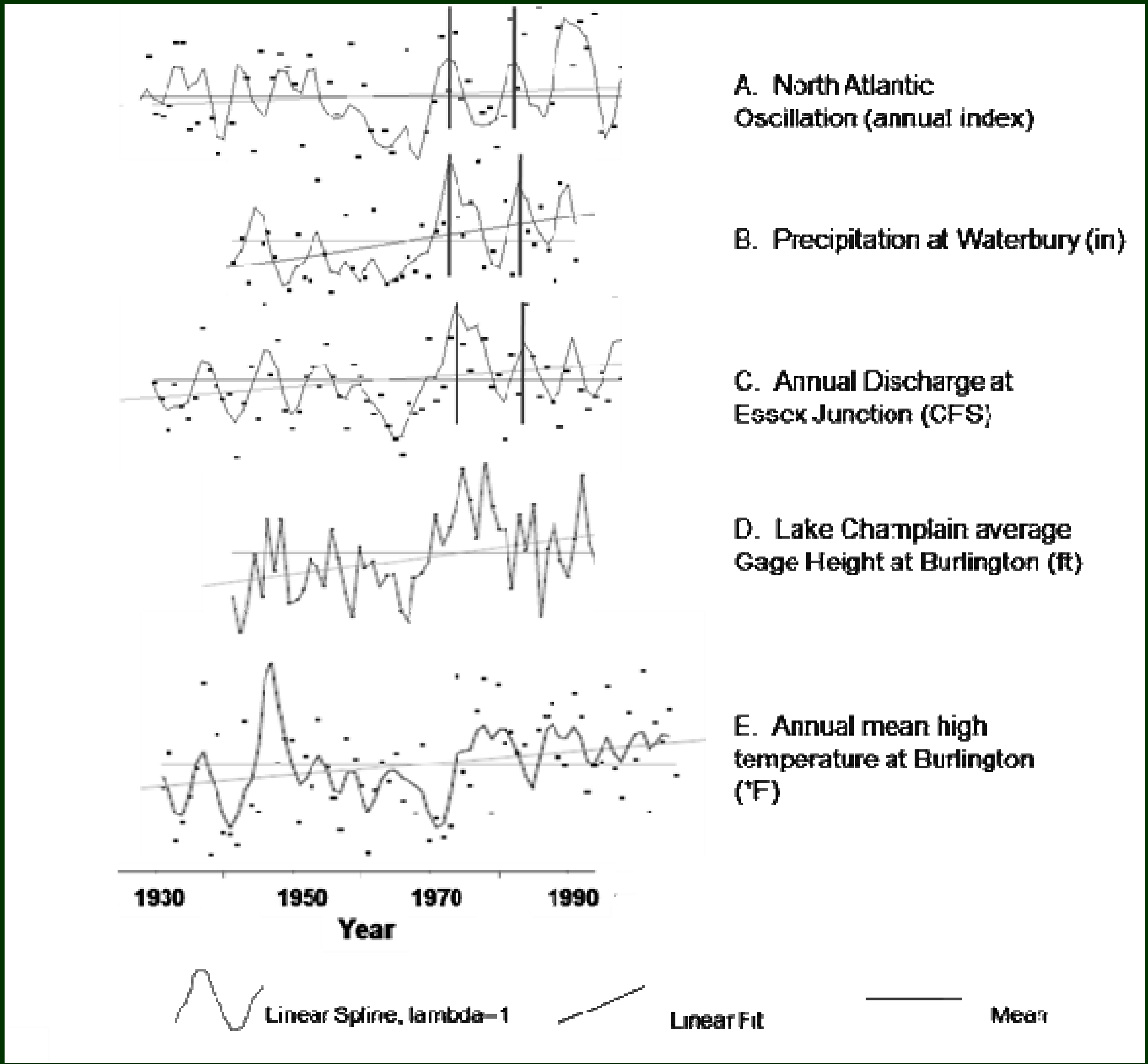
Results- Storms and Baseflow

Trends	Dog River Northfield	Mad River Moretown	Little River Waterbury	Winooski River Wrightsville	Winooski River Montpelier	Winooski River Essex Jct
First, second, and third highest 24 hour period of discharge per year	↓ 0.221	↓ 0.344	↓ 0.166	↑ 0.225	↓ **0.014**	↓ 0.163
	↓ 0.395	Not Significant	↓ **0.037**	↑ **0.041**	↓ **0.036**	↓ 0.433
	Not Significant	↑ 0.494	↓ **0.006**	↑ **0.009**	↓ 0.105	Not Significant
First, second, and third lowest 24 hour period of discharge per year	↑ **<0.0001**	↑ **<0.0001**	↑ **0.001**	↑ **0.019**	↑ **<0.0001**	↑ **<0.0001**
	↑ **0.001**	↑ **<0.0001**	↑ **0.001**	↑ **0.017**	↑ **0.001**	↑ **<0.0001**
	↑ **0.001**	↑ **0.000**	↑ **0.001**	↑ **0.016**	↑ **0.005**	↑ **0.000**
Intensity of largest annual precipitation events	↑ 0.183	N/A	Not Significant	N/A	Not Significant	Not Significant
Frequency of extreme precipitation	↑ **0.004**	N/A	↑ 0.105	N/A	↑ 0.356	↑ **0.062**
20 largest precipitation events as a percent of total annual precipitation	↓ **0.002**	N/A	↓ 0.123	N/A	↑ 0.230	↓ **0.003**

Results- Monthly Temperature

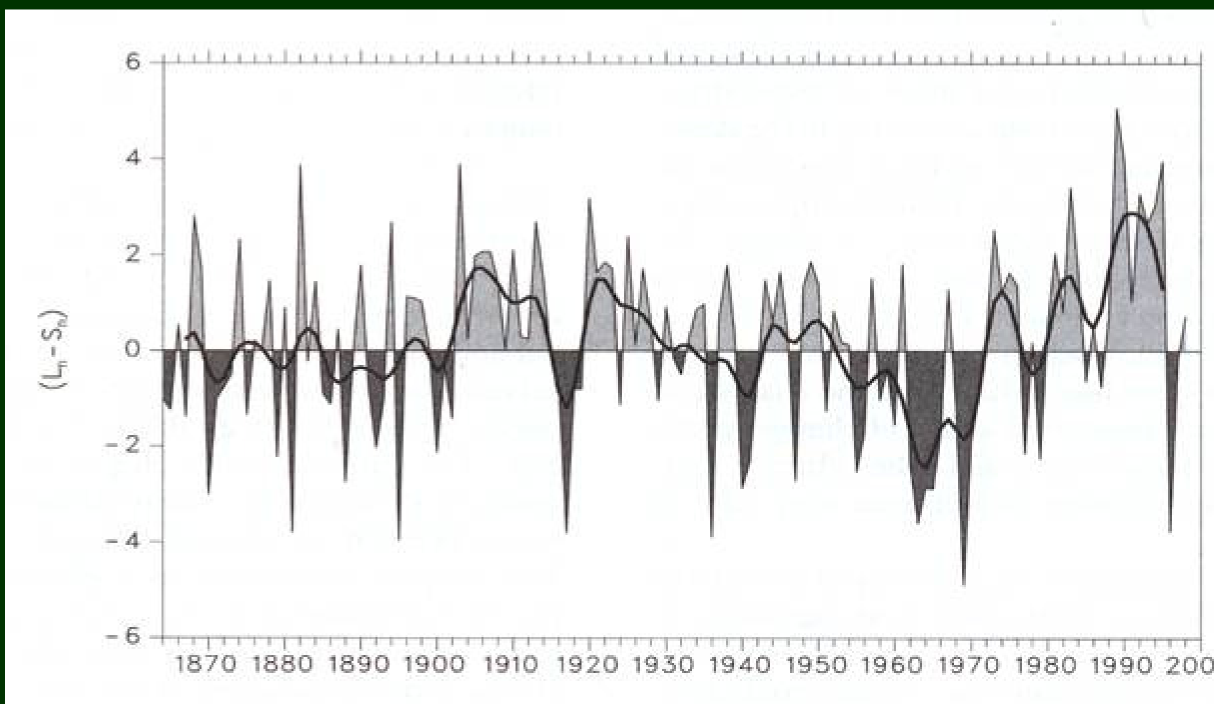
	Burlington Airport				Montpelier
Monthly Temperature	Mean Low	Mean High	Spread: L->H	Mean	Mean
January	Not Significant	Not Significant	Not Significant	Not Significant	⇩ 0.471
February	↑ 0.300	↑ **0.109**	Not Significant	↑ 0.189	⇩ 0.450
March	↑ 0.314	↑ **0.036**	↑ **0.041**	↑ 0.102	↑ **0.049**
April	↑ 0.232	↑ **0.032**	↑ **0.056**	↑ **0.065**	Not Significant
May	Not Significant	↑ 0.254	↑ 0.314	↑ 0.324	↑ 0.426
June	Not Significant	↑ 0.267	Not Significant	↑ 0.302	⇩ 0.470
July	↑ 0.208	↑ 0.252	Not Significant	↑ 0.190	Not Significant
August	↑ **0.055**	↑ 0.121	Not Significant	↑ **0.069**	Not Significant
September	↑ 0.446	↑ 0.441	Not Significant	↑ 0.396	⇩ 0.384
October	⇩ 0.484	⇩ 0.373	Not Significant	⇩ 0.371	⇩ **0.031**
November	↑ 0.255	↑ 0.182	Not Significant	↑ 0.197	Not Significant
December	↑ **0.093**	↑ **0.069**	Not Significant	↑ **0.075**	Not Significant

Periodicity

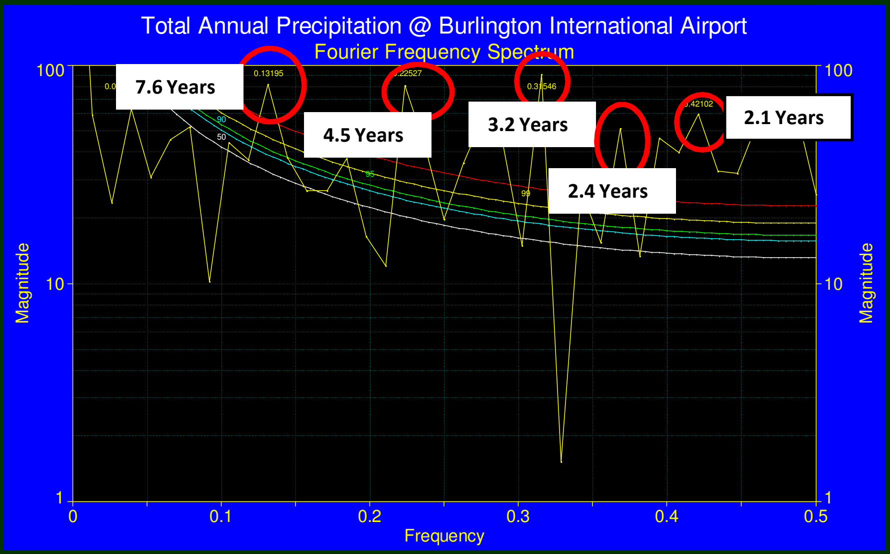


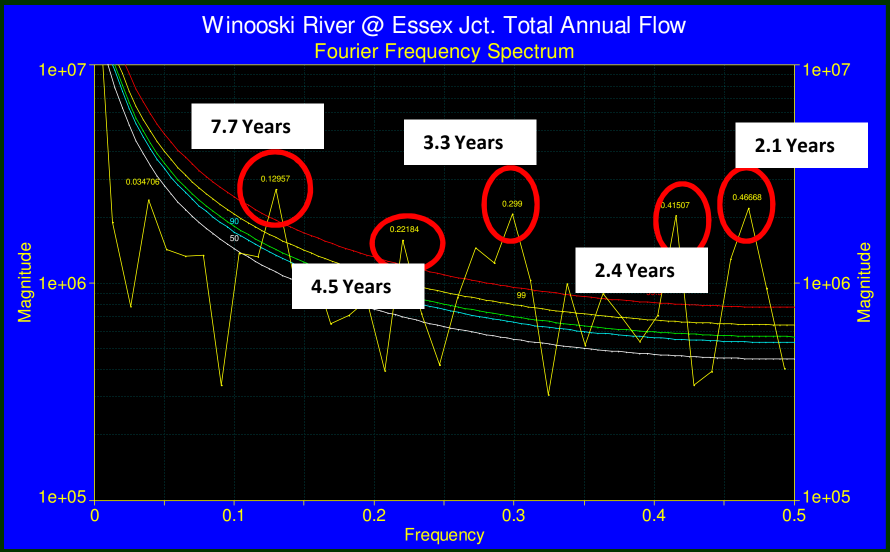
North Atlantic Oscillation (NAO)

-NAO signal fluctuates and can drastically effect winter weather.
-Difference between Azores High and Icelandic Low.
-More of an effect in Europe, but US winters can be mild and wet during positive NAO winters, and colder during negative winters.



Spectral Analysis





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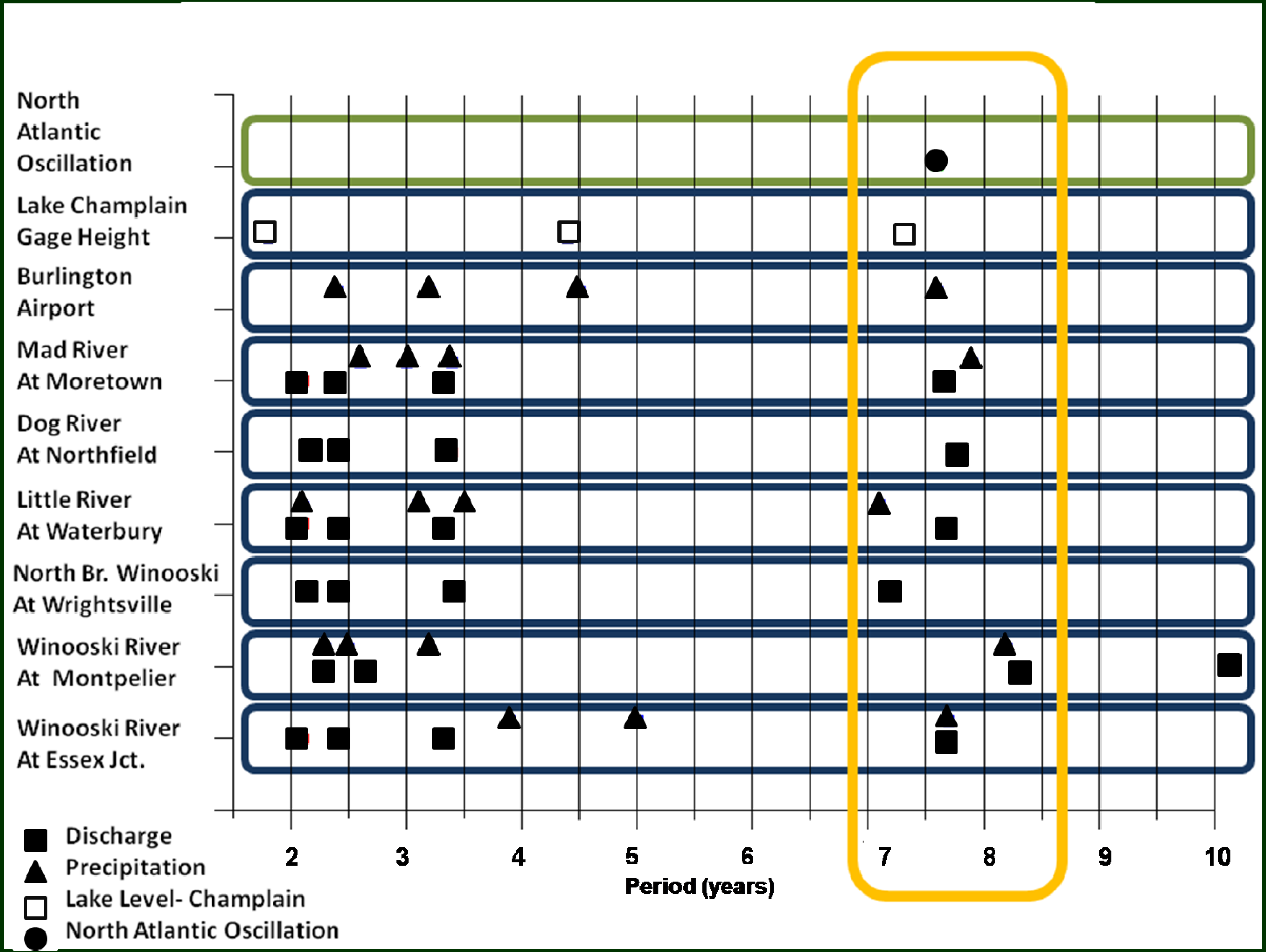
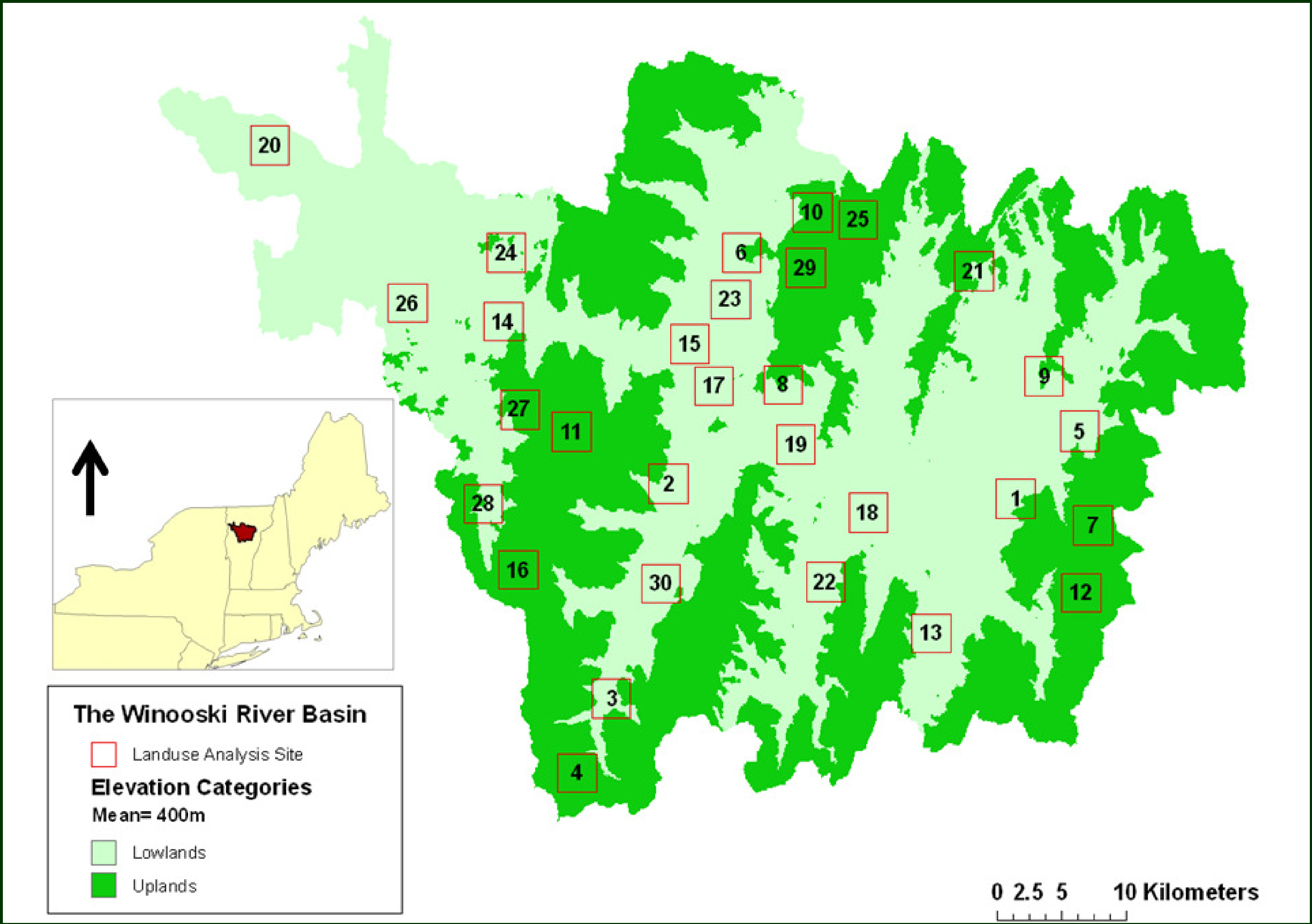
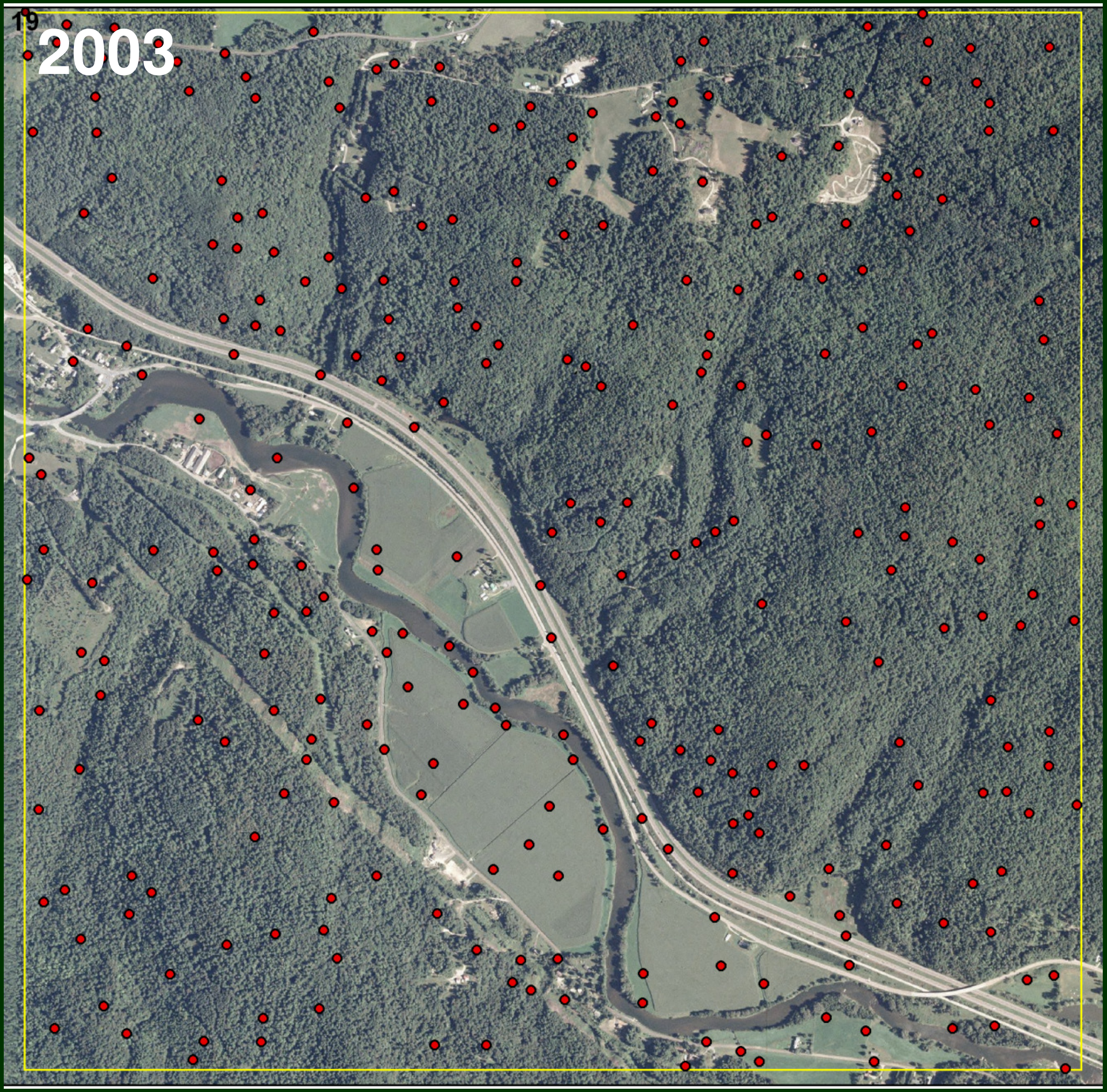


Intro to landuse

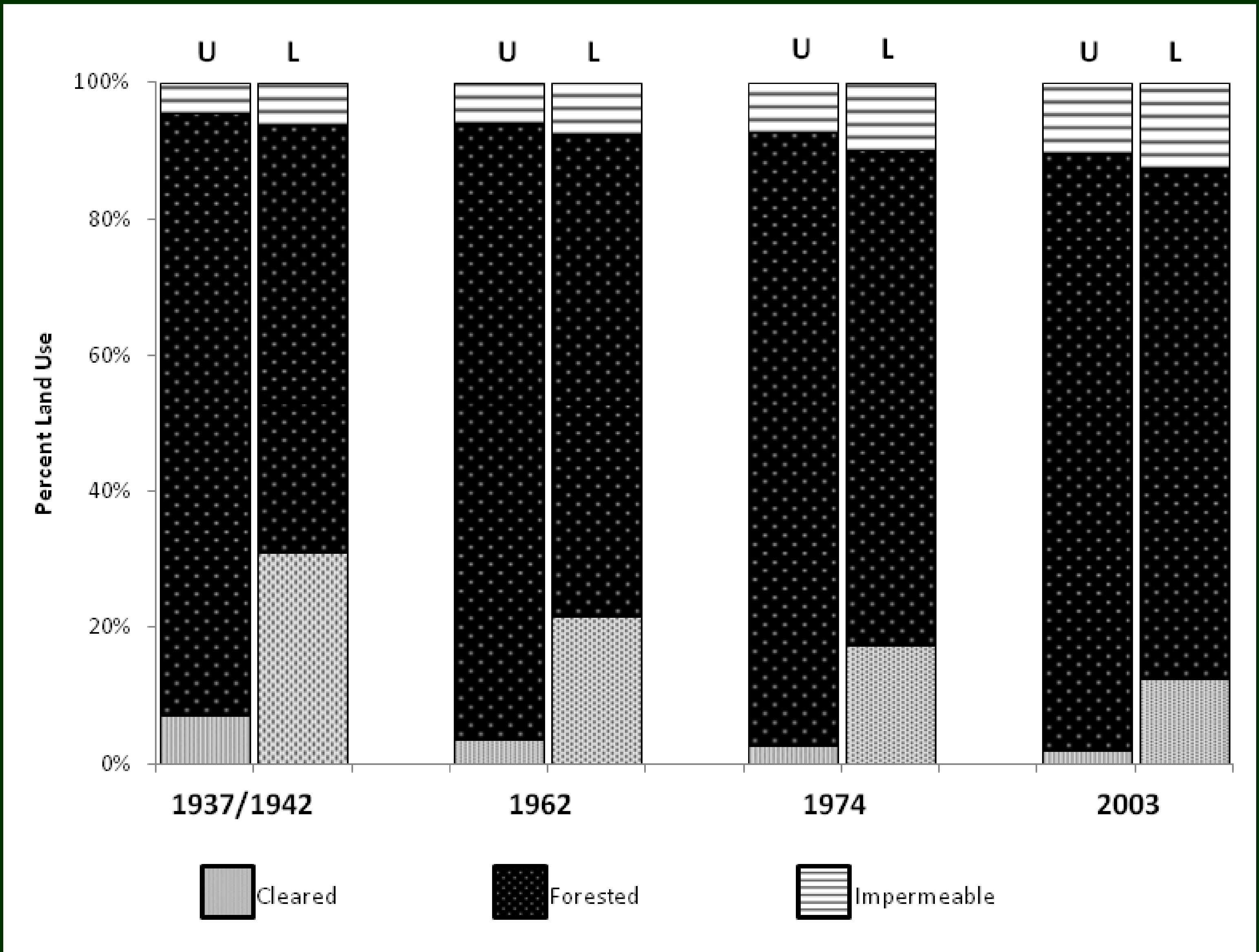
Methods- Land Use



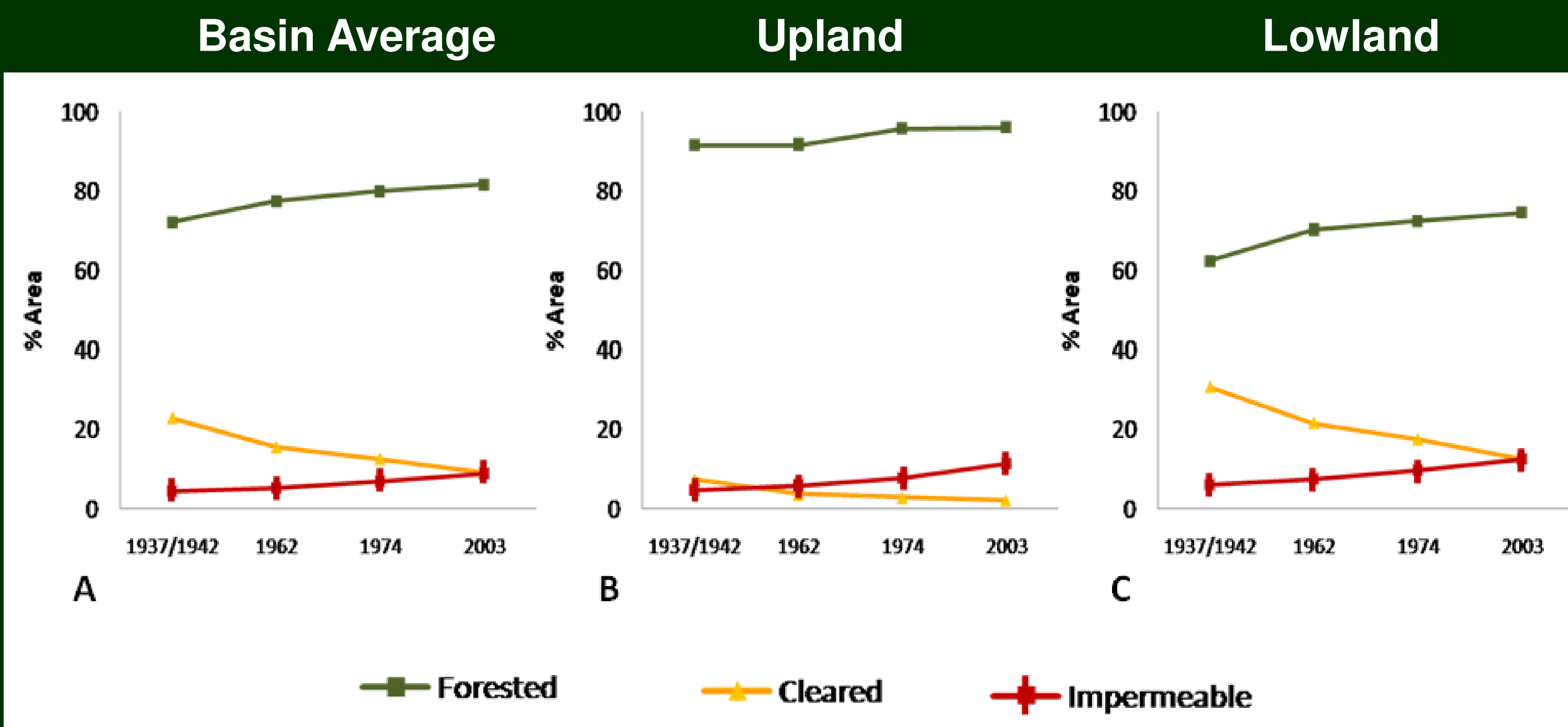
Methods- Land Use



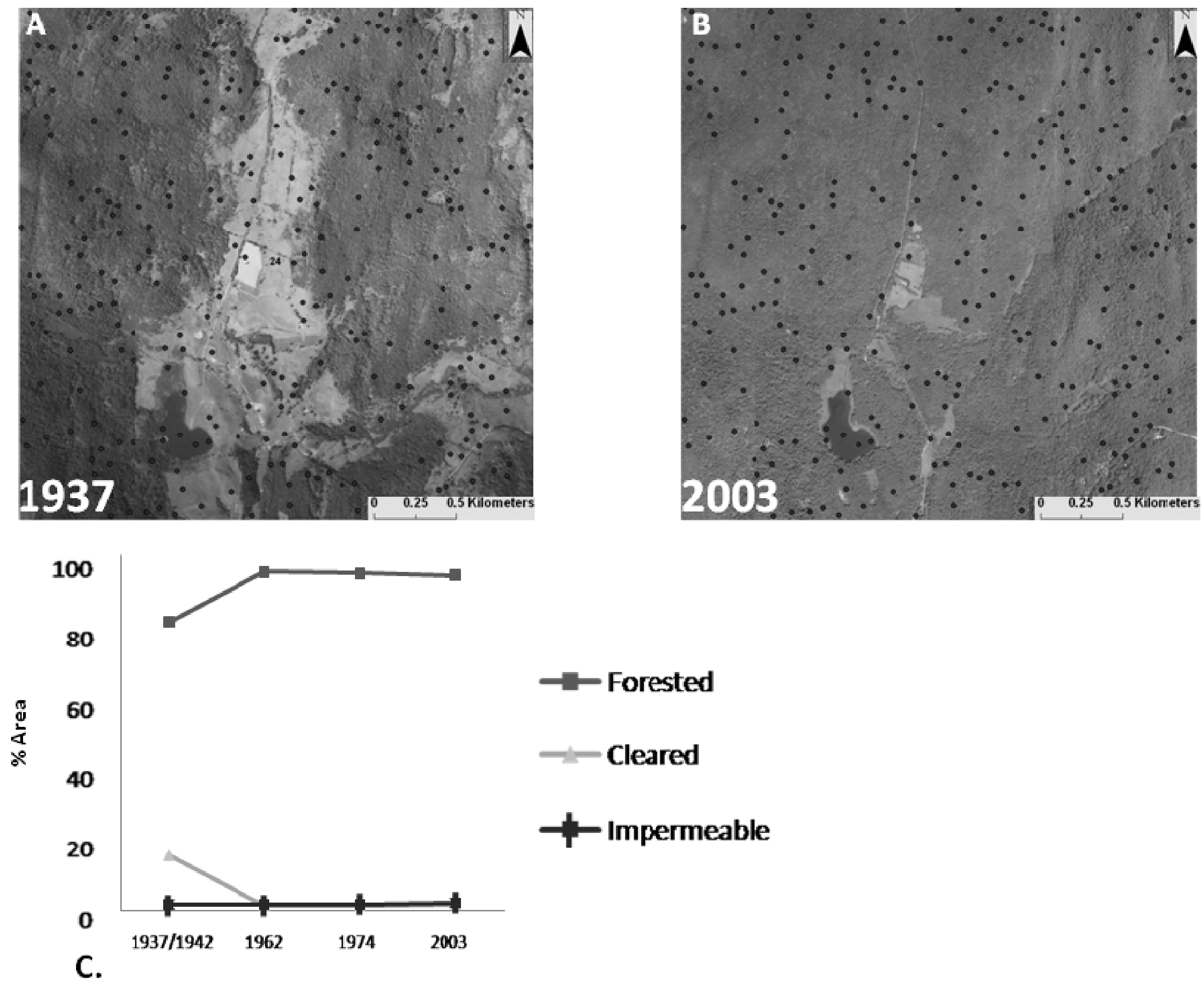
Results- Land Use Change



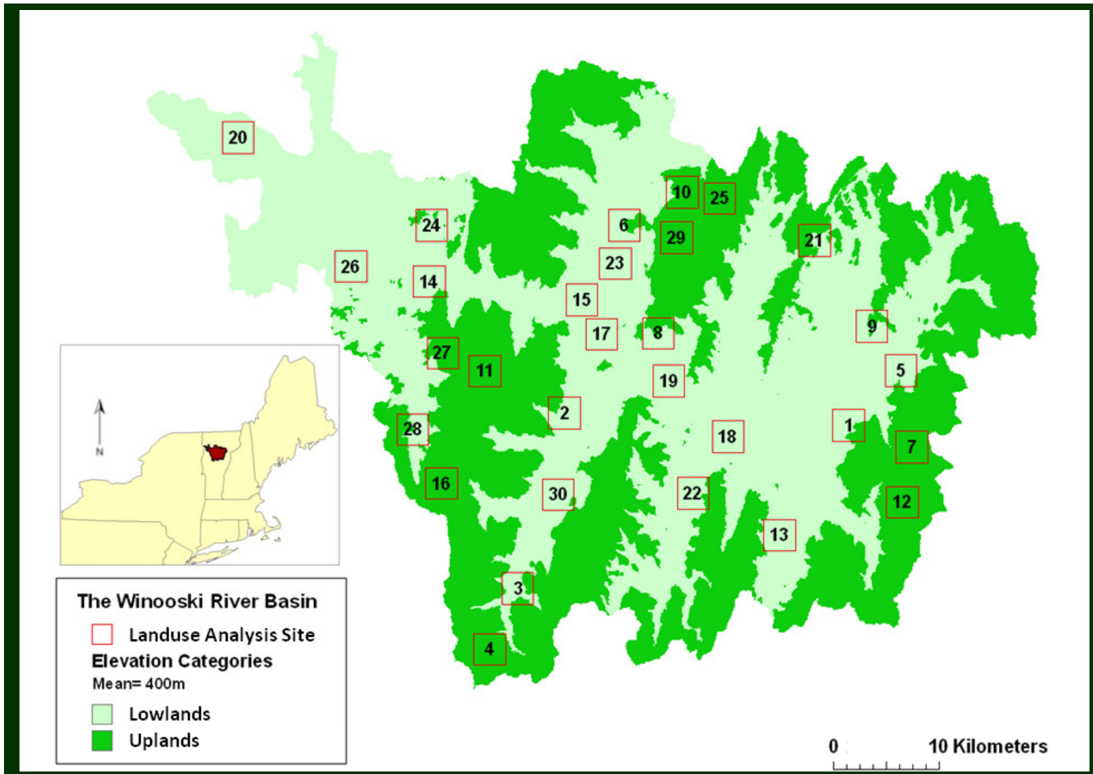
Results- Land Use Change



Results- Land Use Change

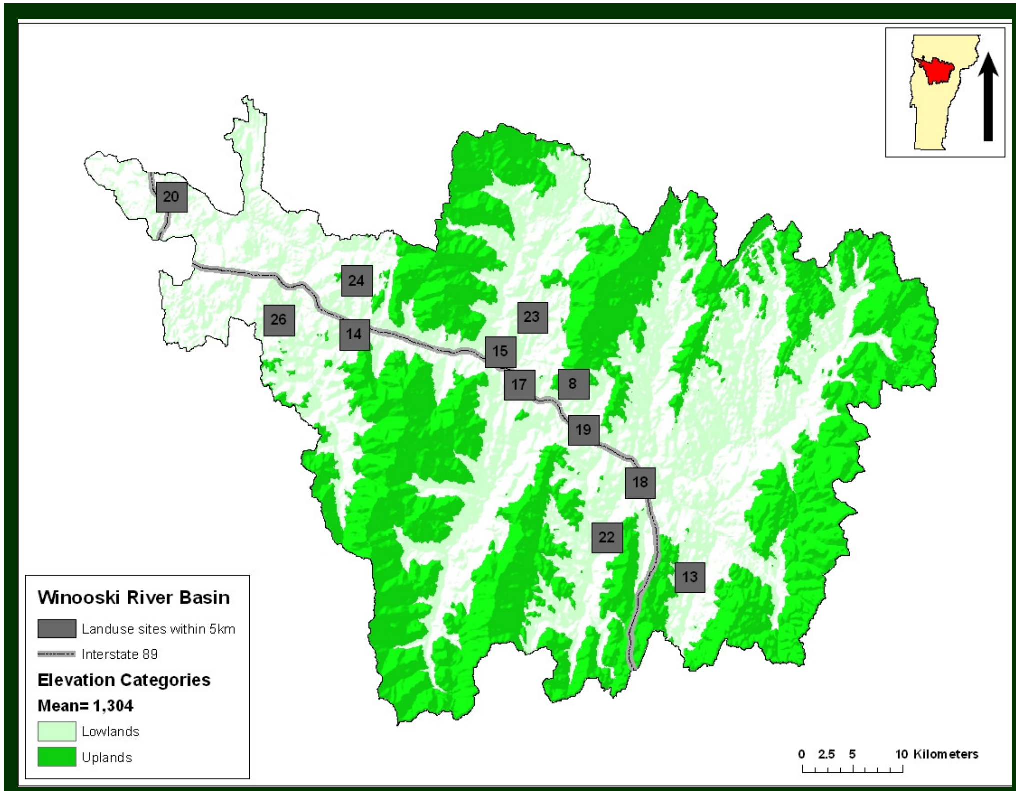


Elevation split



- All eleven quadrats with >10% impervious area are in the lowlands

- All five unchanged, mainly forested quadrats are in the uplands

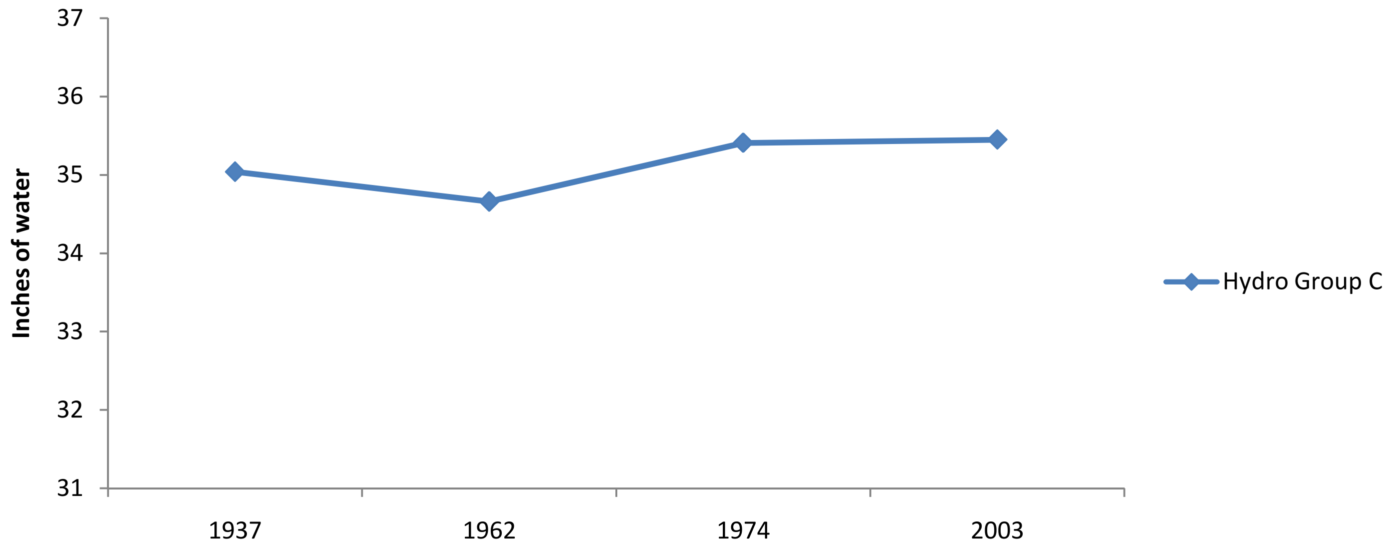


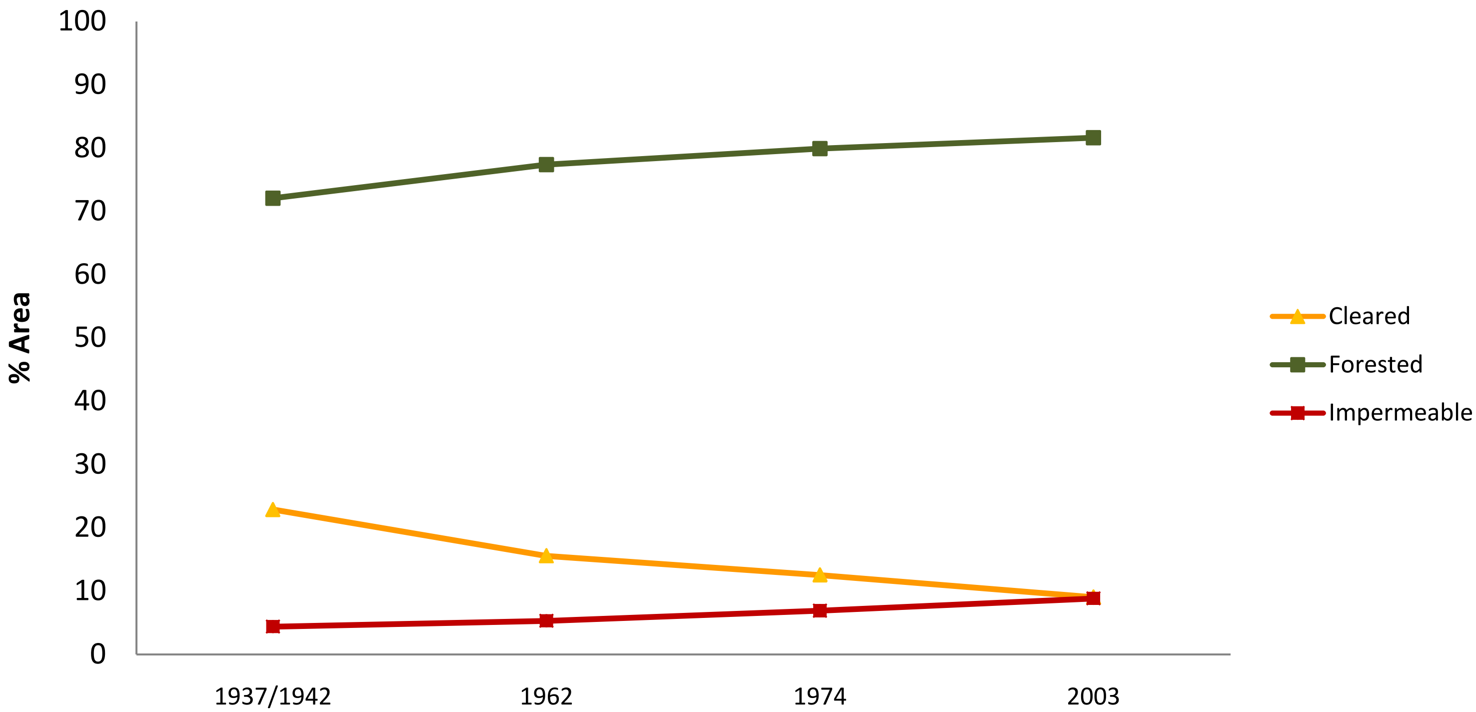
Distance to highway

- Five of the seven quadrats within 600 m (Ecological Road Effect Zone) are among those with highest proportions of impervious surfaces

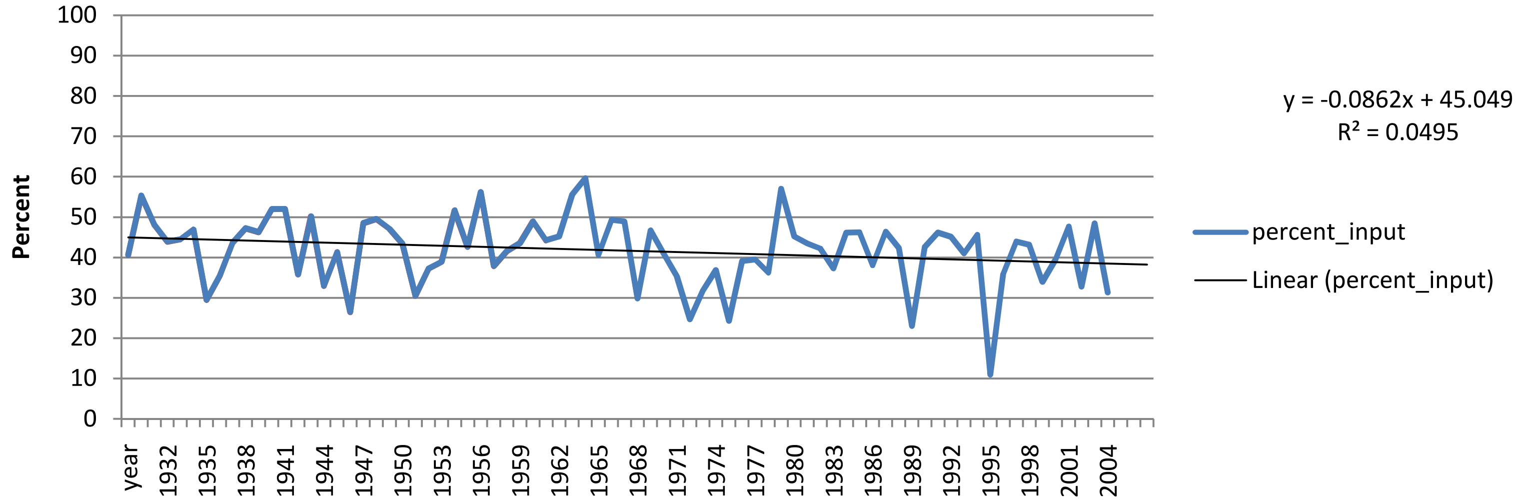
- Eight of the twelve quadrats within 5km of Interstate have the highest proportions of impervious surface

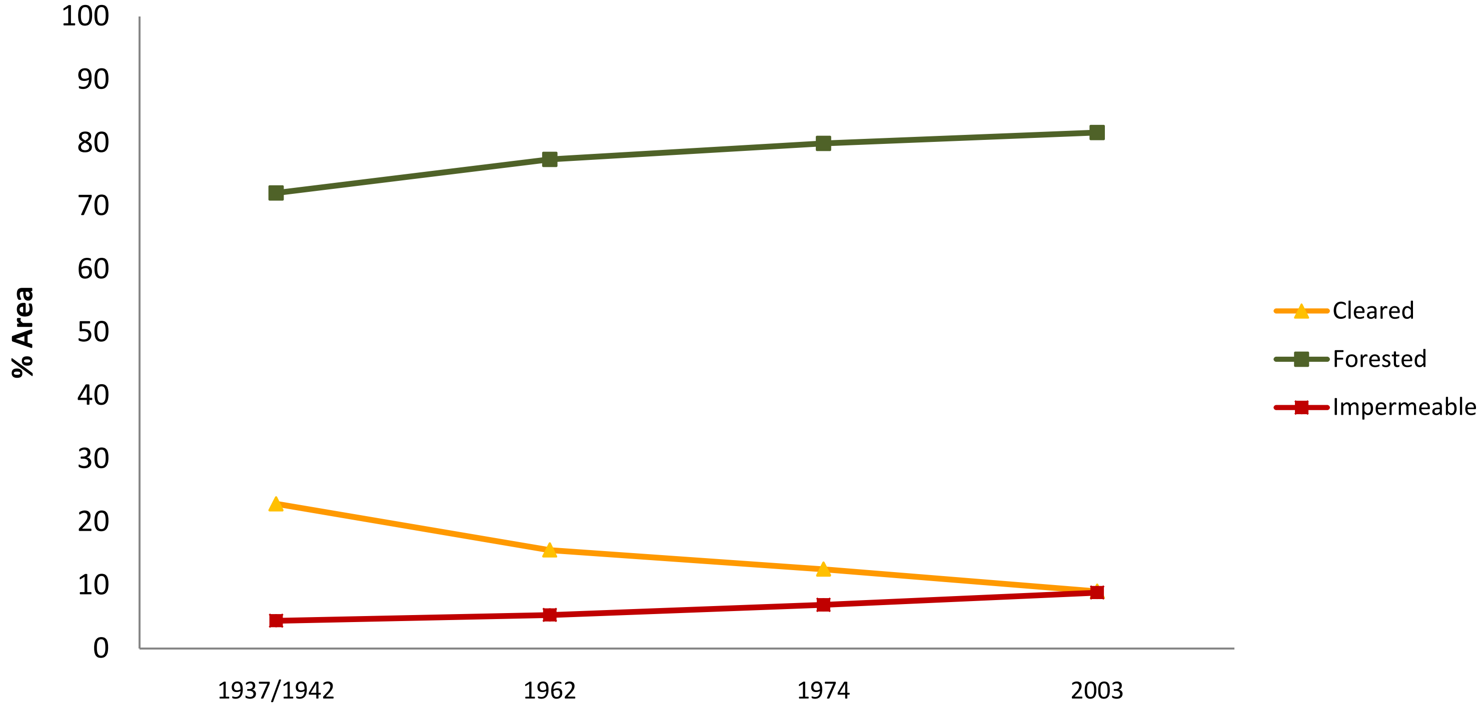
Land Use Area Weighted Runoff per 40 inches of precipitation





Evapotranspiration





So how does it all fit together?

Determine how the individual results relate back to the original question of what has happened within the discharge record

Interpretations

Changing Seasonality:

-Warmer early spring months
  -less snowpack
  -earlier spring melt

-Less/unchanged precipitation

-More discharge

Interpretations

-Less discharge in early summer months despite more rain

-More ET with reforestation

-Higher base flows despite increased ET

Conclusions

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

-Frequency of the largest precipitation events per year has increase

-Baseflow has increased

-Discharge has increased significantly at all stations during fall months along with increased fall precipitation

-Discharge has increased at all stations during early spring months despite decreases in precipitation, the opposite is true for later spring months

-Changing Seasonality- earlier spring, warmer winters

-Land use has changed yielding more forest and impervious surfaces but less cleared land

Conclusions

-Climate drives precipitation, discharge

-Short-term oscillations (NAO) can be detected throughout the system

-Landuse has changed but plays only a subtle role in the system

-Climate is changing and is the main system driver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