Trends in Sulfate Deposition and Stream Water Base Cation Concentrations in the Catskill Mountains of New York

USGS
science for a changing world

Catskill Long-Term Monitoring

USGS
science for a changing world

Funded by:

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

NEW YORK CITY DEPARTMENT OF ENVIRONMENTAL PROTECTION
DEP

USGS
science for a changing world

USGS
science for a changing world

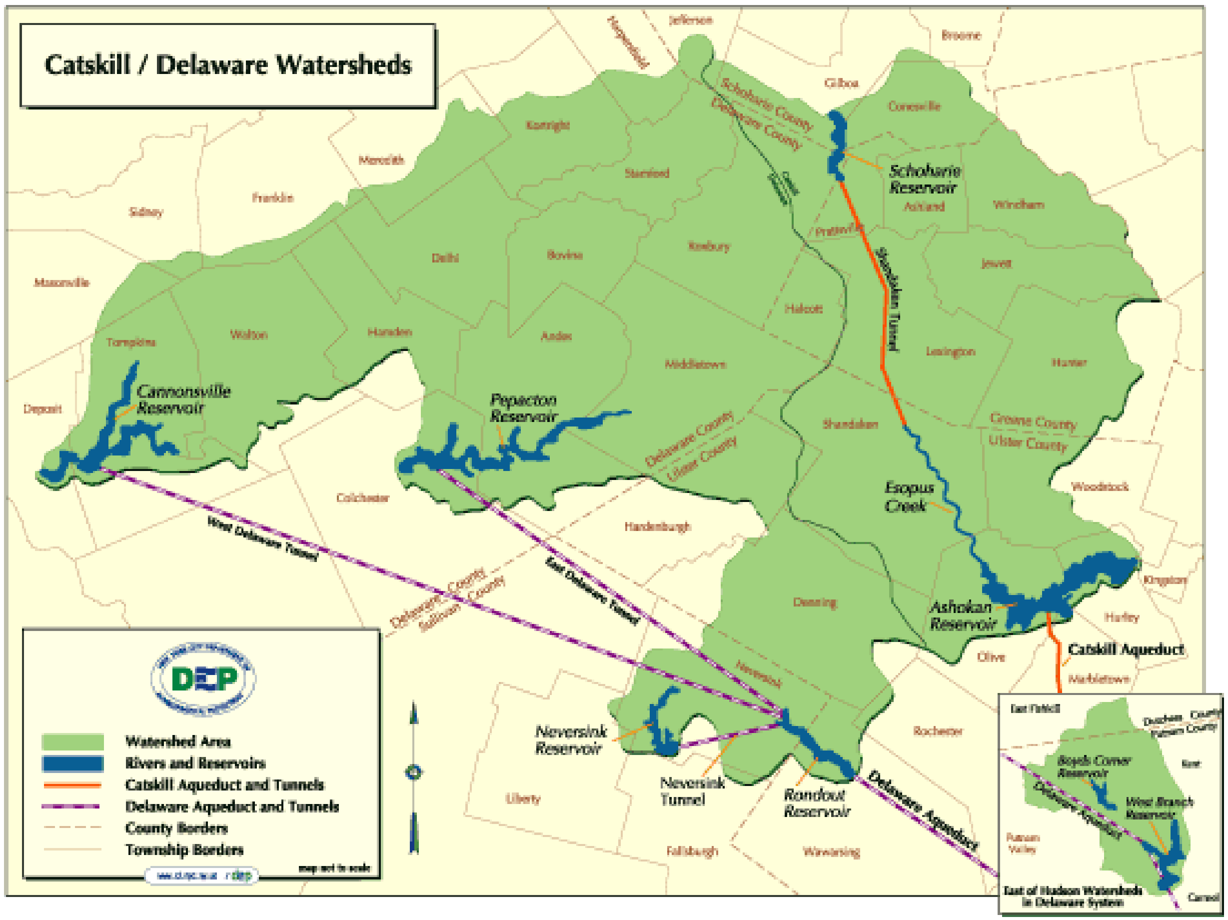
Co-authors:

Angelika Winner
Doug Burns
Greg Lawrence
Pete Murdoch

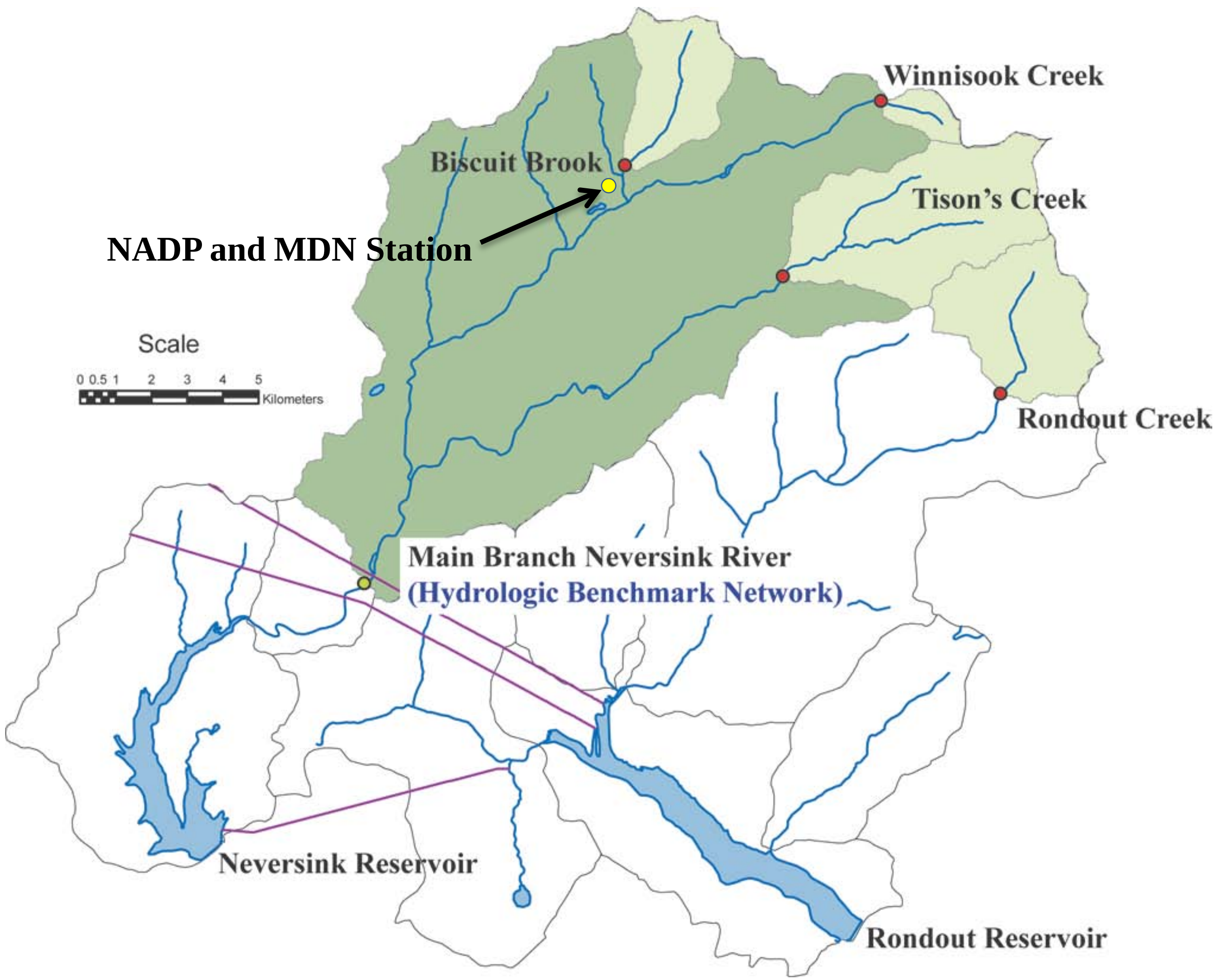
USGS
science for a changing world


New York

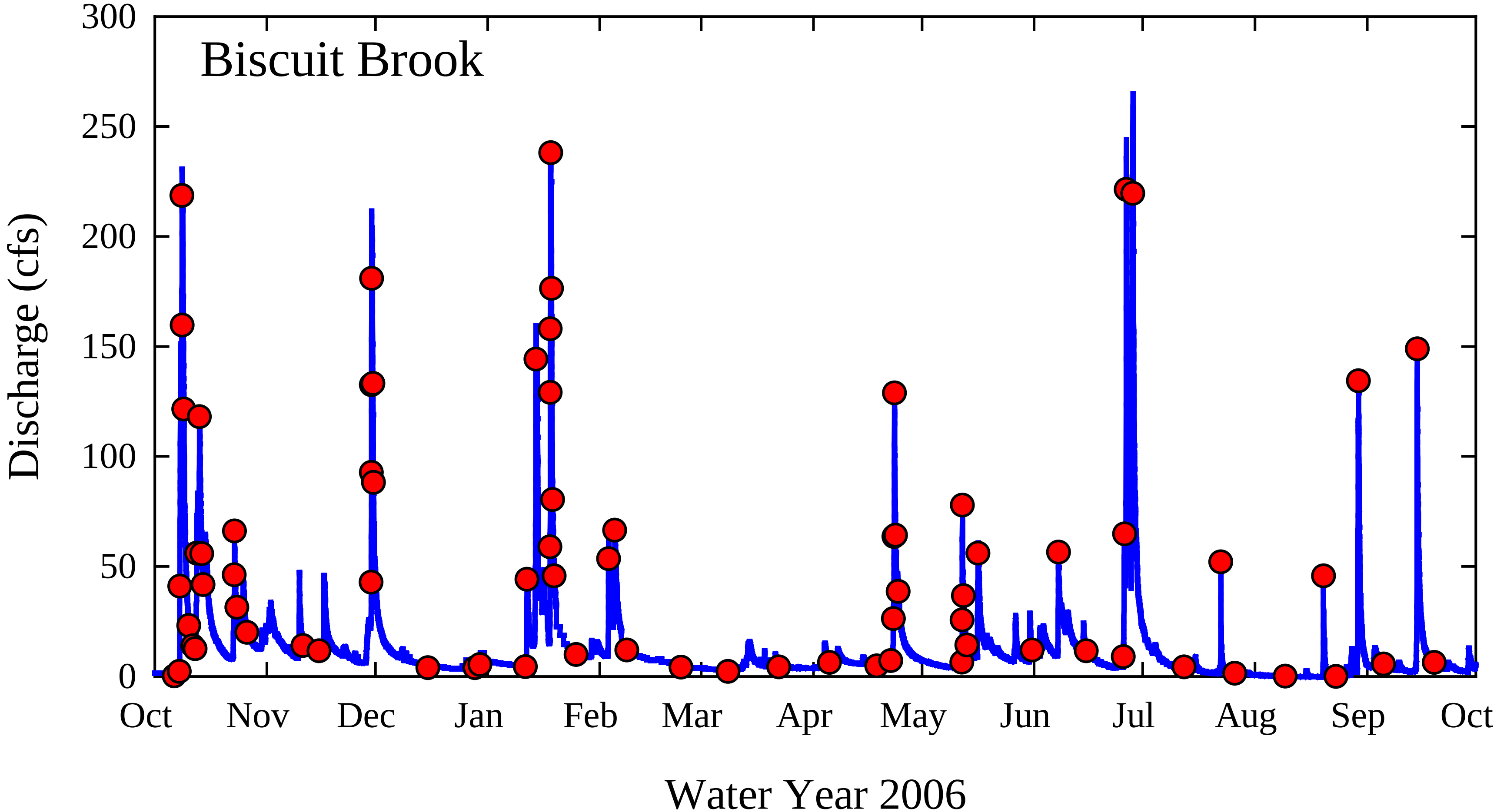

New York City's
Water Supply System
Catskill/Delaware
Watersheds
Croton
Watershed
OTSEGO COUNTY
CHENANGO COUNTY
SCHOHARIE COUNTY
ALBANY COUNTY
RENSSELAER COUNTY
DELAWARE COUNTY
GREENE COUNTY
COLUMBIA COUNTY
MASSACHUSETTS
DUTCHESS COUNTY
ULSTER COUNTY
CONNECTICUT
SULLIVAN COUNTY
ORANGE COUNTY
PUTNAM COUNTY
WESTCHESTER COUNTY
ROCKLAND COUNTY
NASSAU COUNTY
PENNSYLVANIA
NEW YORK
NEW JERSEY
Albany
Oneonta
Gilboa
Delhi
Hunter
Walton
Downsville
Phoenicia
Kingston
Deposit
Liberty
Ellenville
Poughkeepsie
White Plains
Schoharie Reservoir
Cannonsville Reservoir
Pepacton Reservoir
Ashokan Reservoir
Neversink Reservoir
Rondout Reservoir
West Branch Reservoir
New Croton Reservoir
Kensico Reservoir
Shandaken Tunnel
Esopus Creek
West Branch Delaware
East Branch Delaware
East Delaware Aqueduct
West Delaware Aqueduct
Delaware Aqueduct
Catskill Aqueduct
Croton Aqueduct
Neversink Tunnel
Neversink River
Delaware River
Hudson River
125 Miles
100 Miles
75 Miles
50 Mile
25 Miles (from City Hall)
Bronx
Manhattan
Queens
Brooklyn
Staten Island
New York Bay
Long Island Sound
Atlantic Ocean
Catskill / Delaware Watershed Area
Croton Watershed Area
Rivers and Reservoirs
Catskill Aqueduct and Tunnels
Croton Aqueduct
Delaware Aqueduct and Tunnels
County Borders
State Borders
www.nyc.gov/dep


Catskill / Delaware Watersheds
Schoharie Reservoir
Cannonsville Reservoir
Pepacton Reservoir
Esopus Creek
Ashokan Reservoir
Catskill Aqueduct
Neversink Reservoir
Neversink Tunnel
Rondout Reservoir
Delaware Aqueduct
West Delaware Tunnel
East Delaware Tunnel
Shandaken Tunnel
Schoharie County
Delaware County
Greene County
Ulster County
Sullivan County
Jefferson
Gilboa
Broome
Conesville
Kortright
Meredith
Stamford
Ashland
Windham
Franklin
Sidney
Delhi
Bovina
Roxbury
Prattsville
Jewett
Masonville
Halcott
Tompkins
Walton
Hamden
Andes
Middletown
Lexington
Hunter
Deposit
Shandaken
Woodstock
Colchester
Hardenburgh
Kingston
Denning
Hurley
Olive
Marbletown
Neversink
Rochester
Liberty
Fallsburgh
Wawarsing
Watershed Area
Rivers and Reservoirs
Catskill Aqueduct and Tunnels
Delaware Aqueduct and Tunnels
County Borders
Township Borders
DEP
map not to scale
East Fishkill
Dutchess County
Putnam County
Boyds Corner Reservoir
West Branch Reservoir
Kent
Putnam Valley
Carmel
East of Hudson Watersheds in Delaware System

Catskill LTM Network



Biscuit Brook Sampling Hydrograph



Study Area

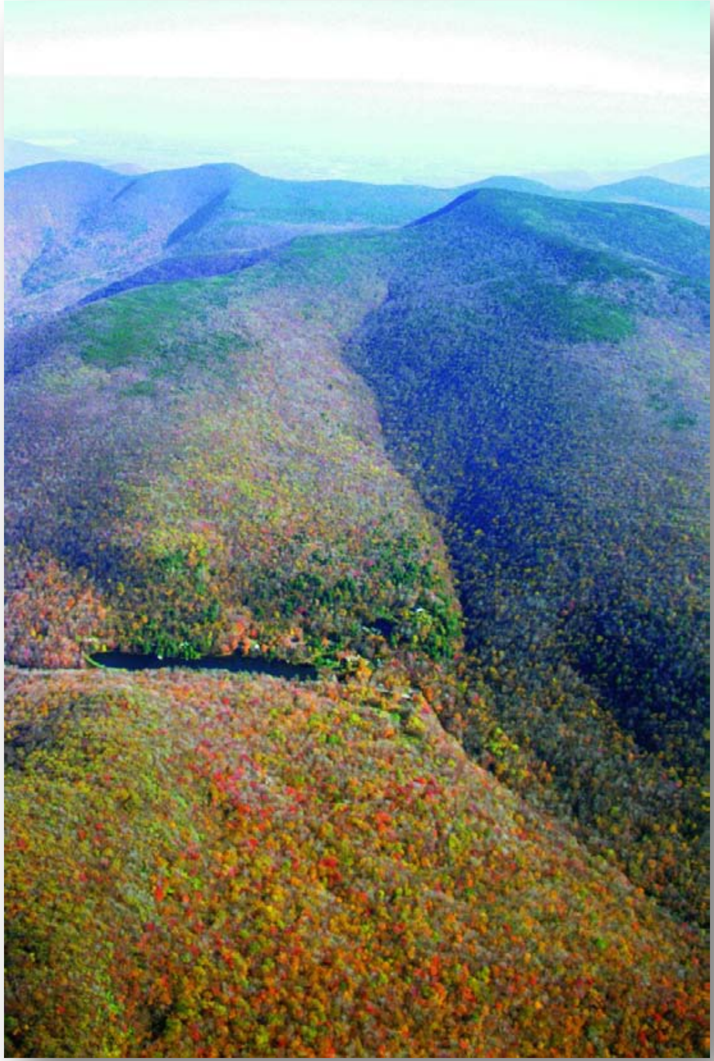
- **Geology:** uplifted plateau of sedimentary bedrock (sandstone, conglomerate and some shale and siltstone), covered by variably thick layer of till from the most recent glaciation.

- **Topography:** steep slopes, dissected by streams

- **Soils:** thin till and soil cover,

  soils are inceptisols: bouldery silt loam with thin organic horizons

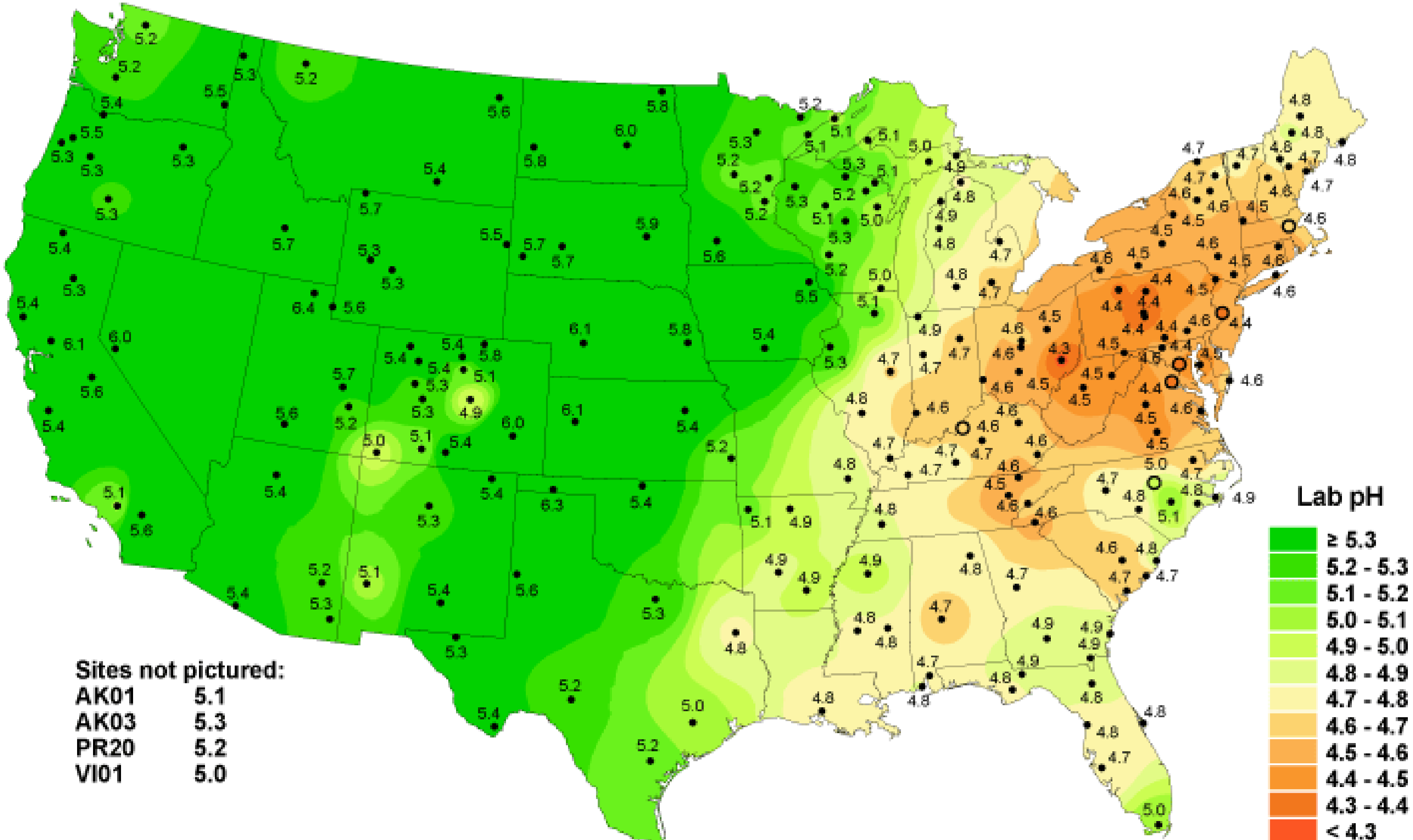
- **Vegetation and land use:** 99% forested, dominated by American Beech, Sugar Maple, Yellow Birch



Rondout Creek above Peekamoose (RC)

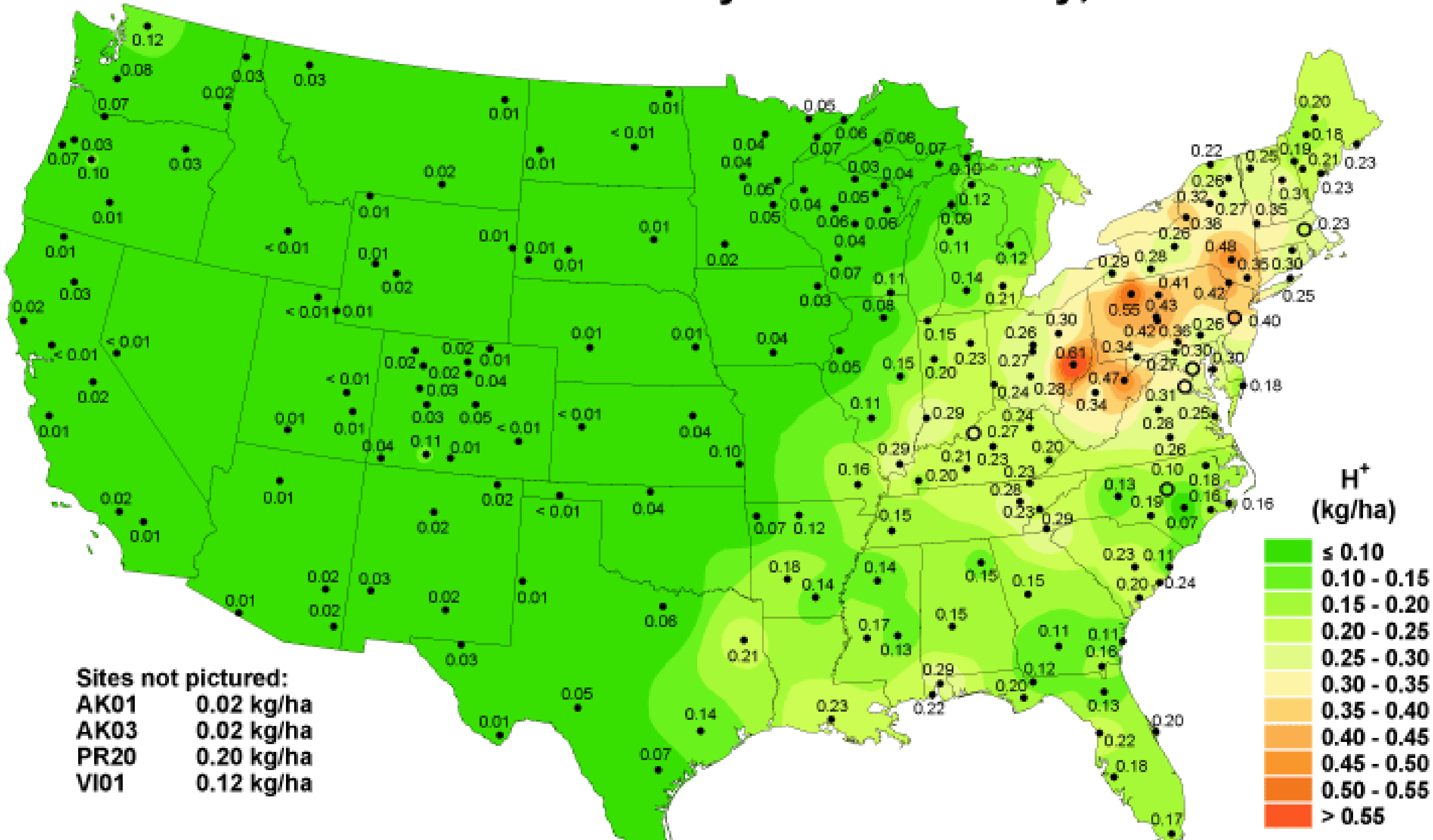
Winnisook Watershed (WN) on the slopes of Slide Mountain in the headwaters of the Neversink River basin

Hydrogen ion concentration as pH from measurements made at the Central Analytical Laboratory, 2007



National Atmospheric Deposition Program/National Trends Network
http://nadp.sws.uiuc.edu

Hydrogen ion wet deposition from measurements made at the Central Analytical Laboratory, 2007

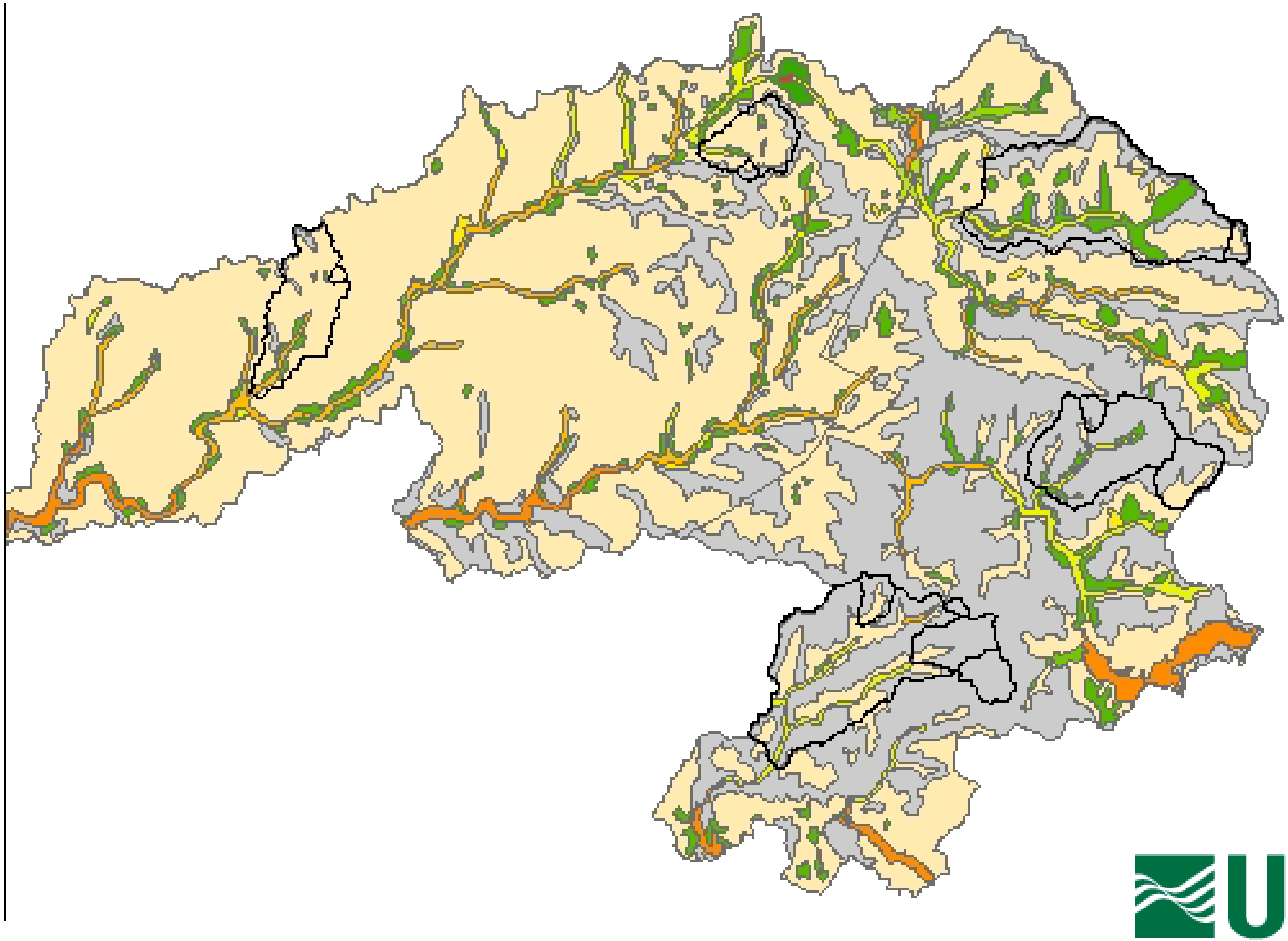


Sites not pictured:

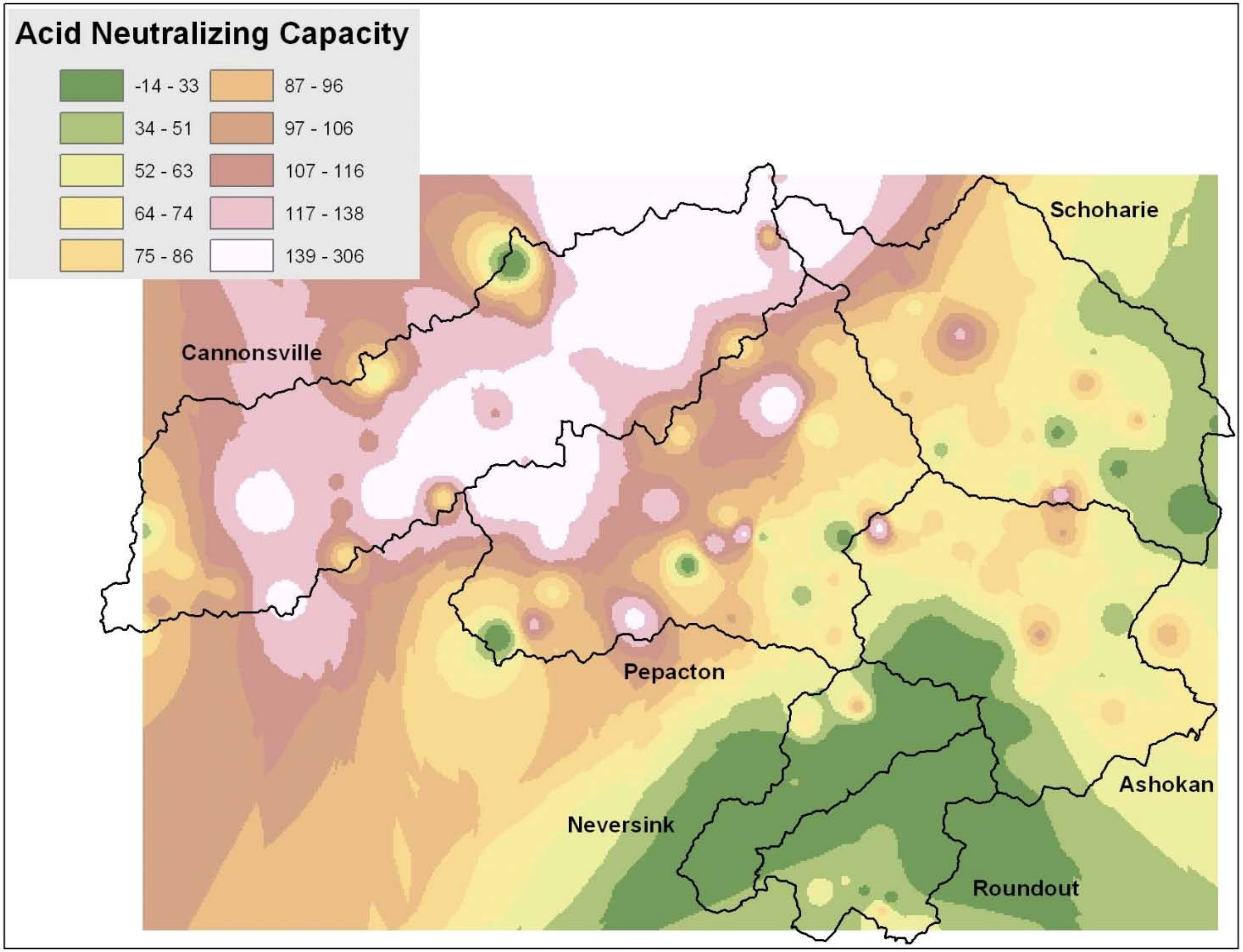
AK01	**0.02 kg/ha**
AK03	**0.02 kg/ha**
PR20	**0.20 kg/ha**
VI01	**0.12 kg/ha**

National Atmospheric Deposition Program/National Trends Network
http://nadp.sws.uiuc.edu

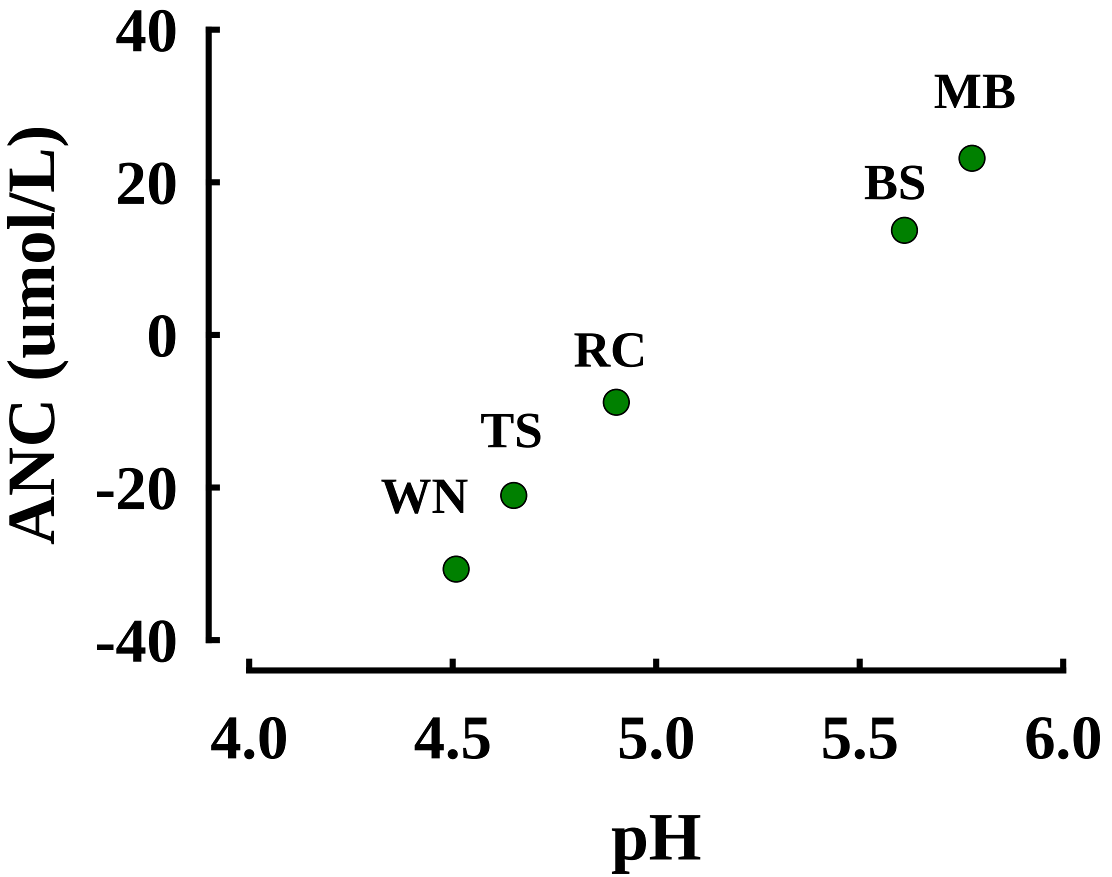
Surficial Geology



Catskill Stream Survey: ANC (N=180)

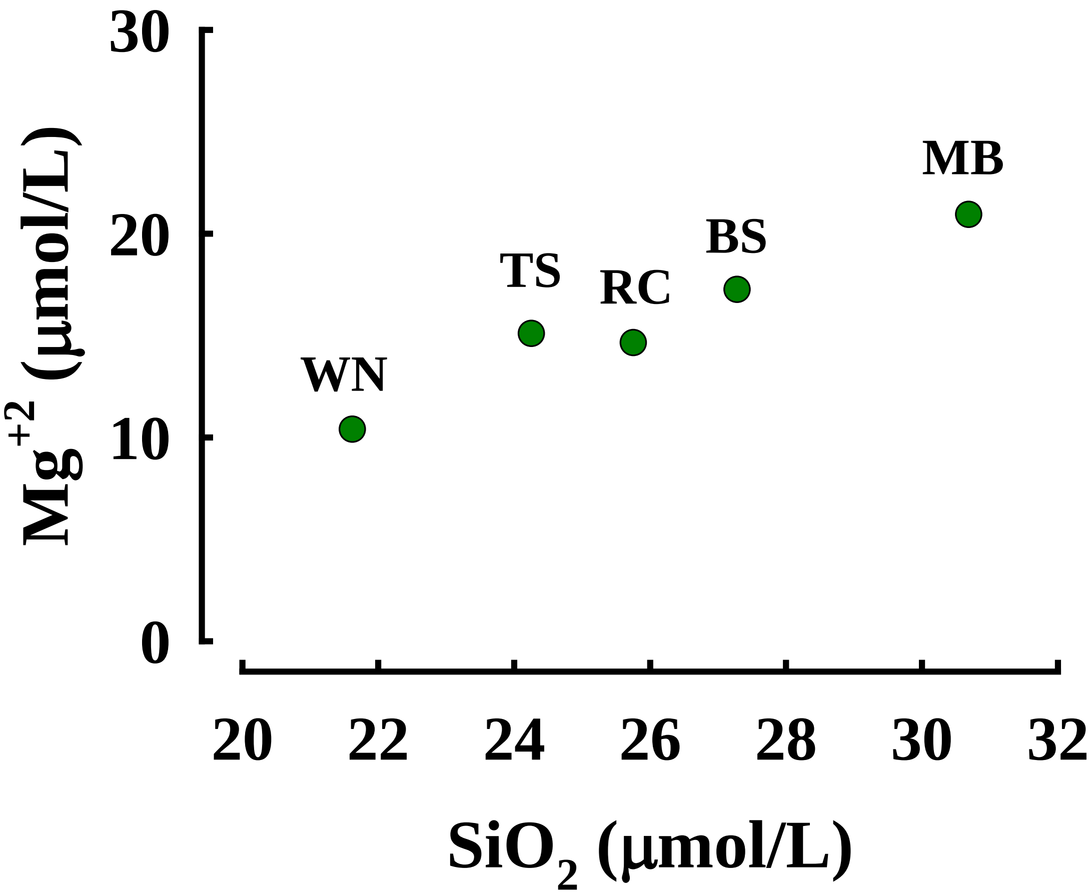


Mean Annual Flow Wt. Concentrations 1991-2008



Most Acidic: WN

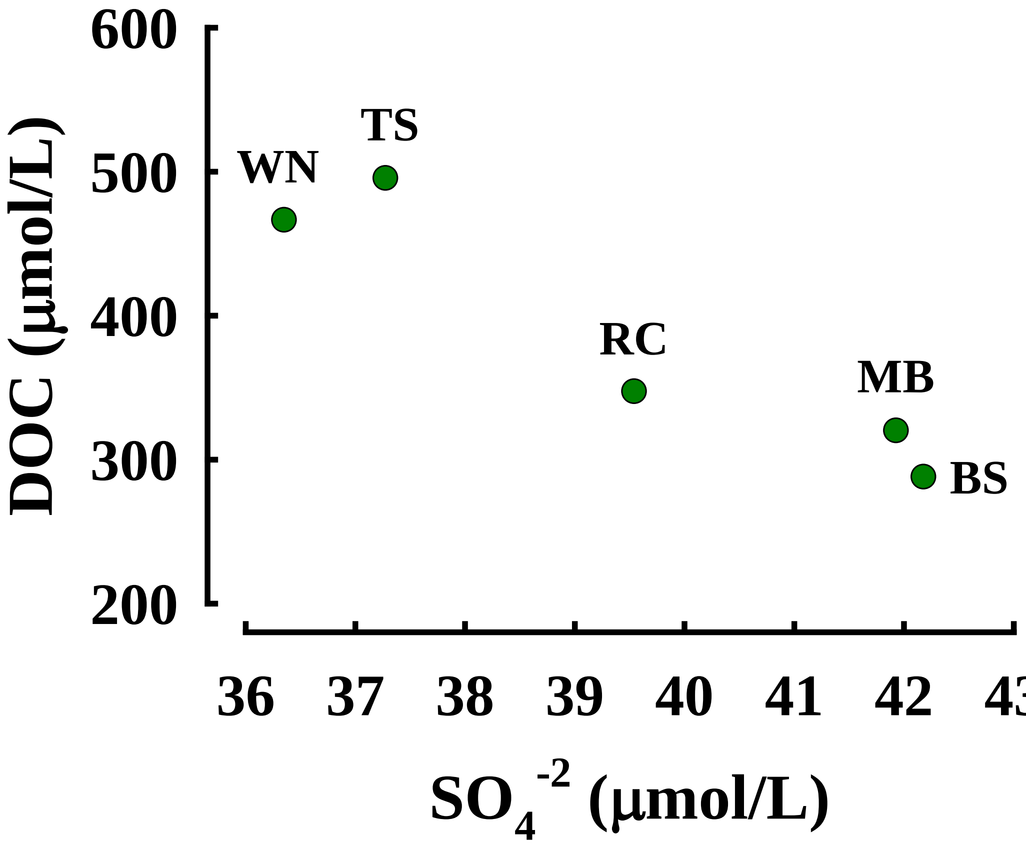
Mean Annual Flow Wt. Concentrations 1991-2008



Highest Silica MB

Highest Mg: MB

Mean Annual Flow Wt. Concentrations 1991-2008



Highest Sulfate: MB & BS

Highest DOC: TS & WN

Catskill LTM Trends
Water Years 1991-2005

Source	pH	SO4	DOC	Ca	Mg	SiO2
Deposition	0.02	-1.15	NA	NS	NS	NA
O-horizon	-0.01	-2.56	34.5	NS	-0.48	NS
Upper B-horizon	-0.01	-2.04	NS	-0.21	-0.33	NS
Lower B-horizon	NS	-2.21	NS	0.30	NS	NS
WN Low Flow	0.01	-1.52	1.91	NS	-0.46	-0.45
BS Low Flow	NS	-2.57	2.99	NS	-0.61	-0.50
RC Low Flow	-0.03	-1.95	5.07	NS	-0.78	-0.82
TS Low Flow	NS	-1.83	3.18	NS	-0.59	-0.41
MB Low Flow	NS	-1.80	0.53	NS	NS	-0.58
WN Stream Water	0.001	-2.65	1.14	NS	-0.38	-0.43
BS Stream Water	NS	-2.42	3.37	NS	-0.52	-0.37
RC Stream Water	-0.02	-1.97	NS	NS	-0.49	-0.41
TS Stream Water	0.01	-1.97	2.14	-0.70	-0.60	-0.33
MB Stream Water	-0.02	-1.97	NS	NS	-0.49	-0.41

All concentrations are in microequivalents per liter per year

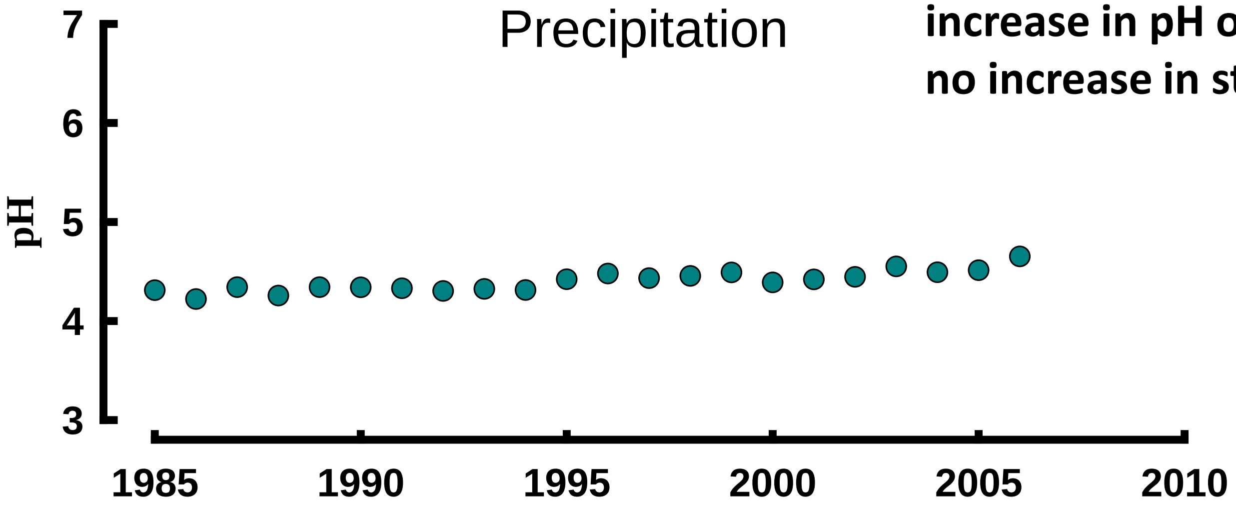
Trends
WY1991-2008

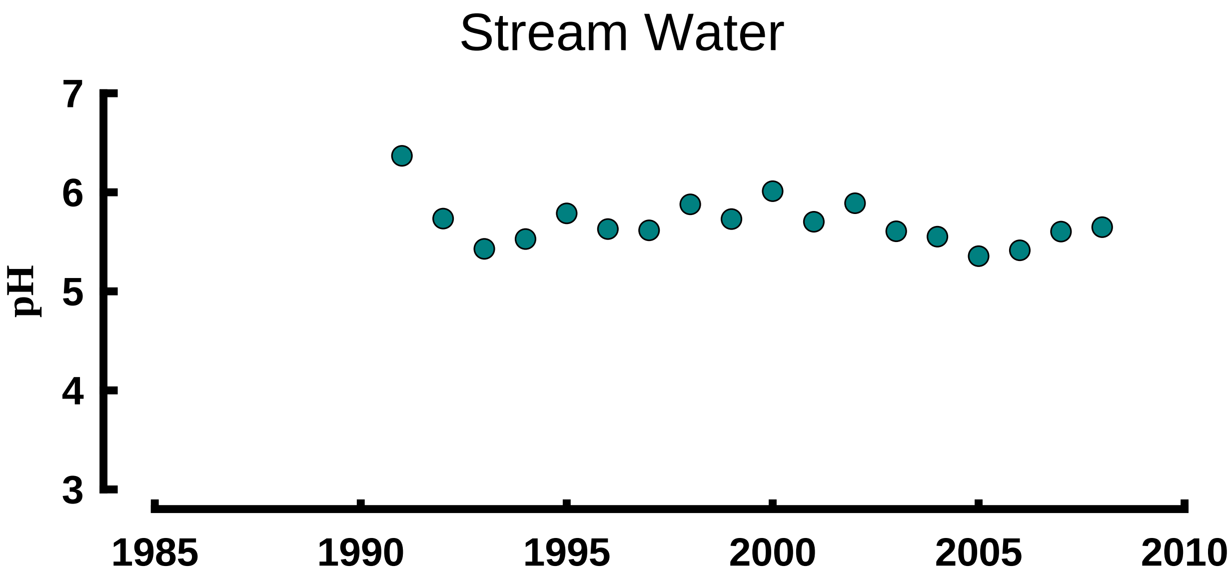
Source	pH	SO4	NO3	DOC	Ca	Mg	SiO2	Almono	Alorg	Altot
BS NADP	0.01	-1.07	-0.51	NA	NS	NS	NA	NA	NA	NA
Winnisook	0.01	-1.92	NS	1.82	-0.32	-0.47	-0.40	-0.20	-0.06	-0.30
Biscuit Brook	NS	-2.42	NS	2.66	-0.49	-0.46	-0.30	-0.05	-0.04	-0.03
Rondout Creek	NS	-2.01	NS	2.20	-0.52	-0.57	-0.40	-0.10	-0.04	-0.10
Tison's Creek	0.02	-1.85	0.21	NS	-0.55	-0.56	-0.30	-0.10	-0.05	-0.20
Main Branch	NS	-2.03	0.29	NS	NS	-0.44	-0.40	-0.04	-0.02	NA

All concentrations are in microequivalents per liter per year

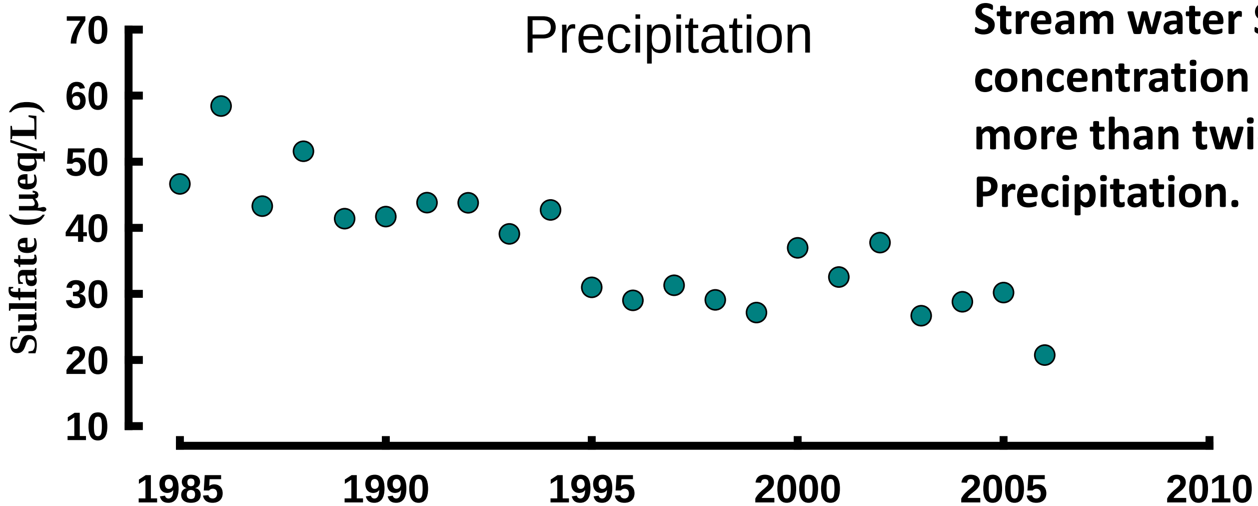
Biscuit Brook Annual Means

increase in pH of precipitation
no increase in stream water pH

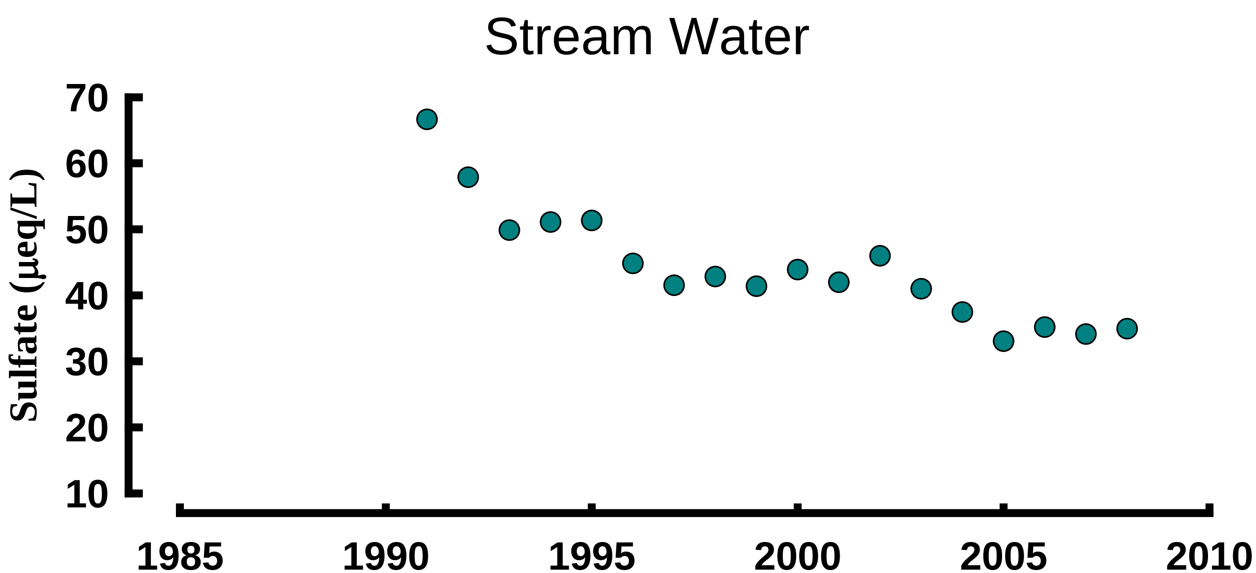




Biscuit Brook Annual Means

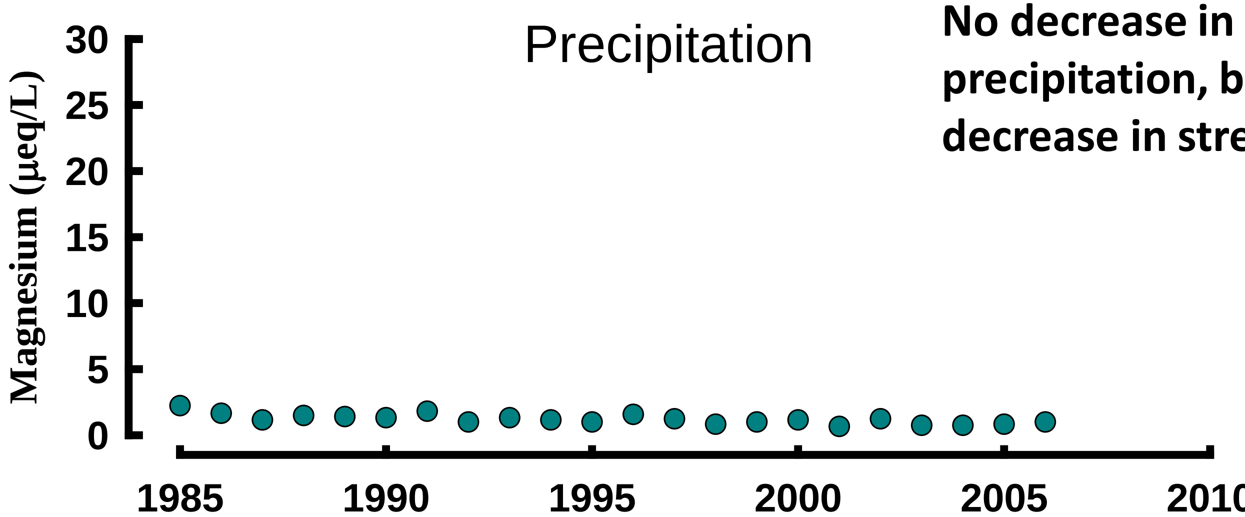


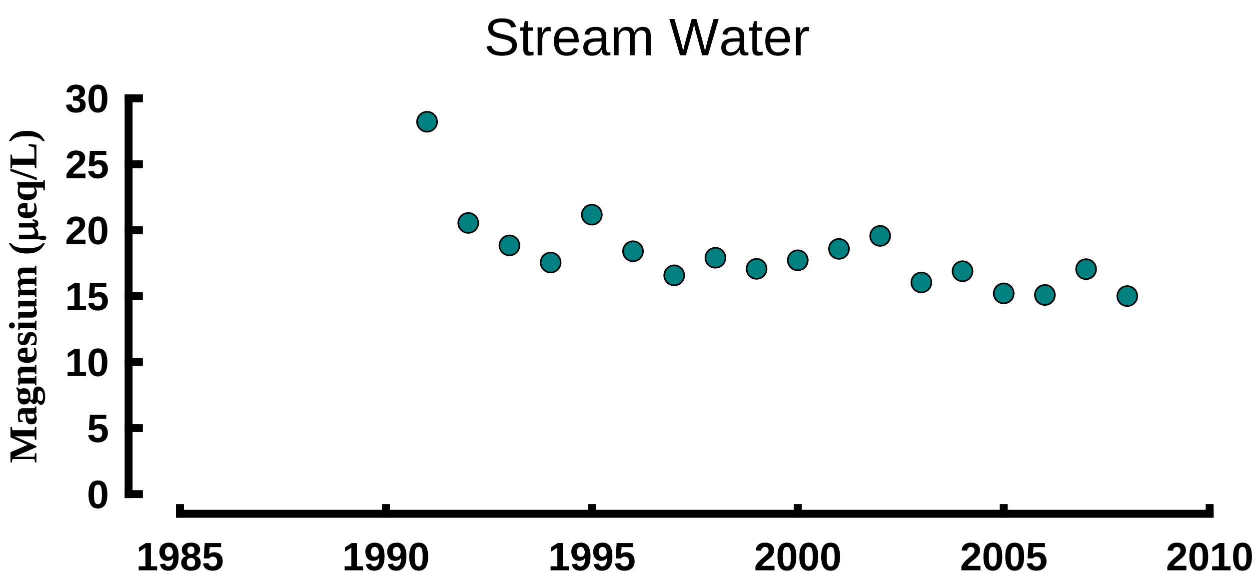
Stream water Sulfate concentration is decreasing at a more than twice the rate of Precipitation.



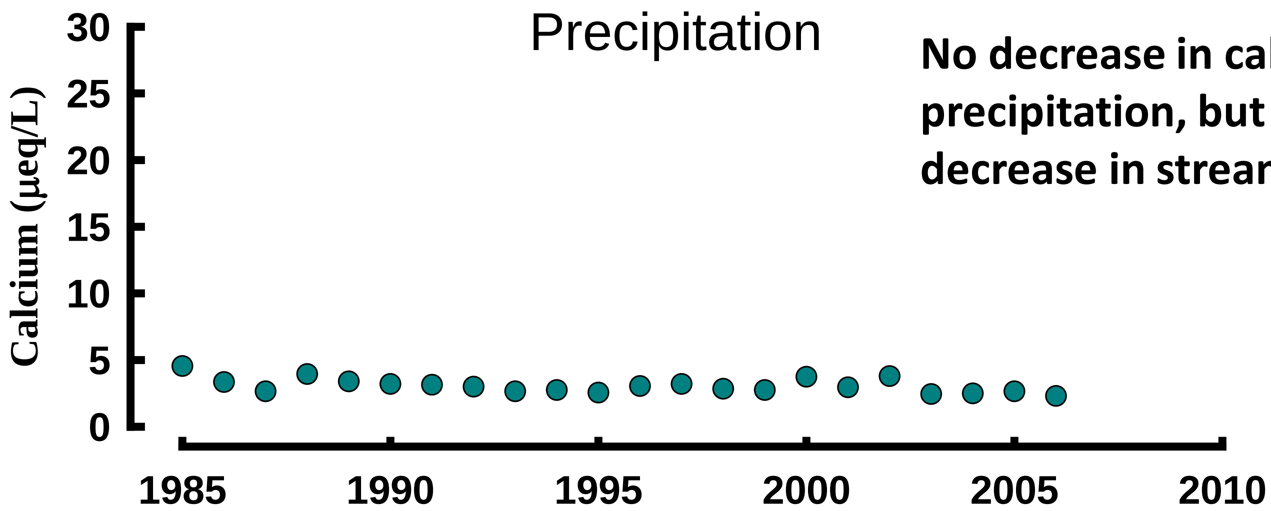
Biscuit Brook Annual Means

No decrease in magnesium in precipitation, but a significant decrease in stream water.

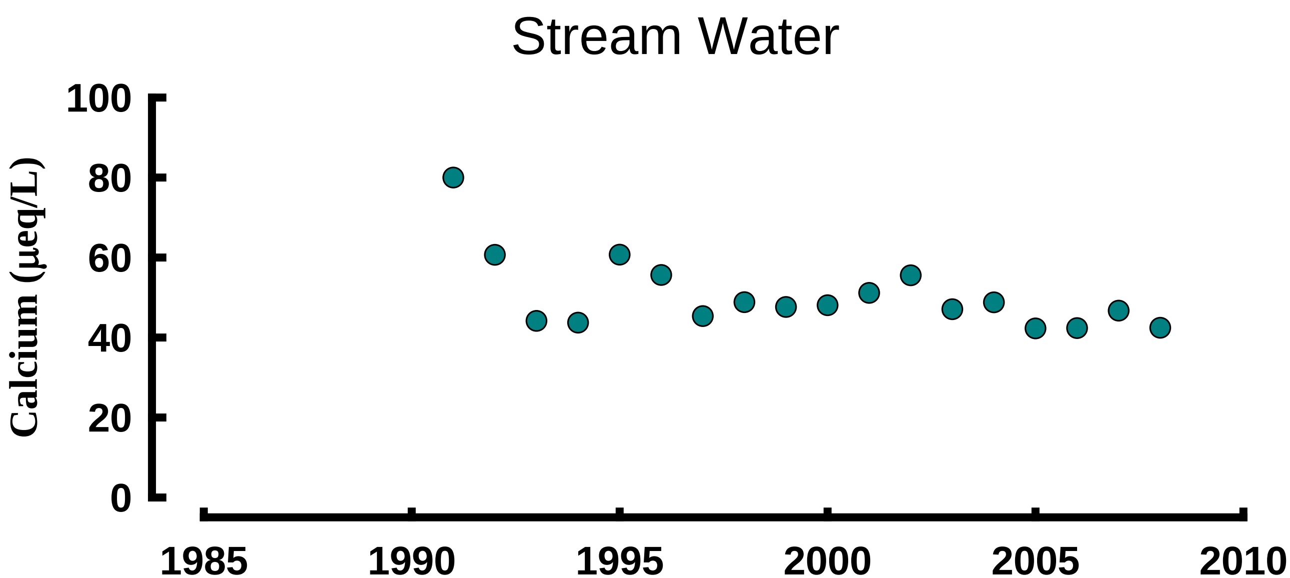




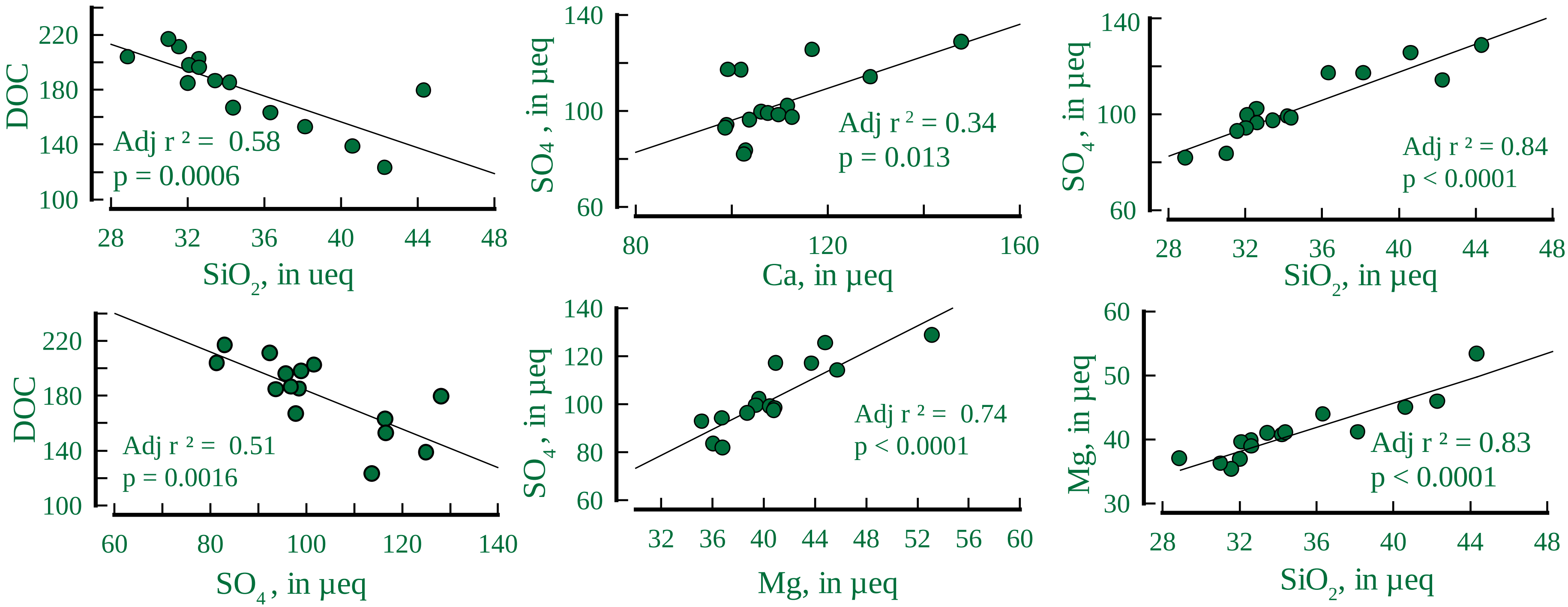
Biscuit Brook Annual Means



No decrease in calcium in precipitation, but a significant decrease in stream water.



Relations between mean annual stream water concentrations for Biscuit Brook



pH

- pH is influenced by many factors:
  - increasing and decreasing trends in stream water at different sites
  - mixing processes in stream water (soil, groundwater and precipitation)
  - regression analyses: no one solute accounted for more than ~40% of variability in mean annual pH

Sulfate

- The sulfate trends in stream water concentration were double those calculated for deposition
  - evapotranspiration is likely responsible for concentration effect
  - adsorption by mineral and organic soil particles
  - biotic cycling: accumulation of SO_4 in litter and soil organic matter

  The decrease in sulfate deposition (reduced anions in solution) leads to a decline in base cations (charge balance).

Calcium

- There were almost no significant trends, except in soil water

DOC

- There were increasing trends at almost all of the sites, even during low flow.
- The strongest increase was in O-horizon soil water
- There is a significant inverse relationship between mean annual SO_4 and DOC:
  - The ionic strength of soil and stream water decreases due to the decline in sulfate deposition, so more DOC is drawn into solution
- The increase in regional air temperature may be causing a greater rate in decomposition and higher DOC concentrations

Magnesium

- There are consistent decreasing trends in stream water

- Mg seems to balance the drop in anions in stream and soil water rather than Ca

    Is this an indication of decreasing bedrock weathering as result of decline in acid deposition?

    (supported by mineral composition of Catskills)

    quartz (SiO_2)
    muscovite ($KAl_2(AlSi_3O_{10})(OH)_2$
    biotite ($K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$)
    chlorite ($(Mg,Fe,Al)_{5-6}(Al,Si)_4O_{10}(OH)_8$)
    pyrite (FeS_2)
    hornblende ($Ca_2(Mg,Fe)_4(Al,Fe)Si_7AlO_{22}(OH)_2$)
    and clays
    (Way 1972)

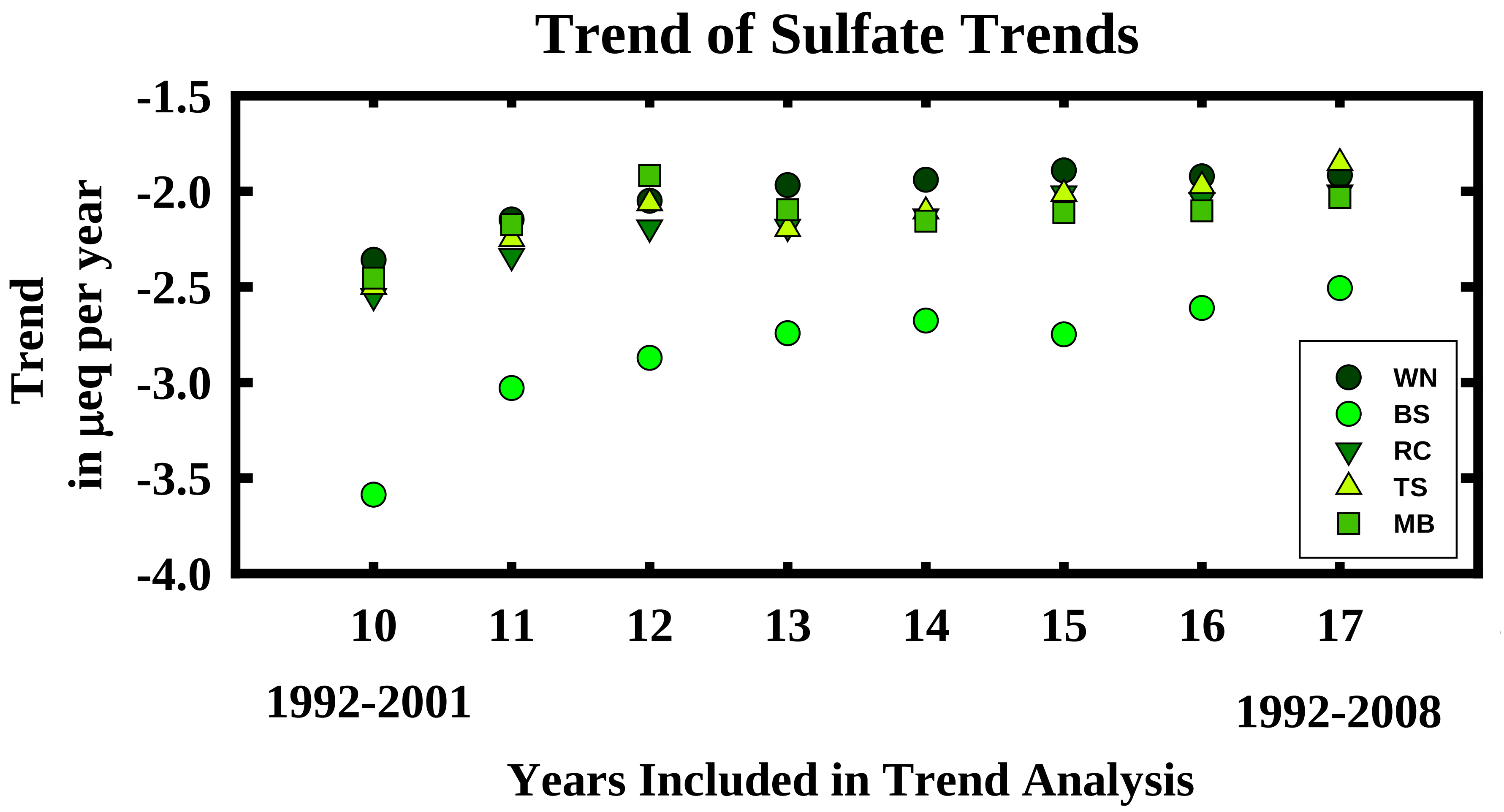
Silica

- There are decreasing trends in SiO_2 in stream water and during low flow

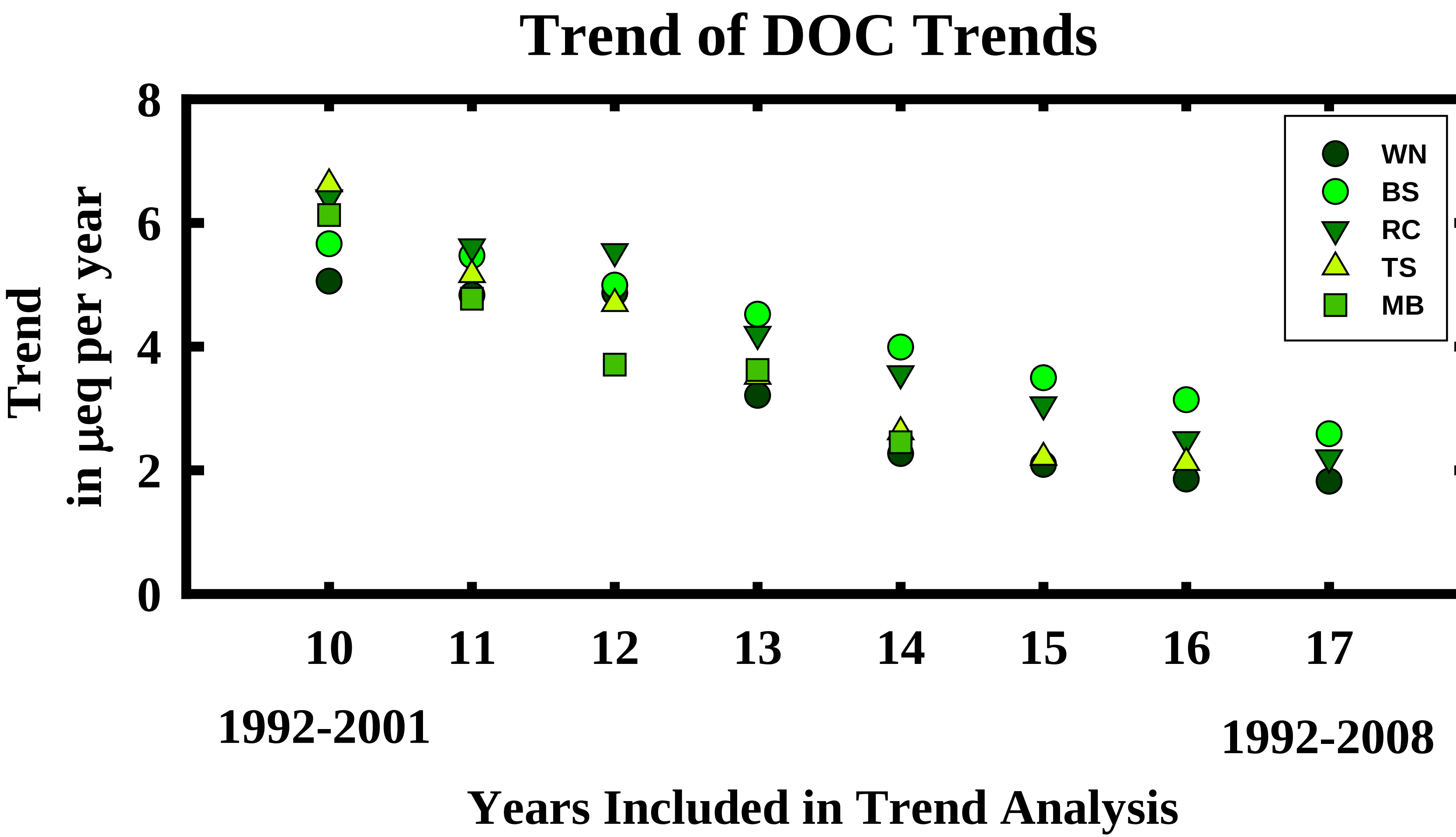
- The strong relationship between Magnesium and Silica supports hypothesis of decline in weathering rate because of decrease in SO_4 deposition

- There are large mineralogical source of silica in these watersheds.

- A decrease in the weathering rate could significantly delay ecosystem recovery from acid deposition



Trend of Sulfate Trends
Trend
in µeq per year
-1.5
-2.0
-2.5
-3.0
-3.5
-4.0
10
11
12
13
14
15
16
17
1992-2001
1992-2008
Years Included in Trend Analysis
WN
BS
RC
TS
MB


Trend of DOC Trends
Trend
in μeq per year
0
2
4
6
8
WN
BS
RC
TS
MB
10
11
12
13
14
15
16
17
1992-2001
1992-2008
Years Included in Trend Analysis