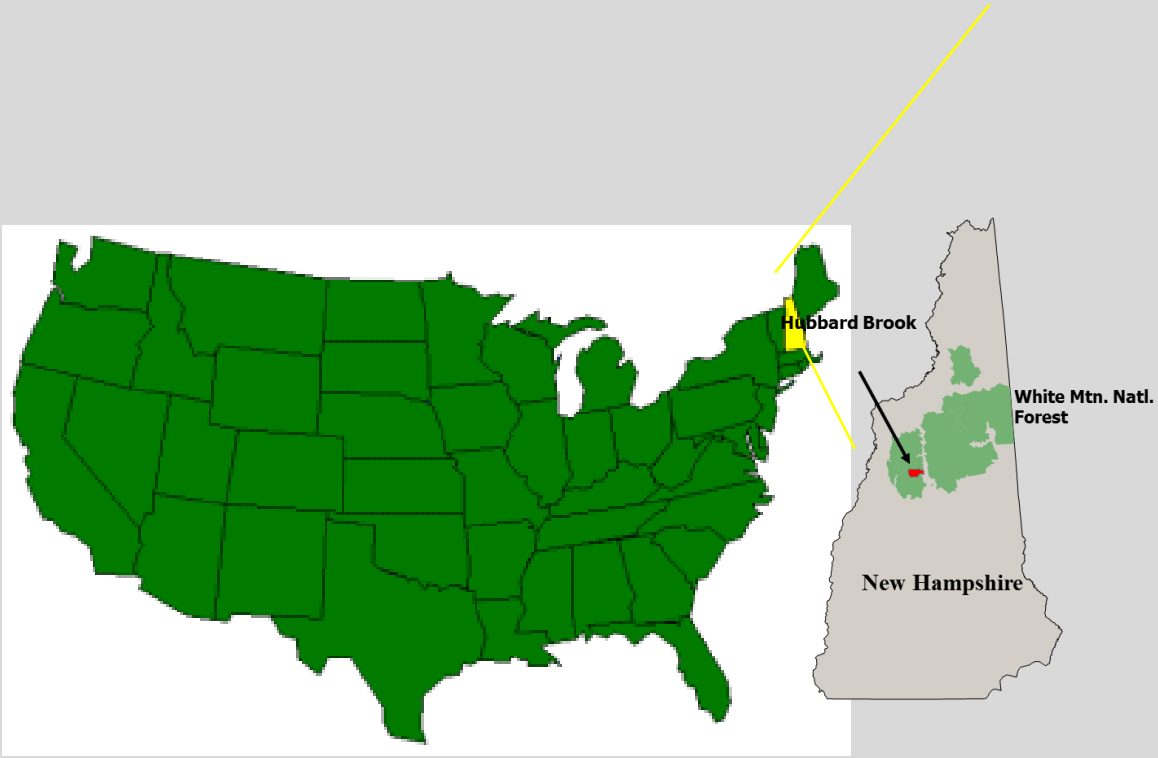
# Effects of Changing Atmospheric Deposition and Climate on the Structure and Function of a Northern Forest: Long-Term Measurements and Experiments from the Hubbard Brook Experimental Forest, NH, USA

# Outline

- History and background of the HBES
- Research approach and long-term observations and experiments
- Ecosystem response to changing climate
  - Long-term trends
  - Experiments
  - Modeling
- Conclusions

- Help from L. Rustad, P. Groffman, H. Fakhraei, T. Fahey, J. Campbell, A. Bailey, S. Hamburg, J. Battles and many others.

# The Hubbard Brook Experimental Forest, NH

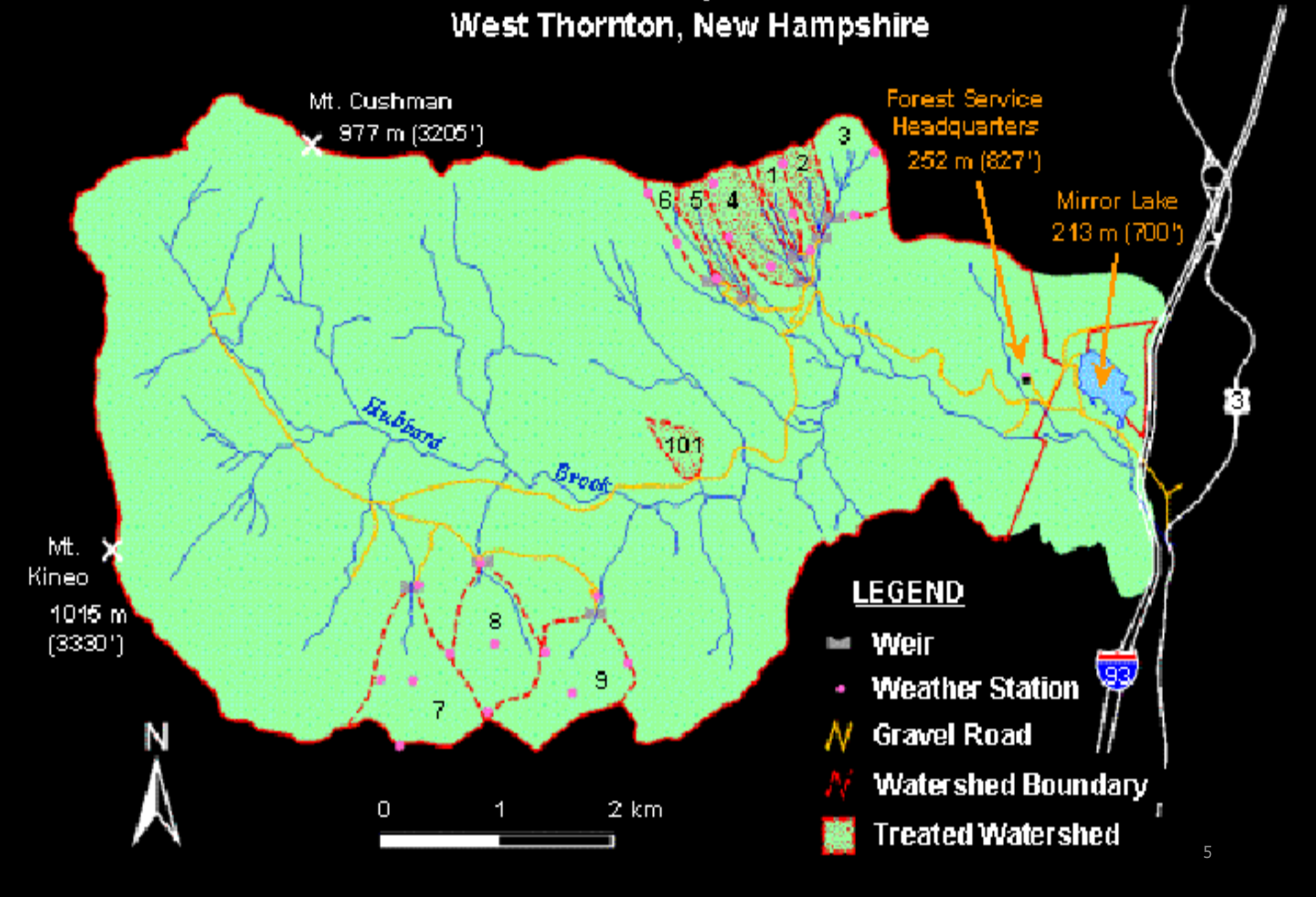


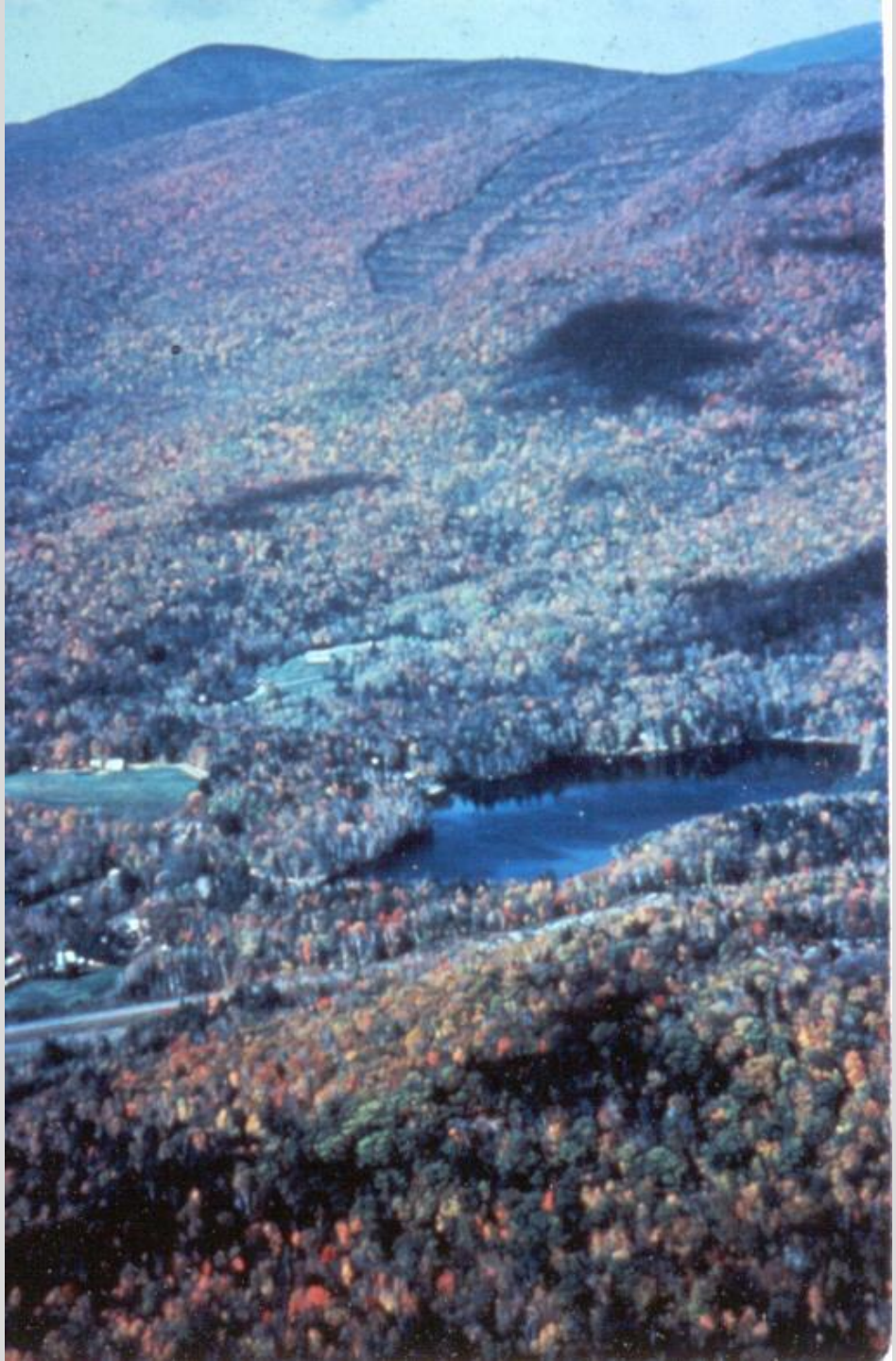

# The Hubbard Brook Experimental Forest and the Hubbard Brook Ecosystem Study

- HBEF- Established in 1955 by the USDA Forest Service for hydrologic research.
- HBES- Initiated in 1963 using the small watershed approach to study hydrologic cycle-element interactions in small undisturbed and human-manipulated forest ecosystems.
- Funded in 1987 as a NSF Long-Term Ecological Research site.

# Hubbard Brook Experimental Forest

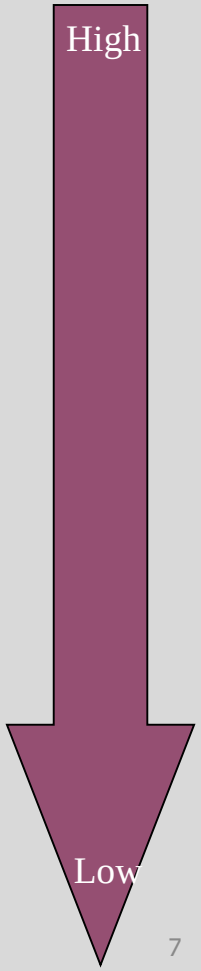
**West Thornton, New Hampshire**





# Scaling Environmental Studies

| | Spatial Scale (m) |
|---|---|
| Laboratory | $10^{-1} – 10^{0}$ |
| Mesocosm/Small Plot | $10^{1} – 10^{2}$ |
| Small Watershed | $10^{2} – 10^{3}$ |
| Medium Watershed | $10^{4} – 10^{5}$ |
| Large Basin | $10^{5} – 10^{6}$ |
| Regional Surveys | $10^{5} – 10^{6}$ |
| National/Continental Assessments | $10^{6} – 10^{7}$ |
| Global Analysis | $10^{7}$ |



# Scaling Environmental Studies

Laboratory

Mesocosm/Small Plot

Small Watershed

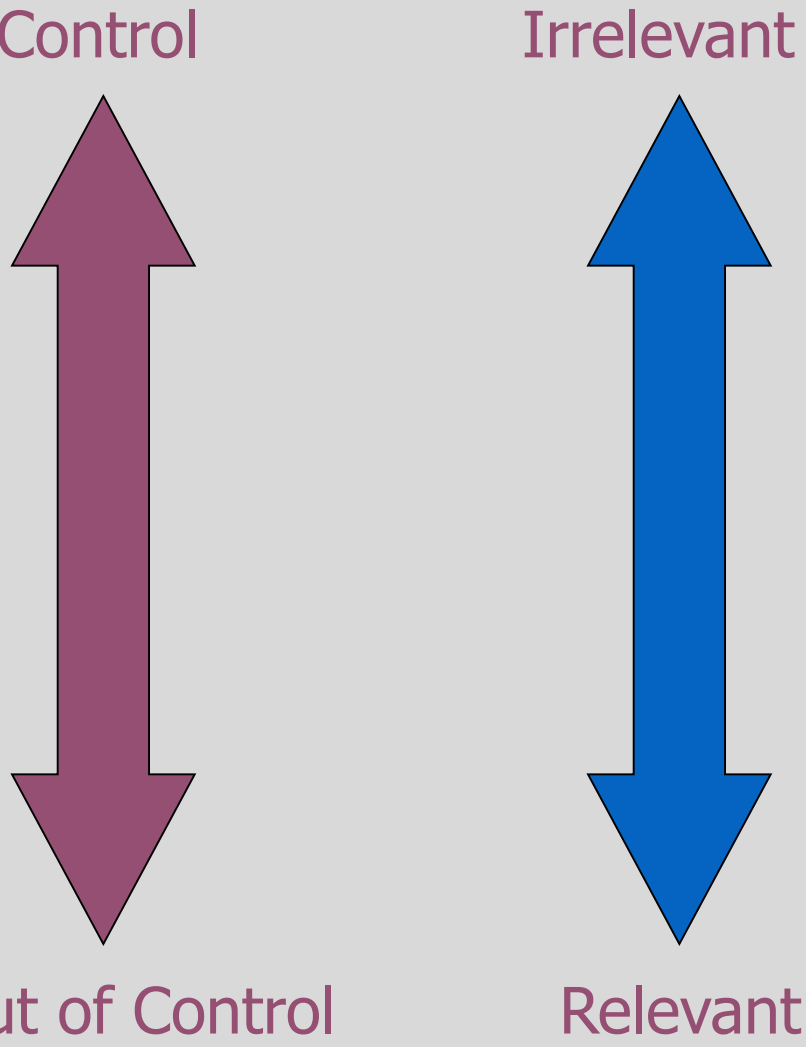
Medium Watershed

Large Basin

Regional Surveys

National/Continental Assessments

Global Analysis



# Characteristics of the Hubbard Brook Experimental Forest

**Bedrock** Quartz Mica Schist and Quartzite

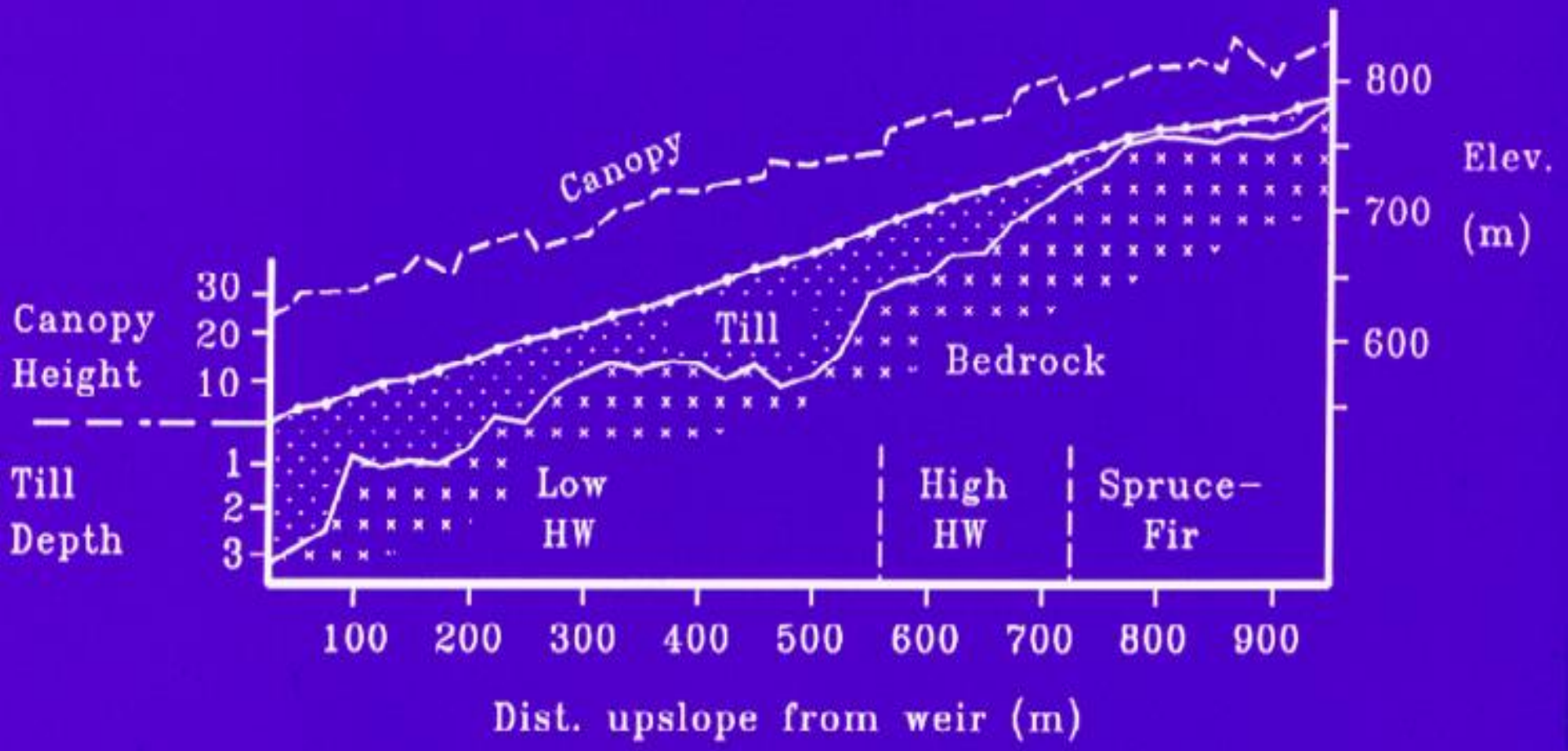
**Landscape** Till-Mantled Glacial Valleys

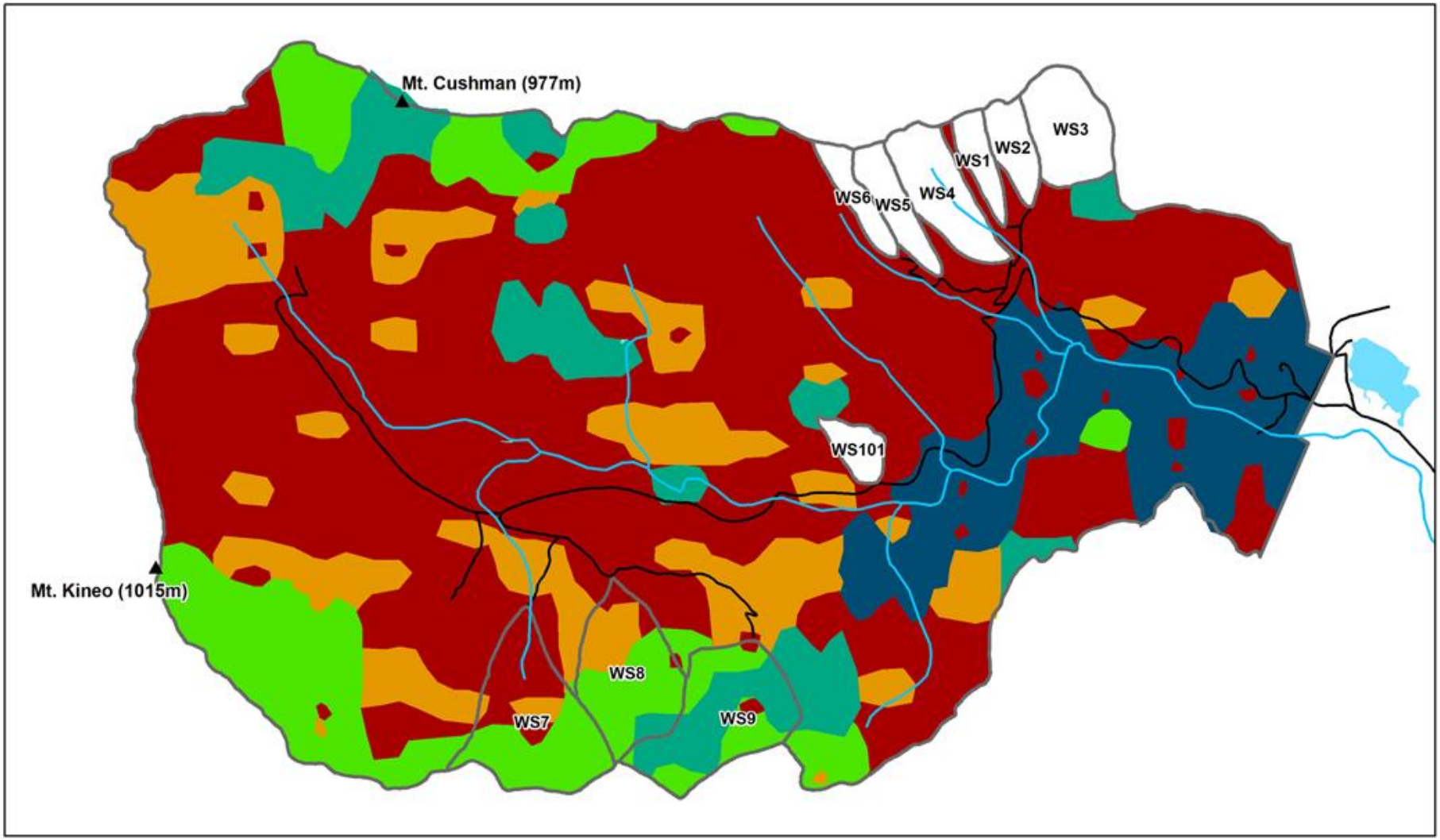
**Soils** Spodosols (Typic Haplorthods)

| | pHw | %BS |
|---|---|---|
| Oa | 3.9 | 50 |
| Mineral Soil | 4.3 | 12 |

**Vegetation** Northern Hardwood Forest; Cutting 1915-17; 80-90% Hardwoods, 10-20% Conifers

**Climate** Humid Continental, Mean Precipitation 1400 mm


Canopy
Till
Bedrock
Canopy Height
Till Depth
30
20
10
1
2
3
Low HW
High HW
Spruce–Fir
800
700
600
Elev. (m)
100
200
300
400
500
600
700
800
900
Dist. upslope from weir (m)




**Legend**

**Forest Type**

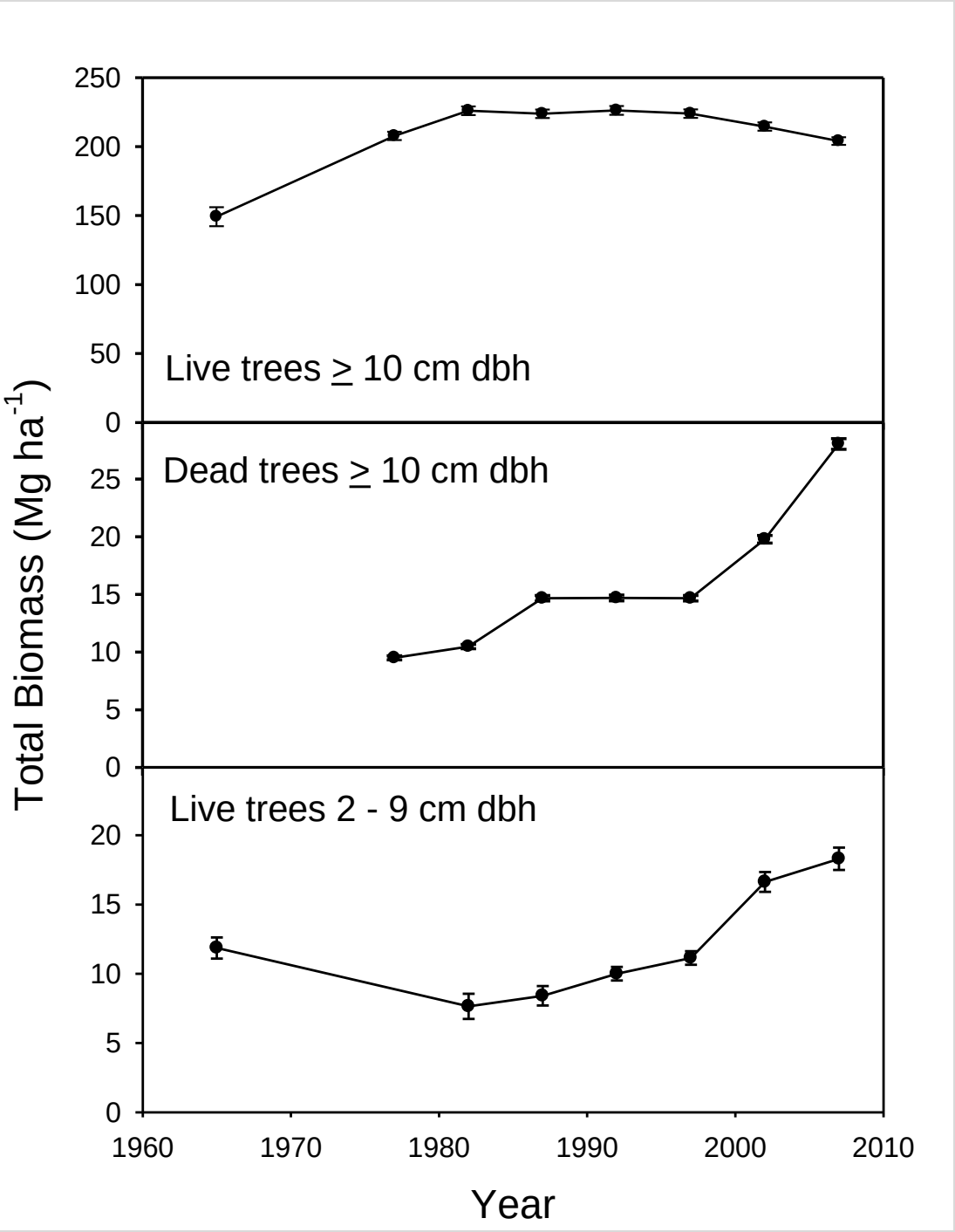
- Northern Hardwood
- High Hardwood
- Fir-Birch
- Spruce-Fir-Birch
- Hemlock

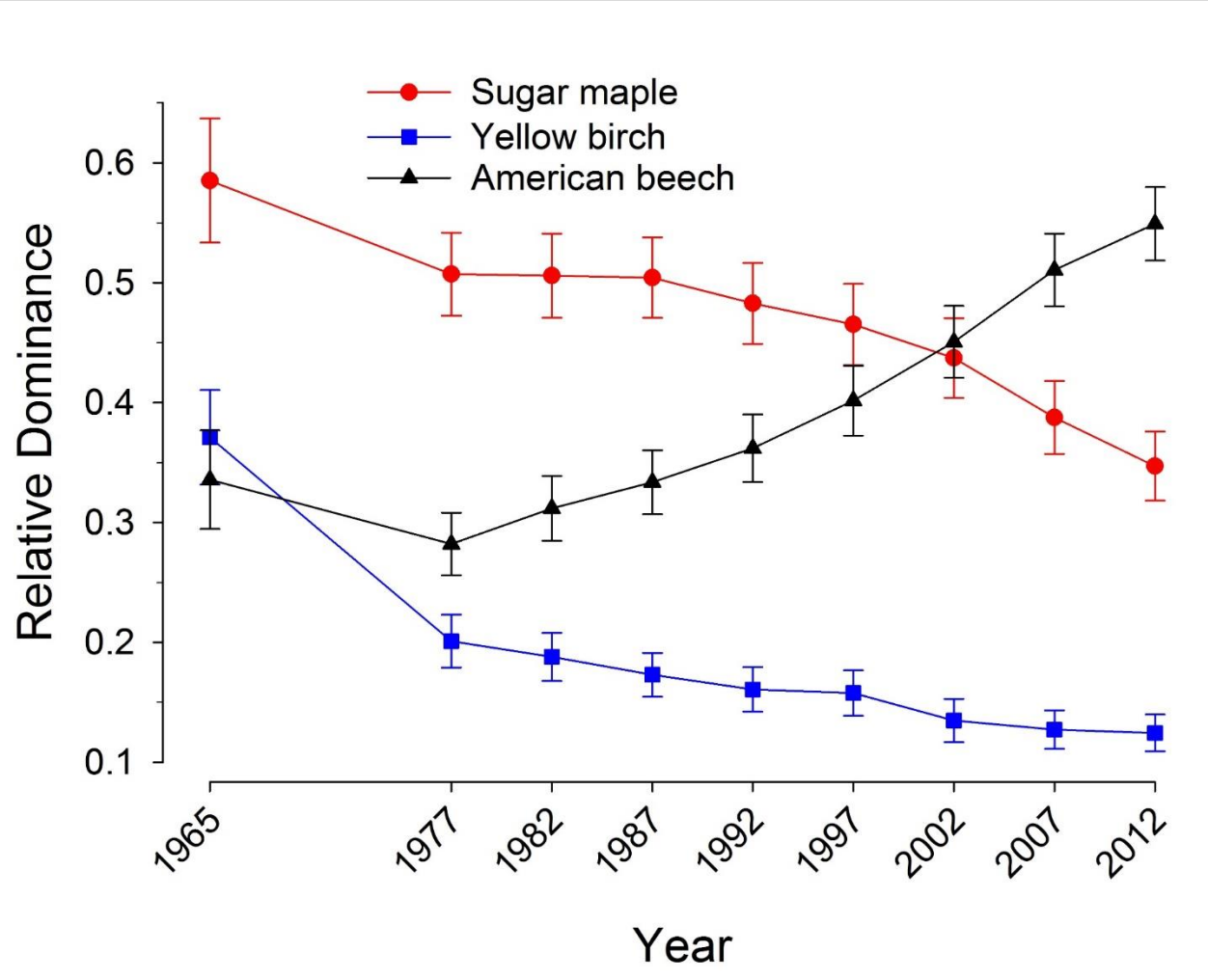
- Peaks
- Rivers
- Lakes
- Roads

## Hubbard Brook Experimental Forest

0 0.5 1 2 3 4 Kilometers

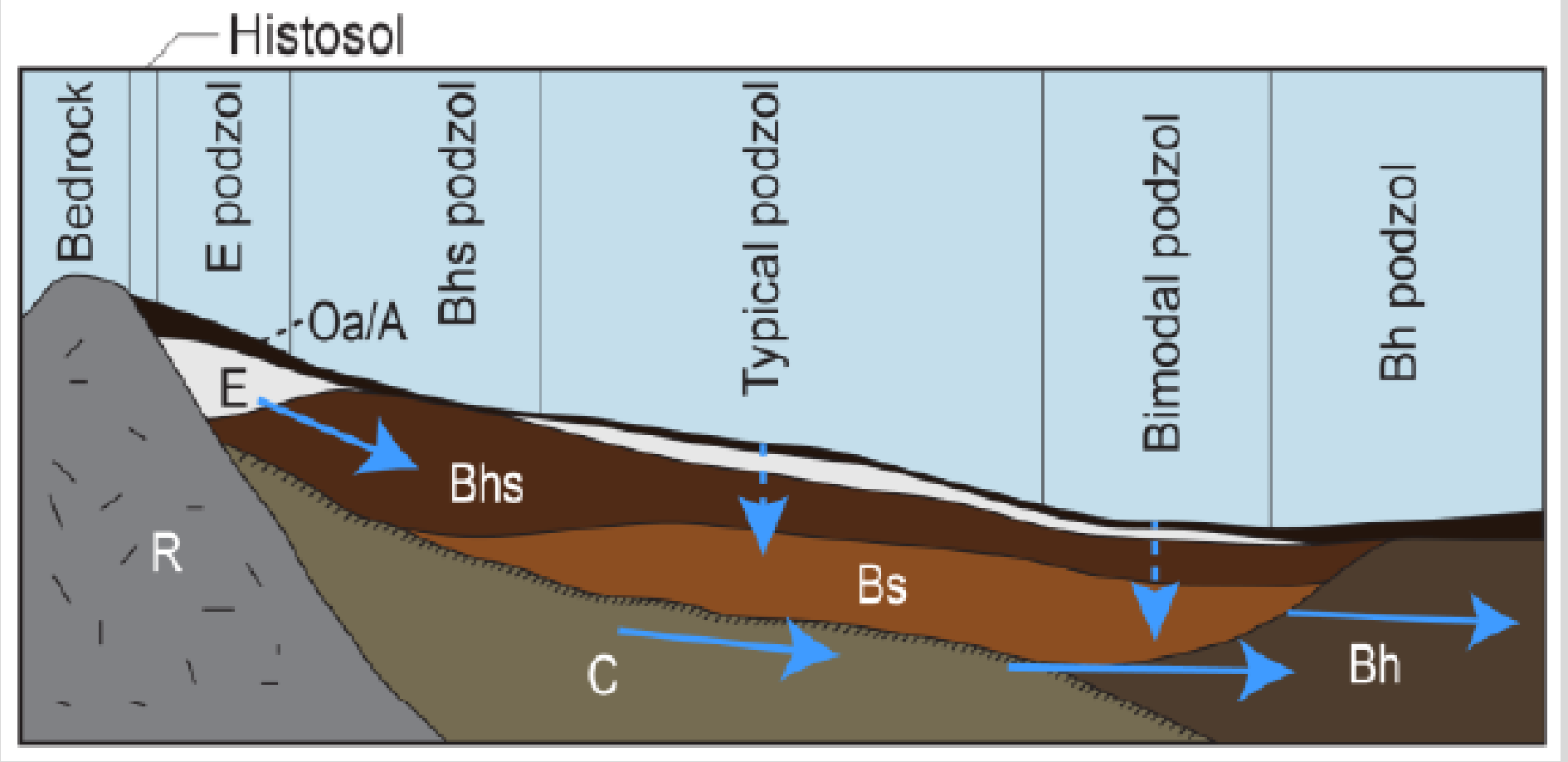
N


Total Biomass (Mg ha-1)
Live trees ≥ 10 cm dbh
Dead trees ≥ 10 cm dbh
Live trees 2 - 9 cm dbh
250
200
150
100
50
0
25
20
15
10
5
0
20
15
10
5
0
1960
1970
1980
1990
2000
2010
Year

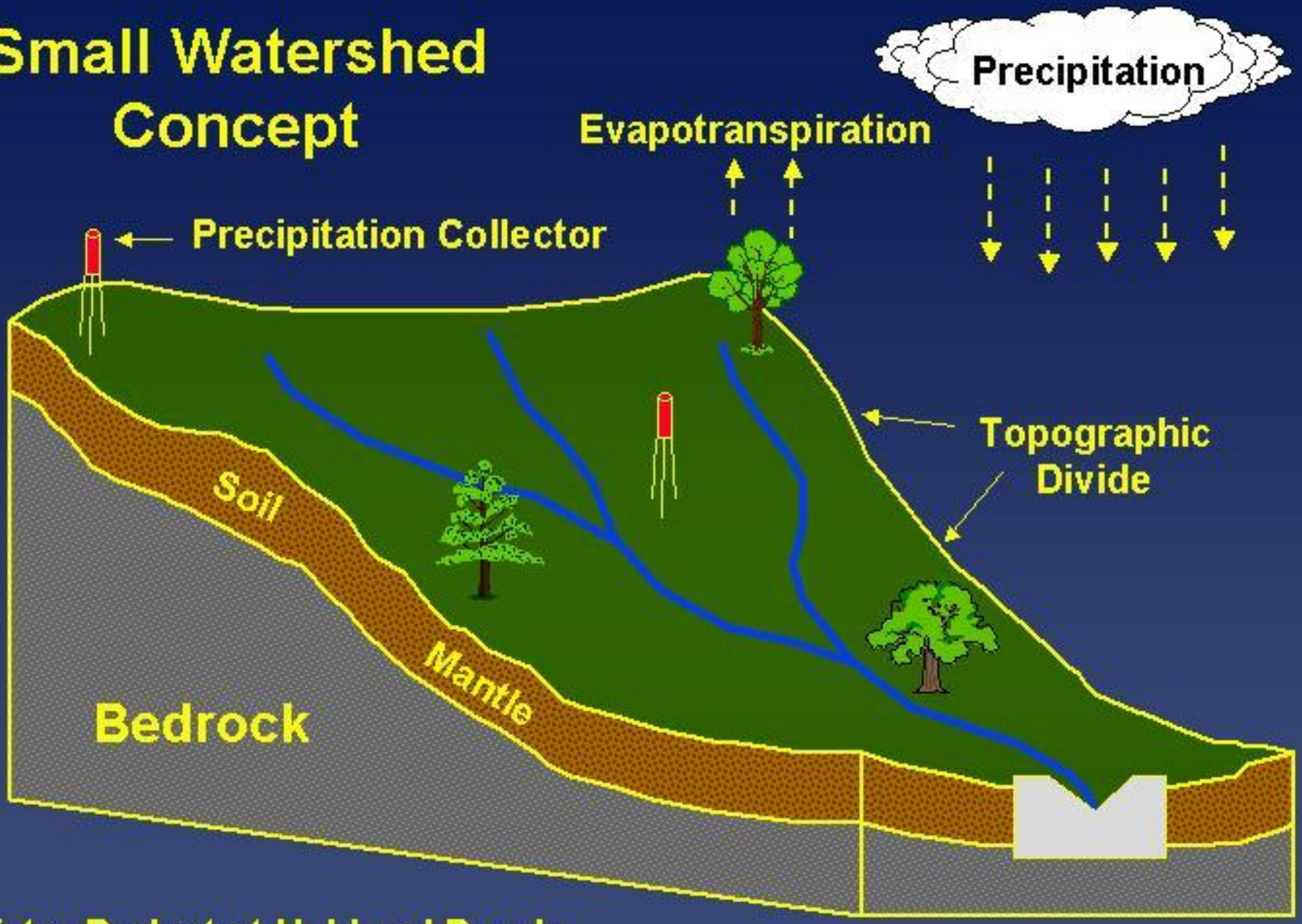



Sugar maple has shown poor growth in recent years

# Flowpaths of water influence soil development (Bailey et al. 2014)



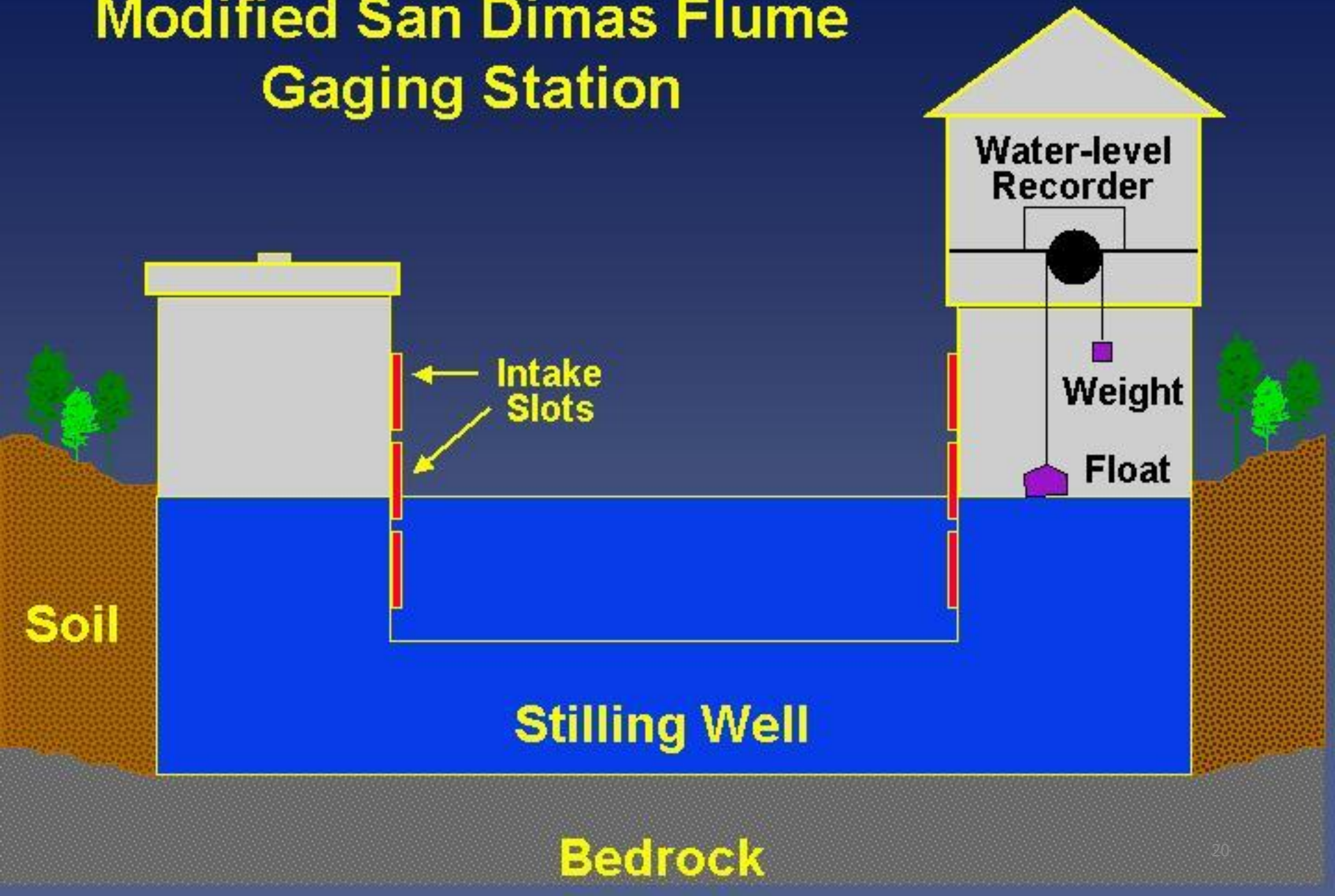
# Small Watershed Concept

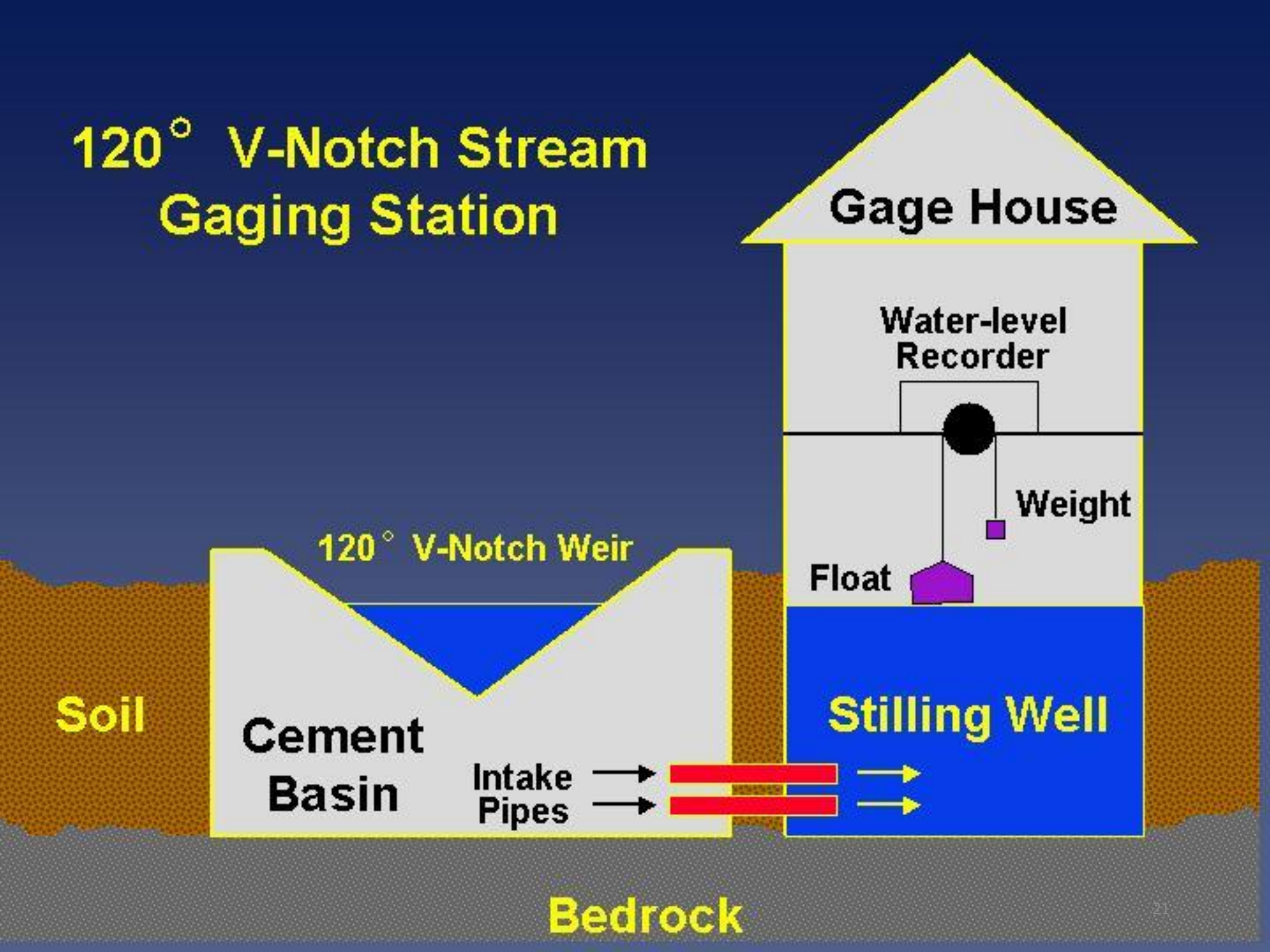


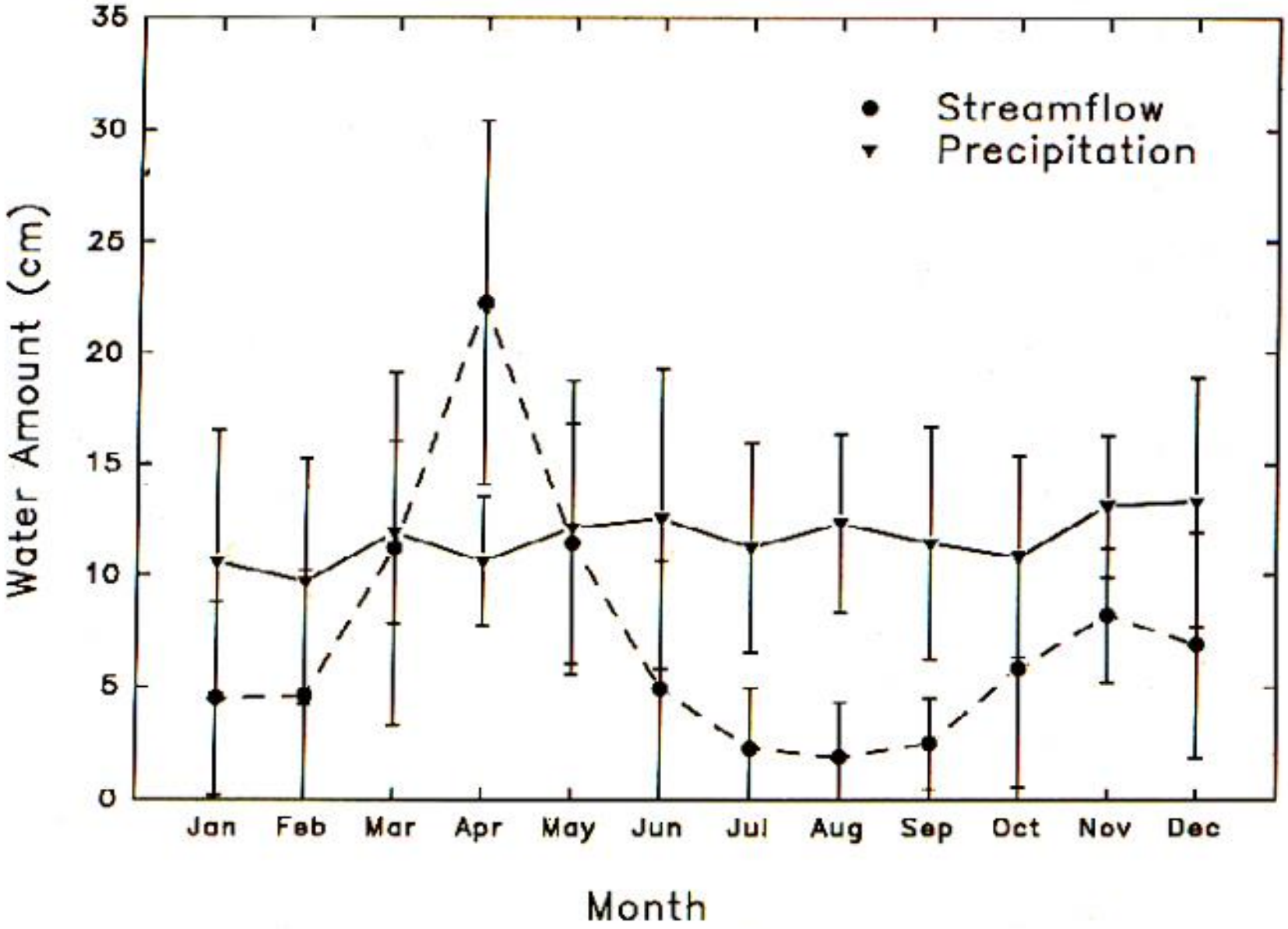

Water Budget at Hubbard Brook:
Precipitation (100%) = Streamflow (60%) + Evapotranspiration (40%)

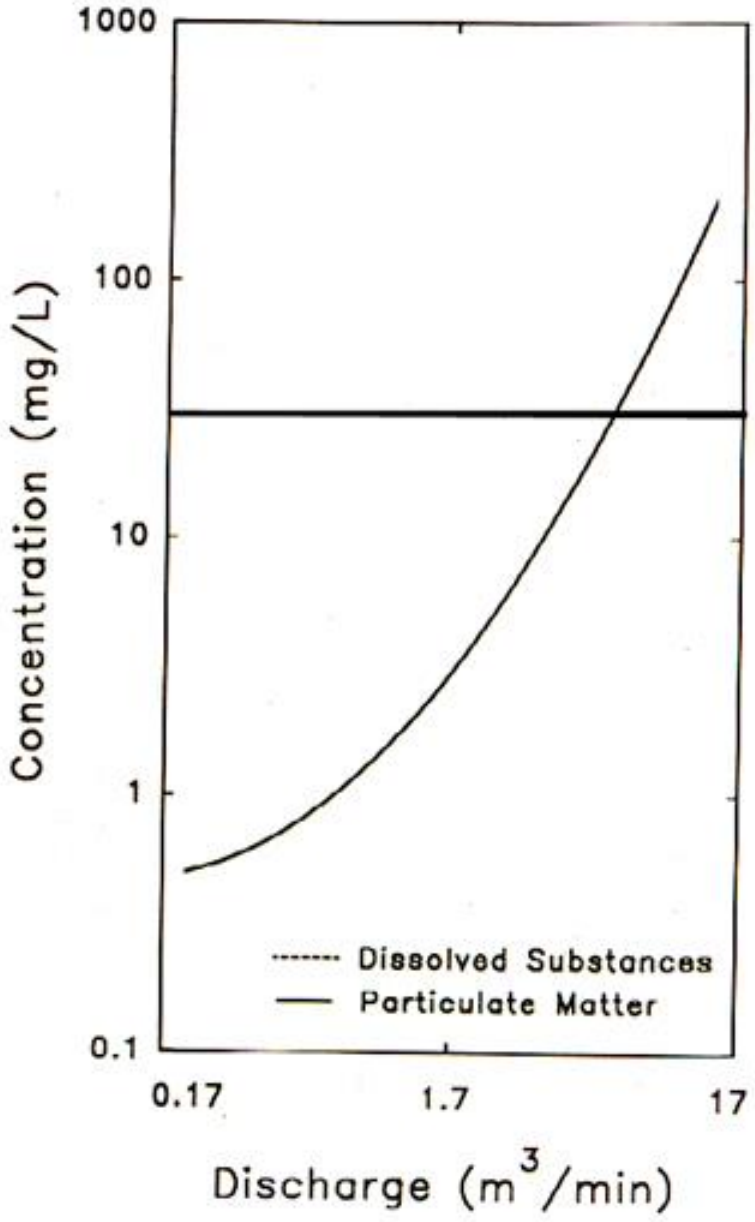

HBHM
131

# Modified San Dimas Flume Gaging Station



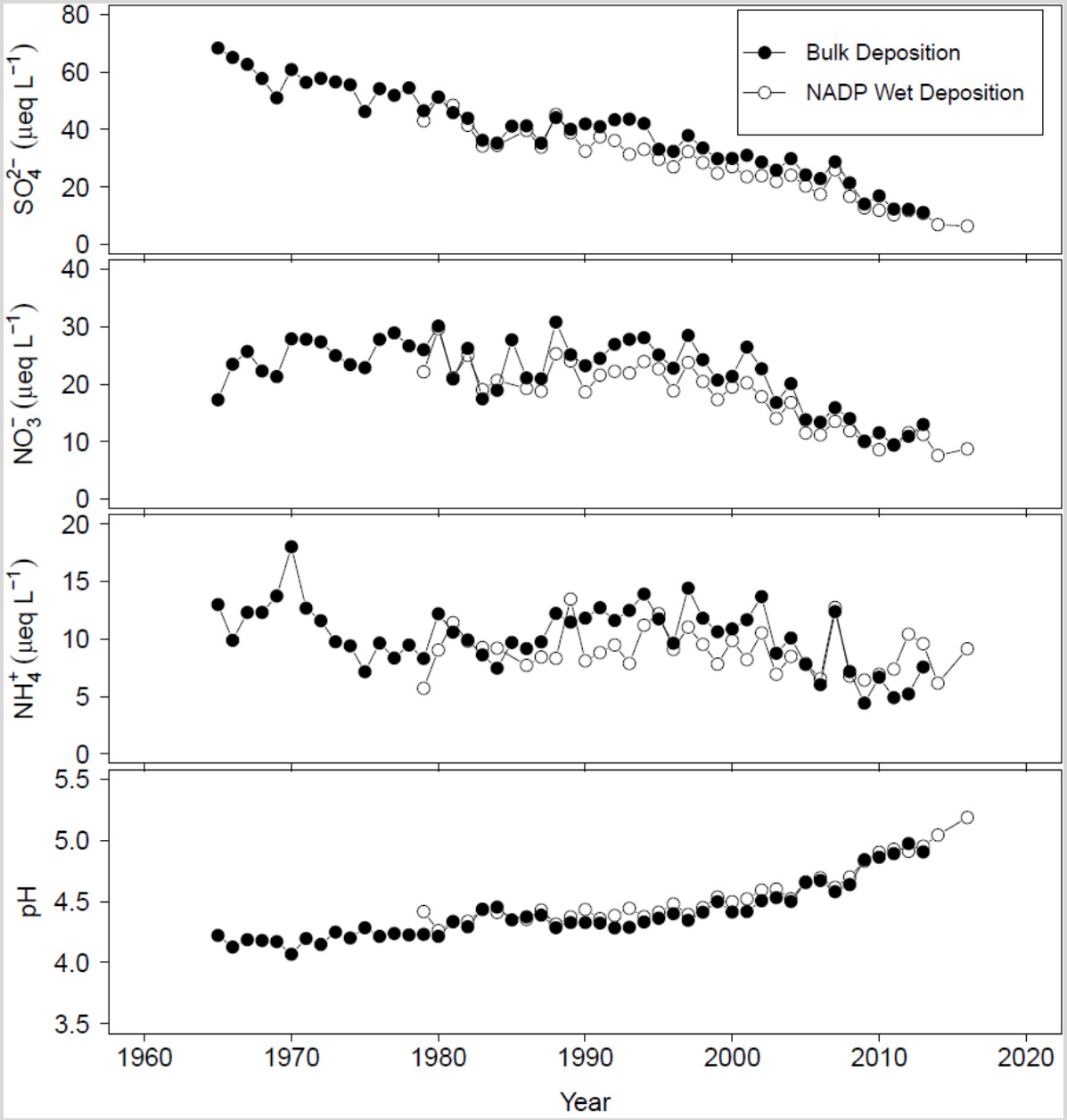

120° V-Notch Stream
Gaging Station
Gage House
Water-level
Recorder
Weight
Float
120° V-Notch Weir
Soil
Cement
Basin
Intake
Pipes
Stilling Well
Bedrock


Streamflow
Precipitation
Water Amount (cm)
35
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month




Relatively little change in concentrations of dissolved materials but large increases in particulate materials with increasing discharge

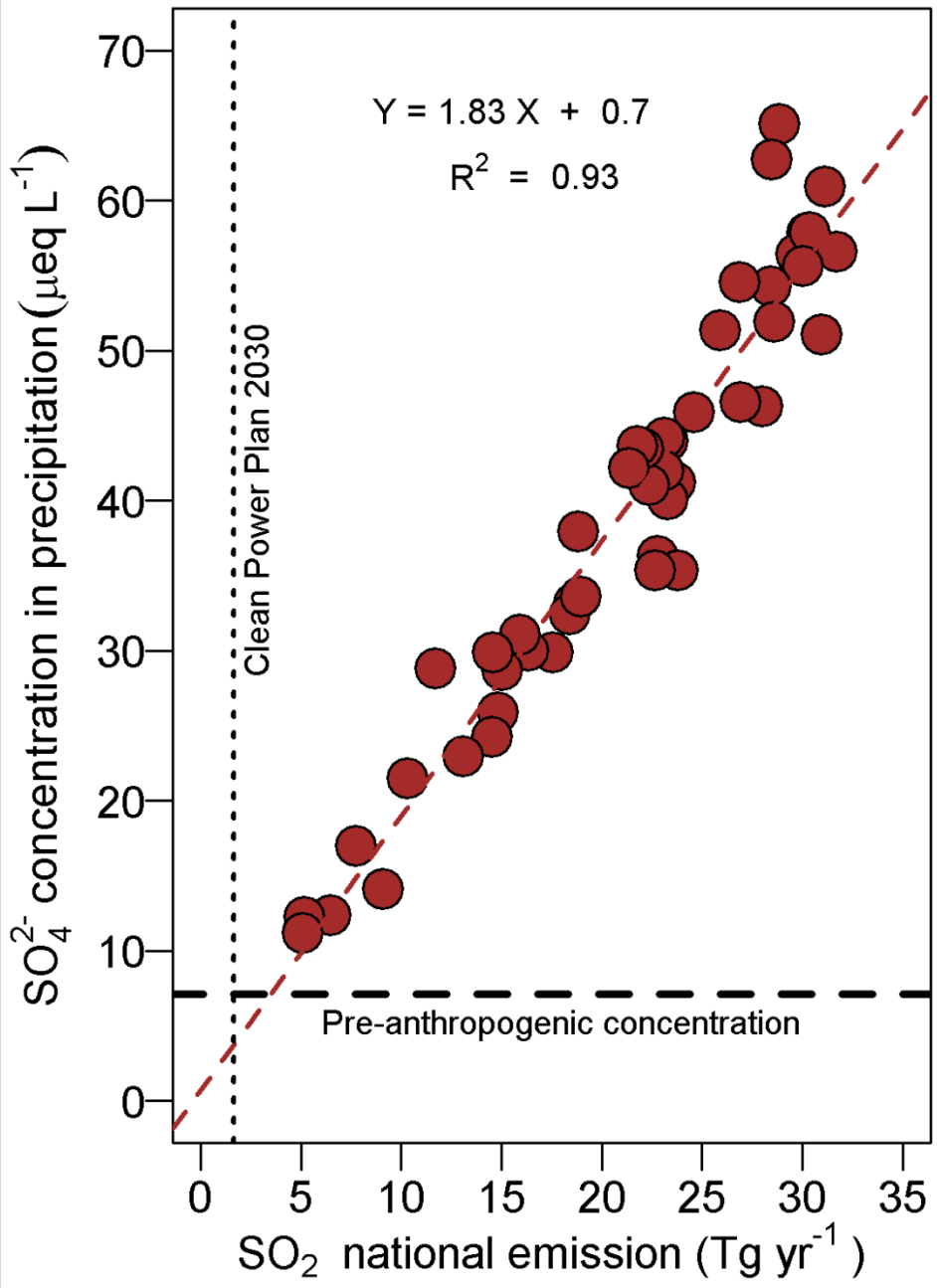
# Precipitation Chemistry Trends

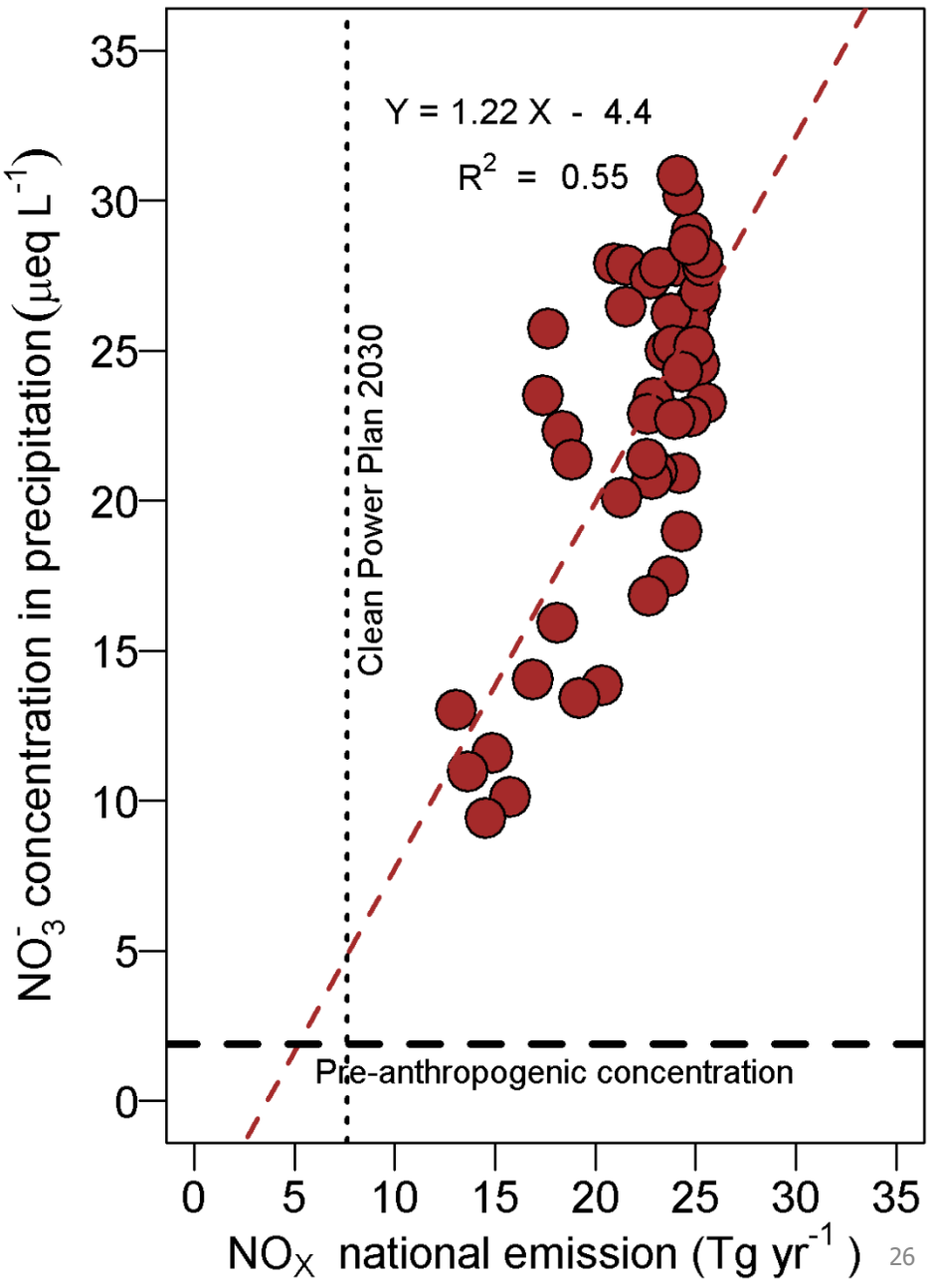



Decreases in precipitation sulfate over the duration of the study.

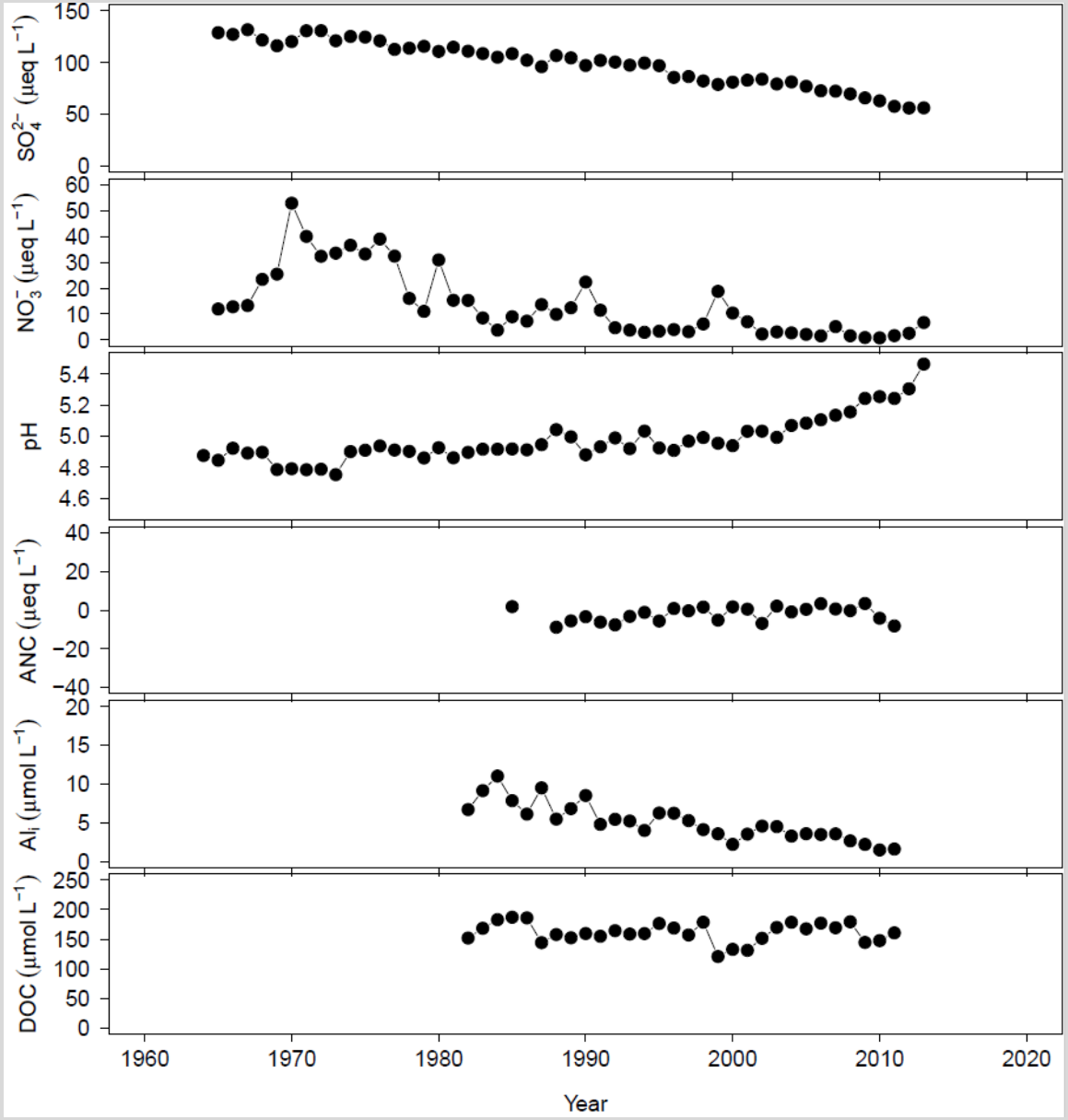
Decreases in nitrate since the early 2000s.

# Deposition Concentration with National Emissions (1966-2013)



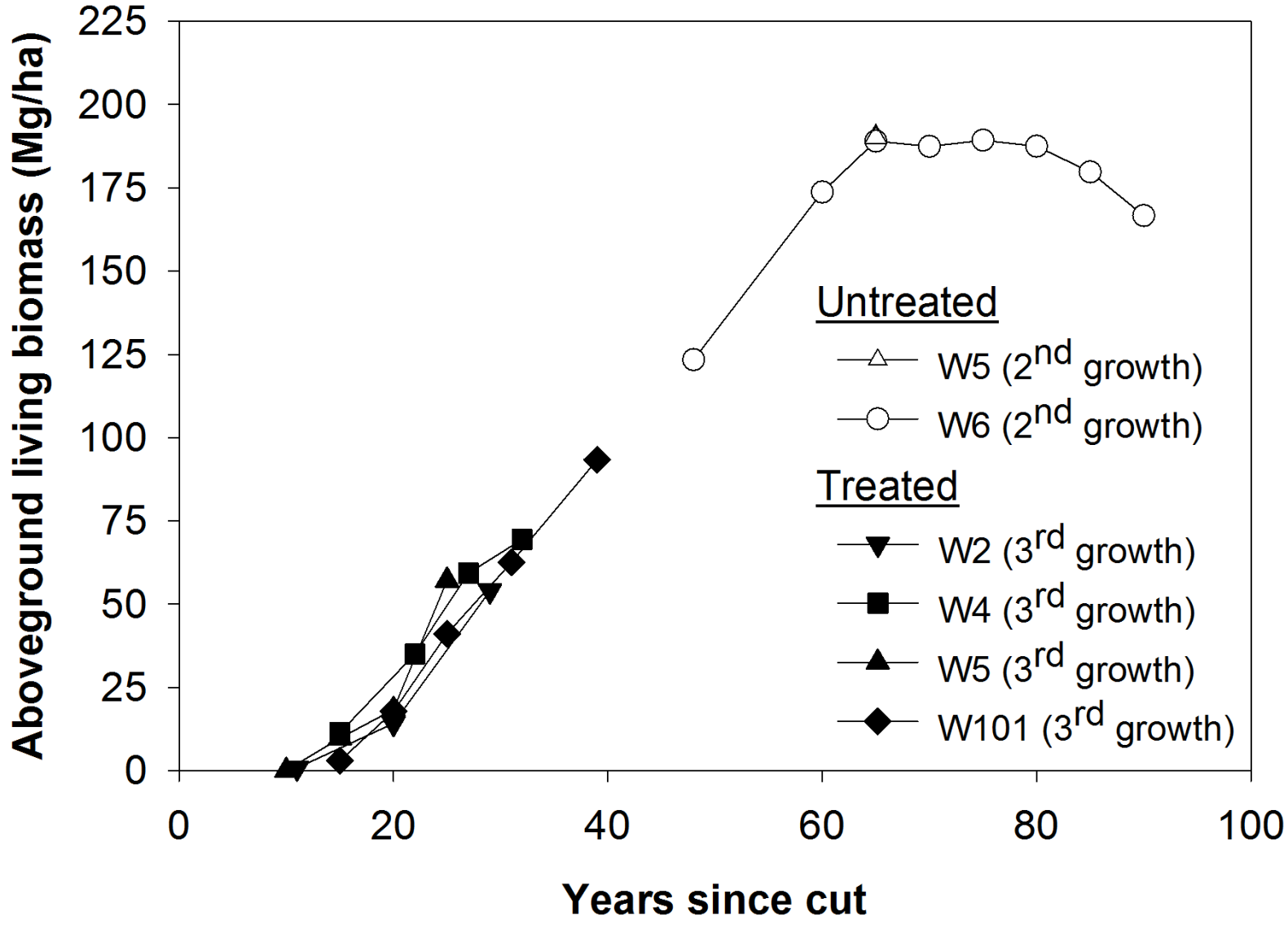
# Stream Chemistry Trends



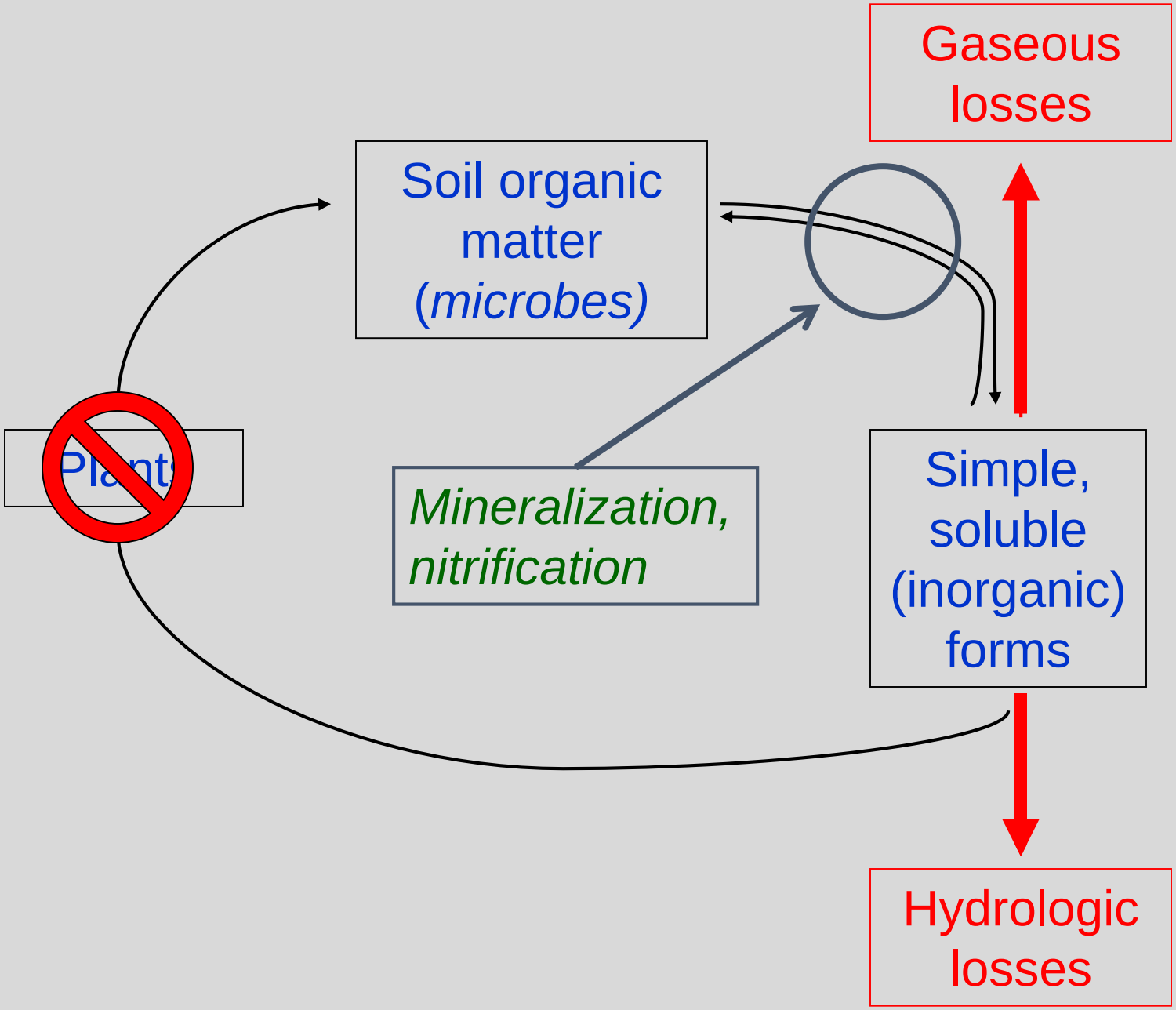

Long-term decreases in stream sulfate and nitrate reflect decreases in atmospheric deposition, resulting in increases in pH, acid neutralizing capacity (ANC) and dissolved organic carbon (DOC), and decreases in aluminum

# Characteristics of Monitored Watersheds

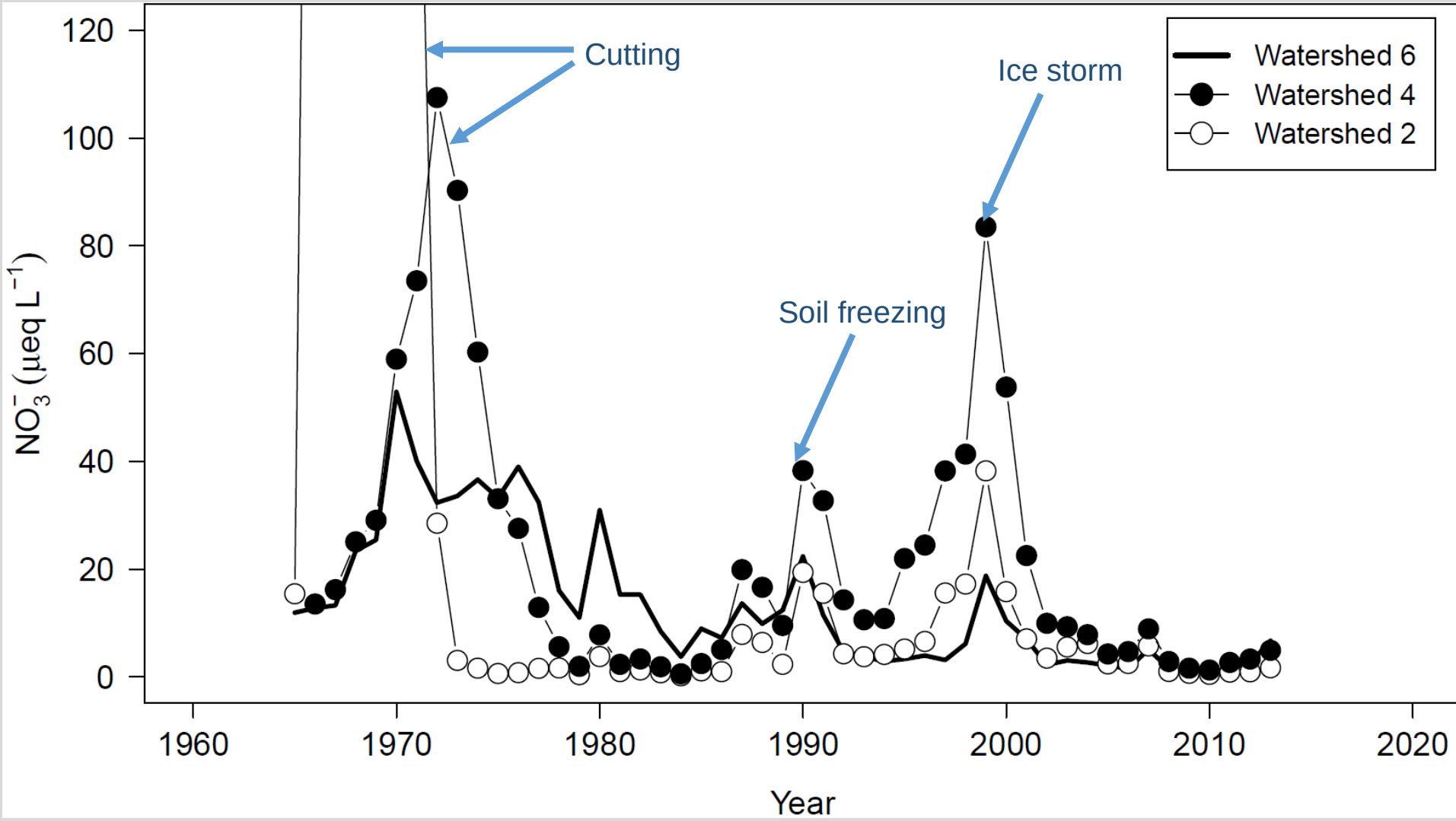
| Watershed Number | Size (ha) | Year Started | Treatment |
|---|---|---|---|
| 1 | 11.8 | 1956 | Calcium silicate addition 1999 |
| 2 | 15.6 | 1957 | Clear-felled in '65-66, no products removed, herbicide application '66,67, 68. |
| 3 | 42.4 | 1958 | None – Hydrologic reference. |
| 4 | 36.1 | 1961 | Clear-cut by strips in three phases – '70,72,74. Timber products removed. |
| 5 | 21.9 | 1962 | Whole-tree clear-cut in 1983-84. Timber products removed. |
| 6 | 13.2 | 1963 | None – Biogeochemical reference. |
| 7 | 76.4 | 1965 | None |
| 8 | 59.4 | 1969 | None |
| 9 | 68.0 | 1994 | None |
| 101 | 12.1 | 1970 | Clear-cut as block in 1970. Timber products removed. |



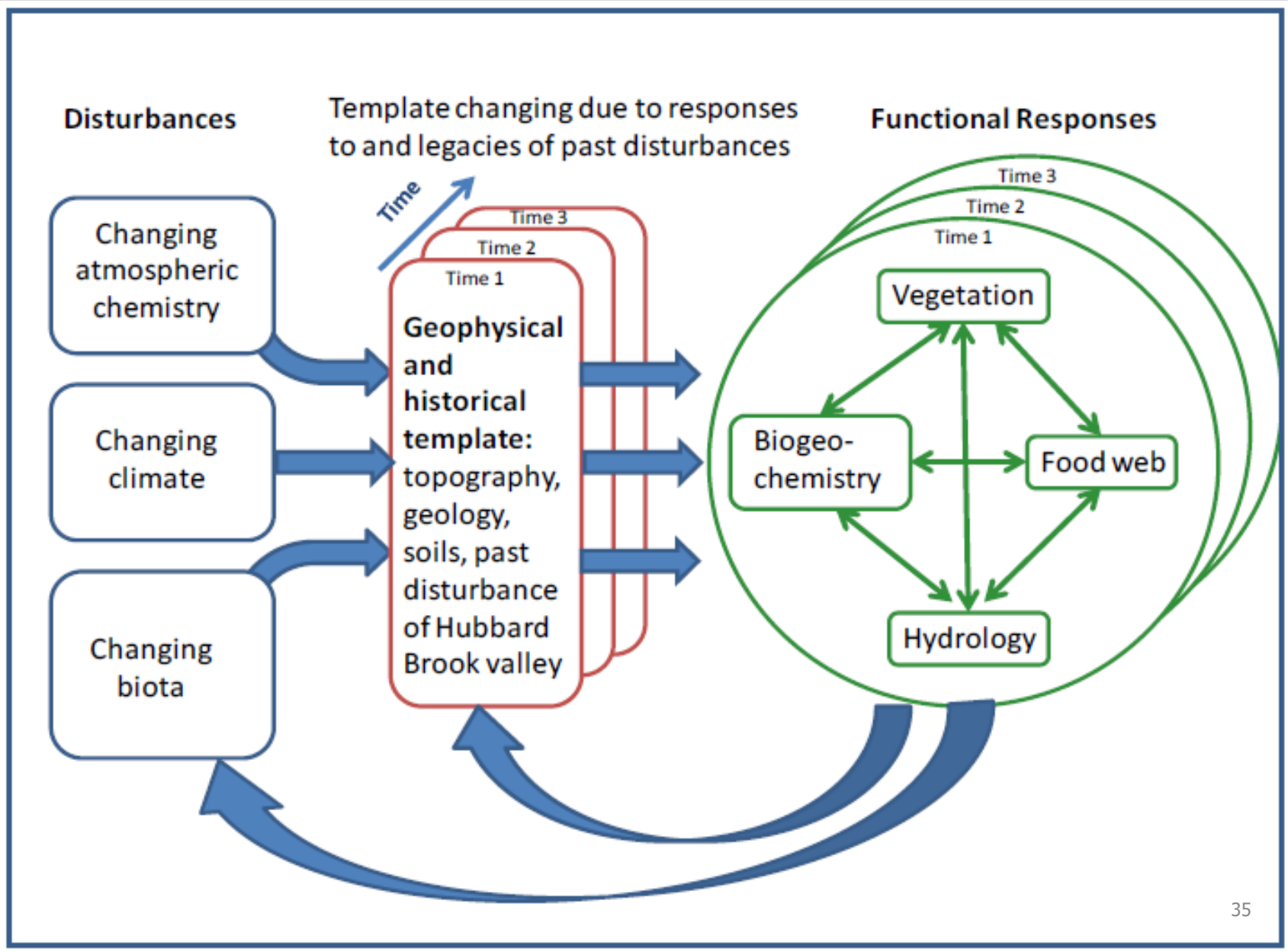

Aboveground biomass accumulation at Hubbard Brook, data from cut watersheds show a trajectory.

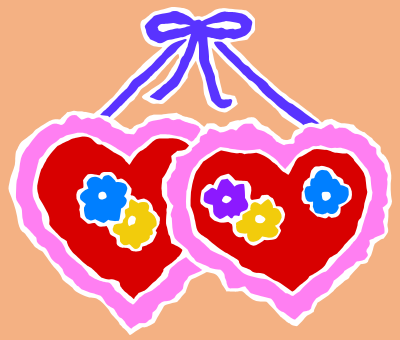

Gaseous losses
Soil organic matter (*microbes)*
Plants
*Mineralization, nitrification*
Simple, soluble (inorganic) forms
Hydrologic losses

# Stream Nitrate Response to Cutting and Climate Disturbance



# Hubbard Brook Ecosystem Study Conceptual Model





Biogeochemical Studies

Experimental Manipulations

Gradient (spatial) studies

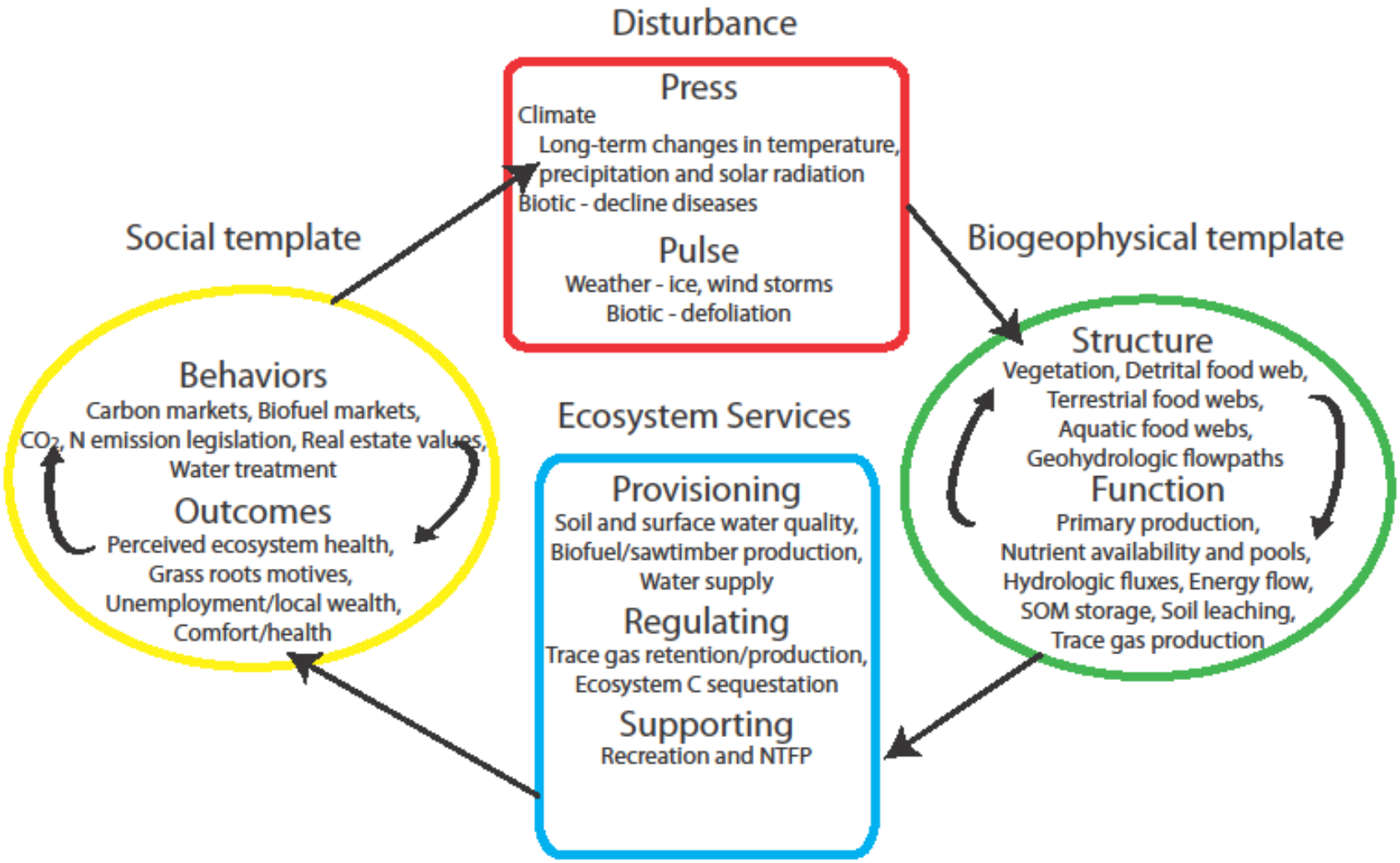
Isotopes

Modeling

Paleoecology

Time-series observations

# Climate Change and Forest Ecosystems



# Hubbard Brook Climate

Air temperature:

19 °C (Jul) to -8 °C (Jan)

Precipitation: 1400 mm

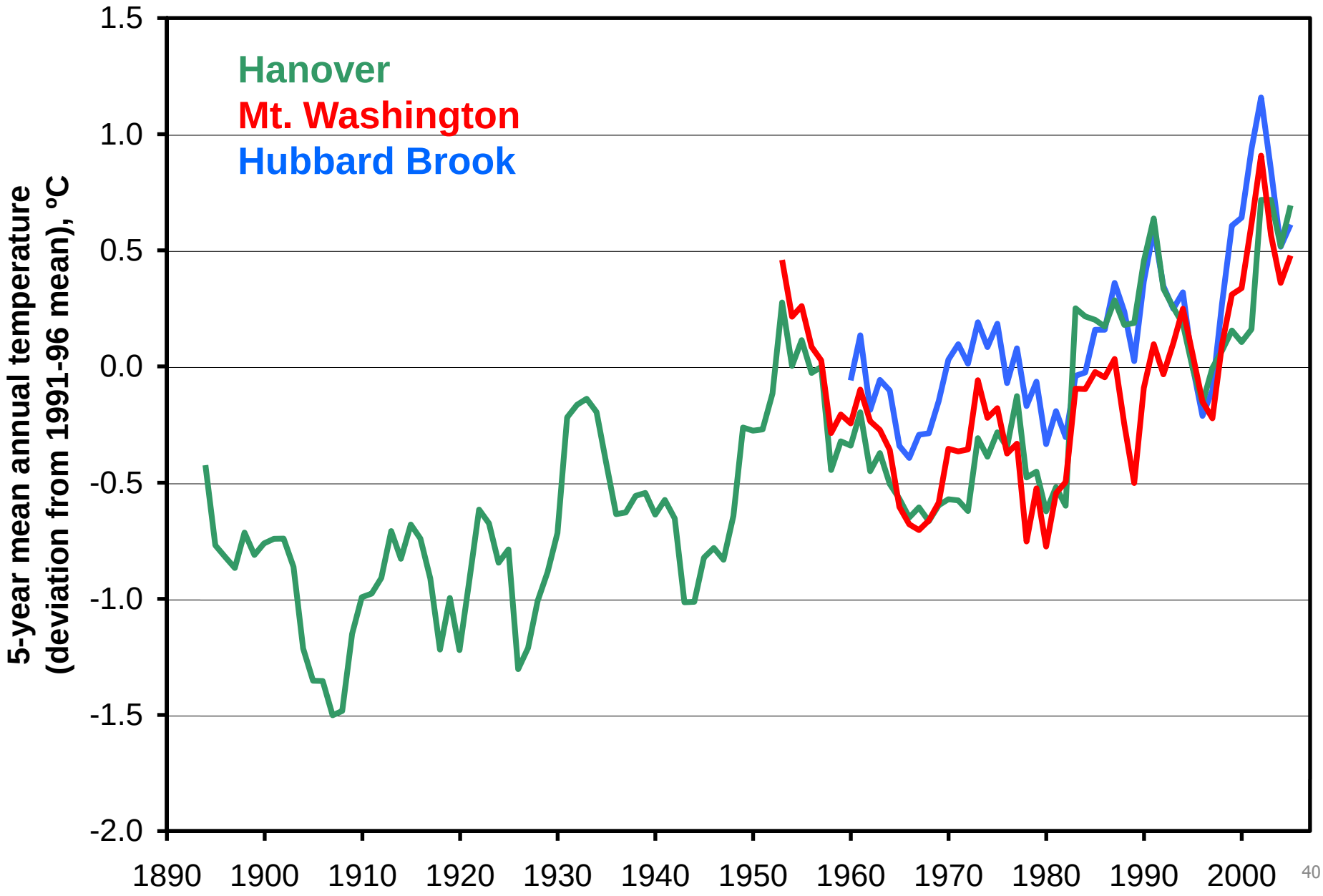
Max. Snowpack: 72 cm

Max. Soil frost: 6 cm

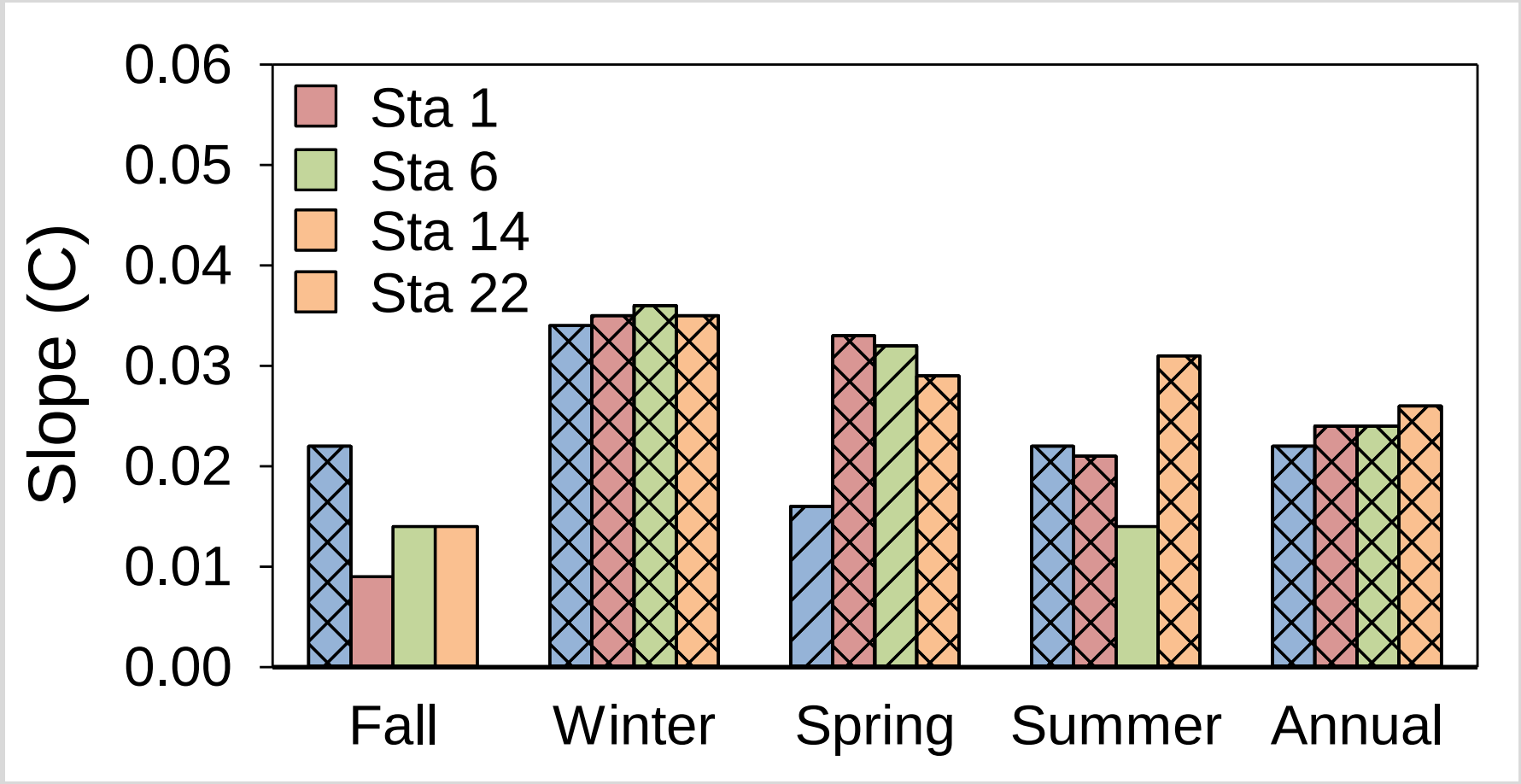
# Examining Changing Climate

- Chronic change through long-term measurements, experiments and modeling
- Extreme events

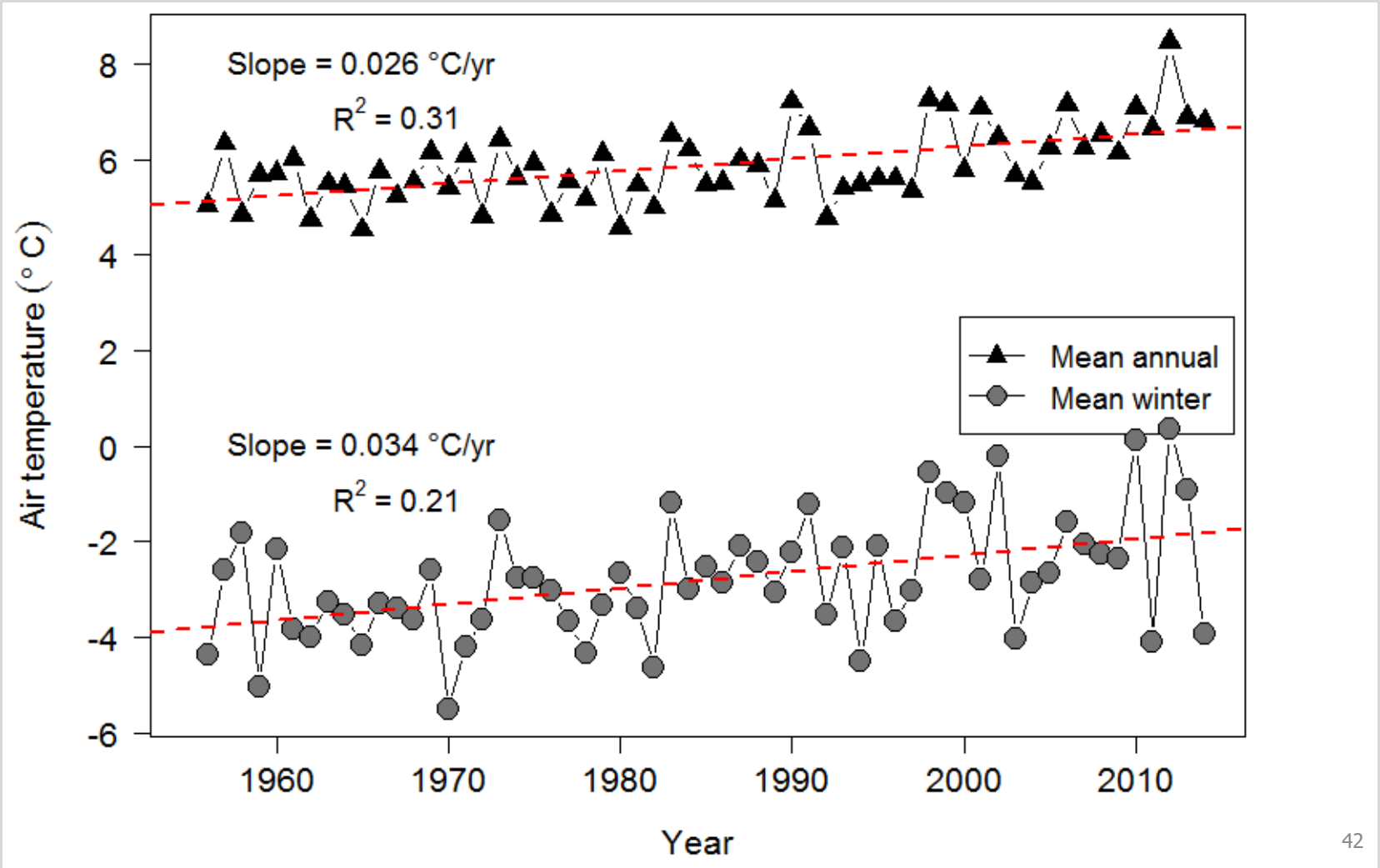
# 20th Century Temperature Record in NH

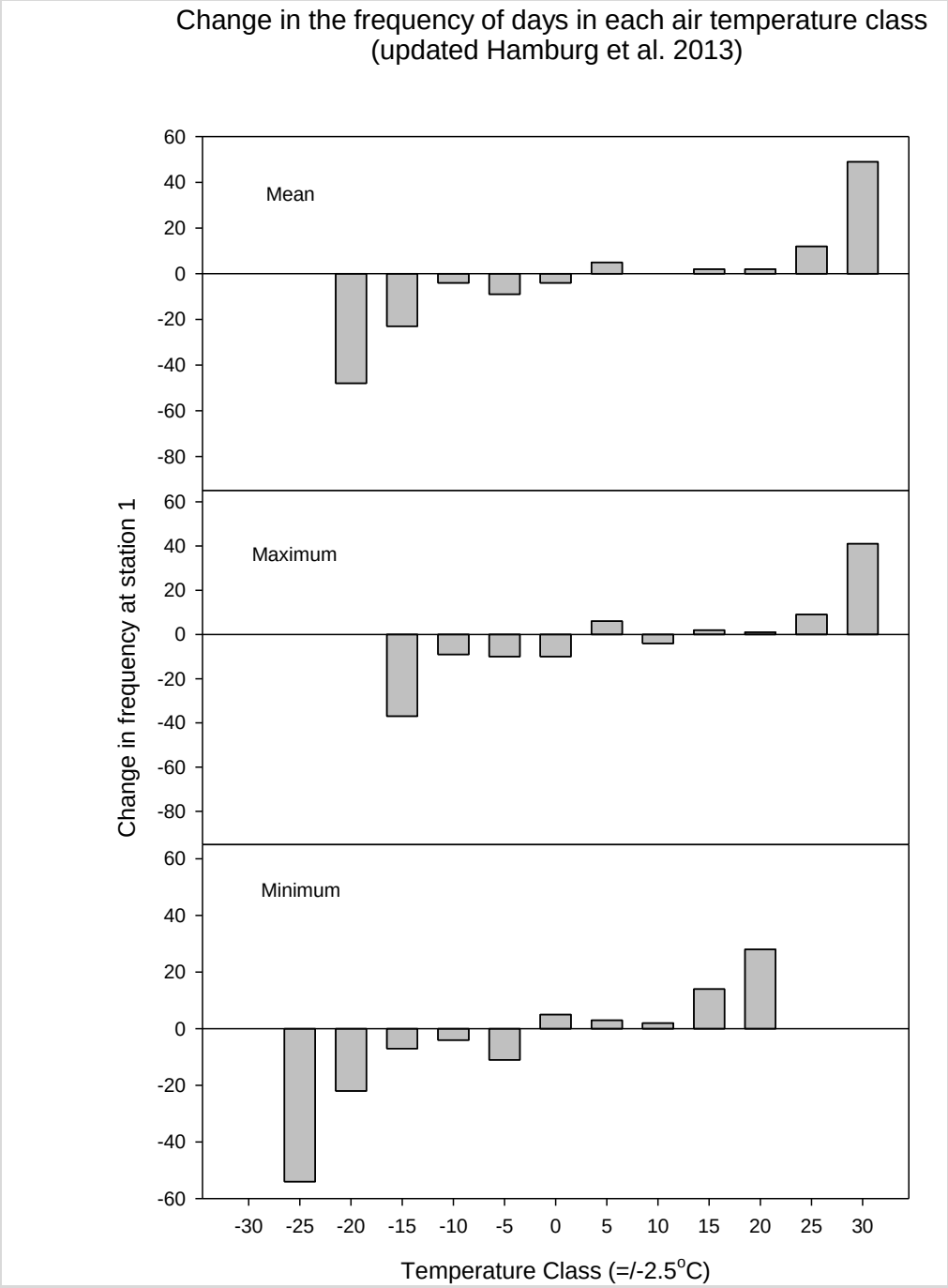


# Air Temperature Trends



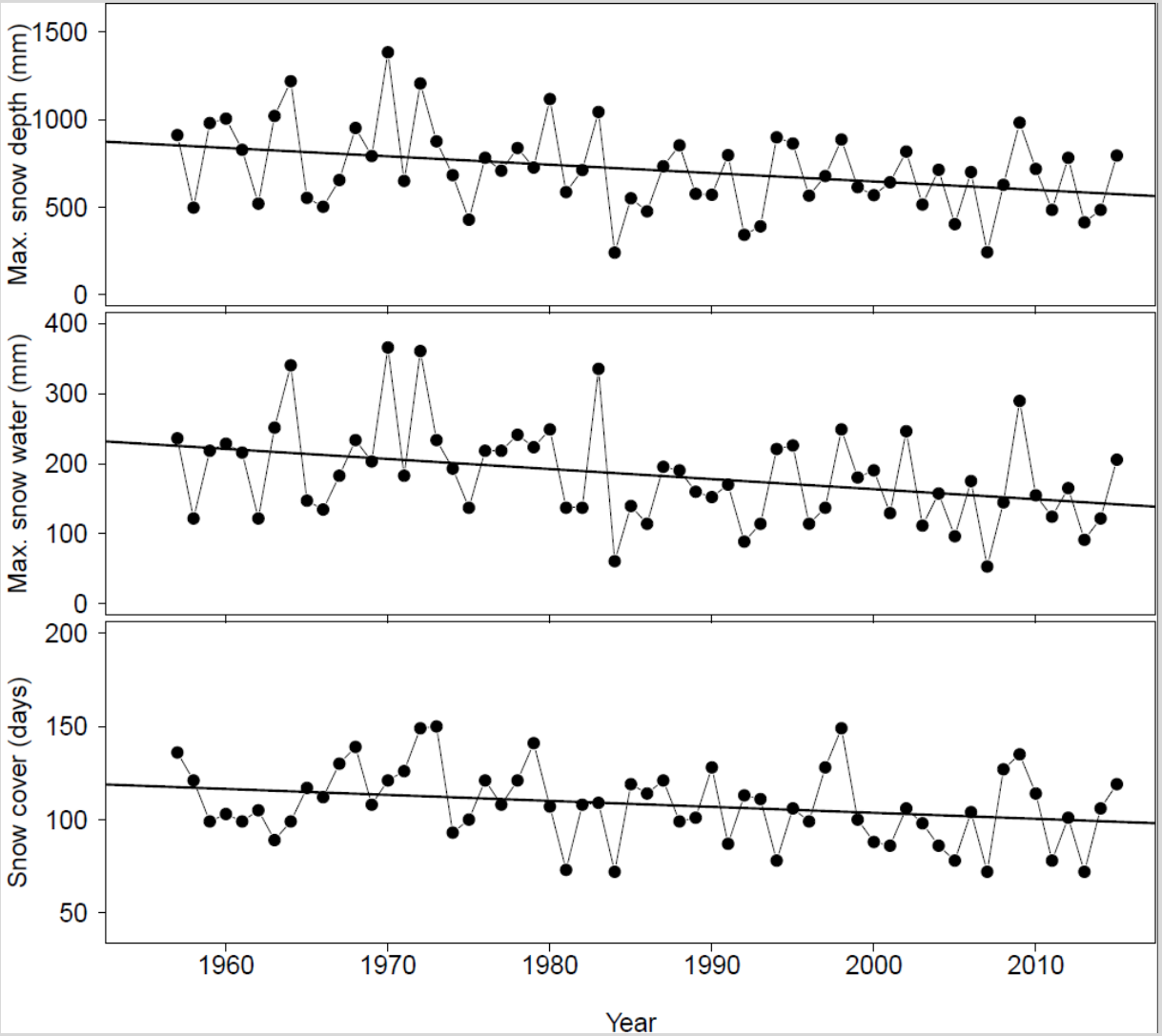
# Warming has been more pronounced and variable in winter than the annual period (data for station 1 at HB)



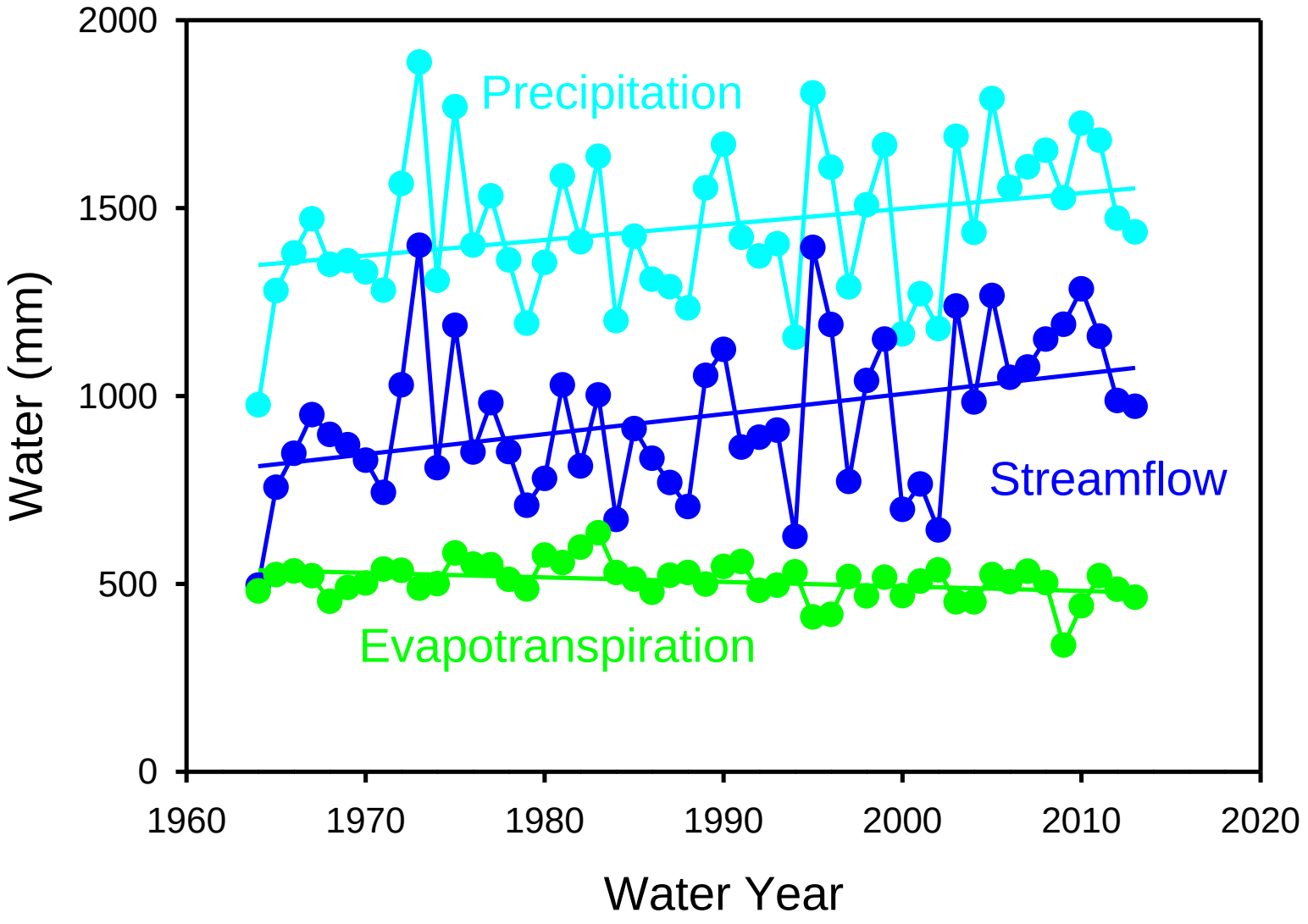



# Winters Are Less Severe

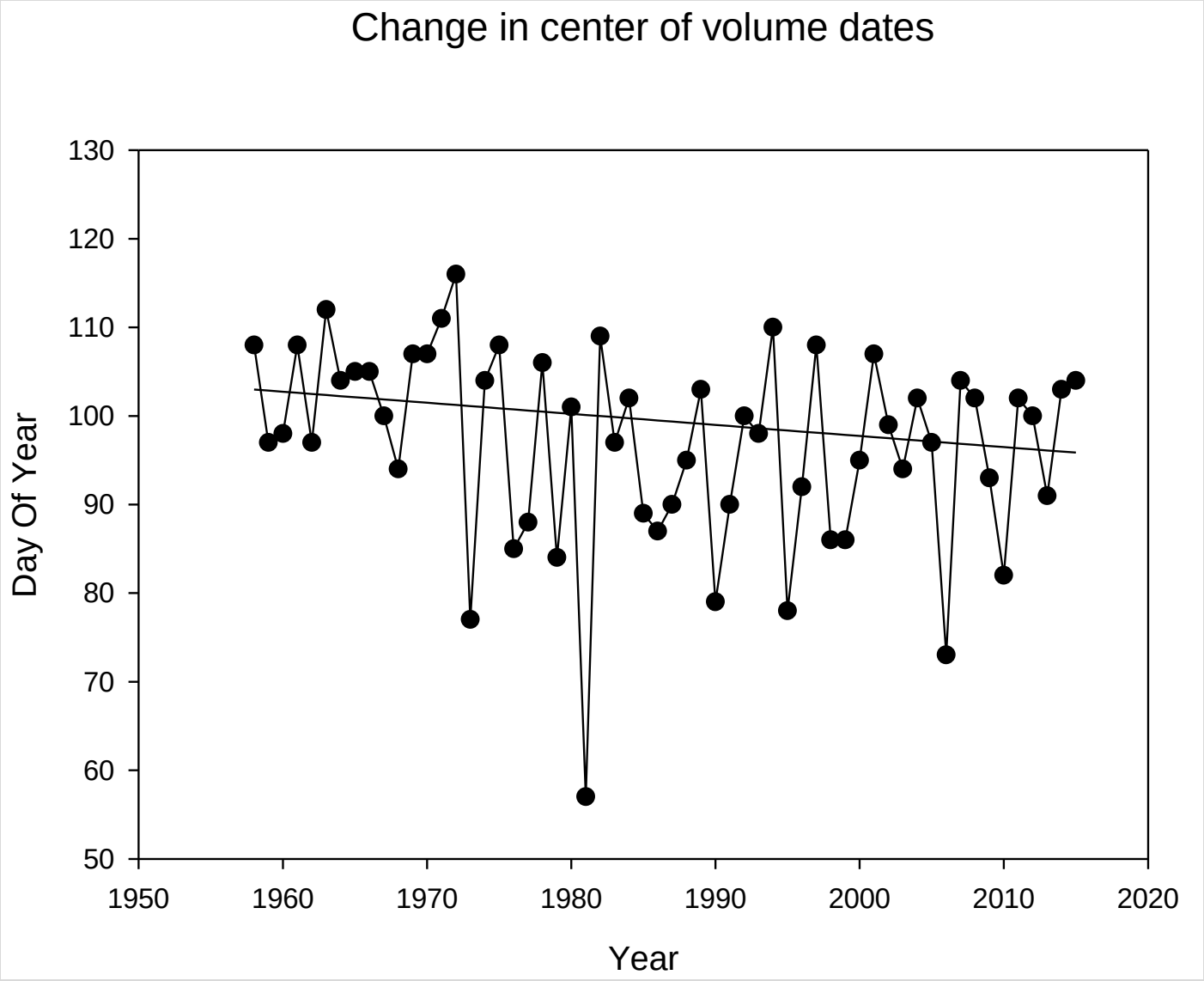
# Less Snow at Hubbard Brook




# Long-term Change in Water Balance

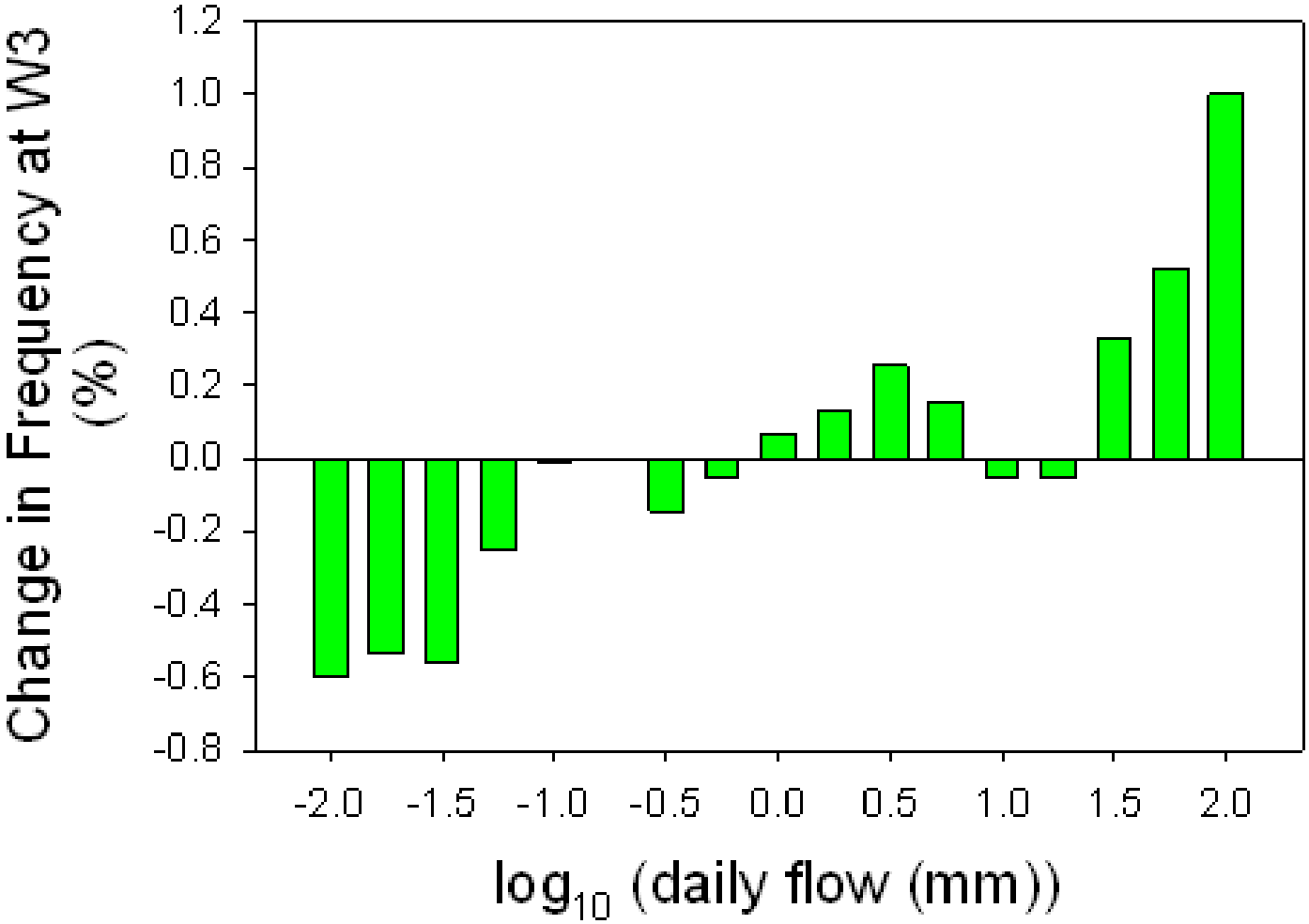


# Changes Center of Streamflow Volume



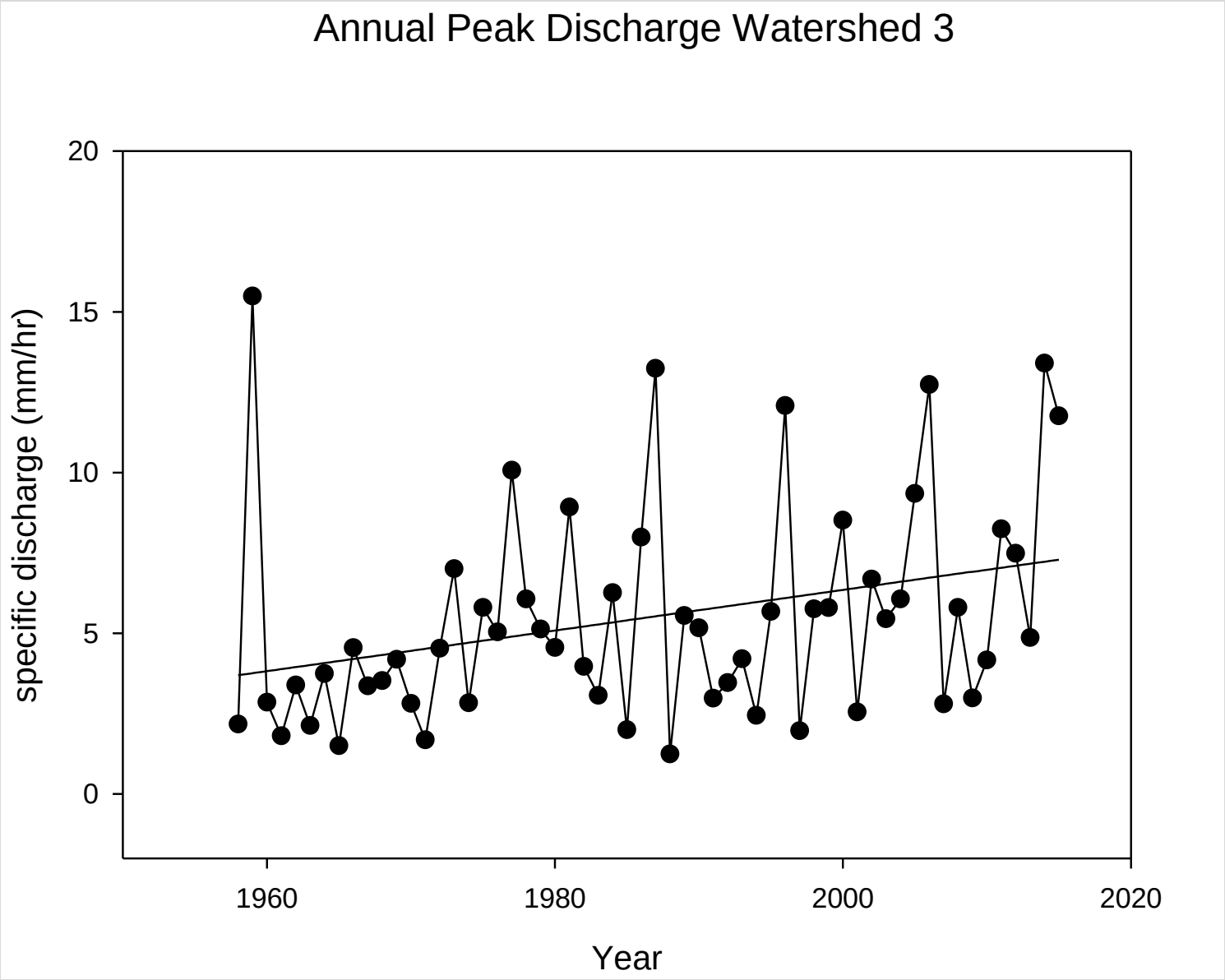

Due to more precipitation as rain and less as snow and less storage of water in snowpack

# Changes in the Distribution of Stream Discharge

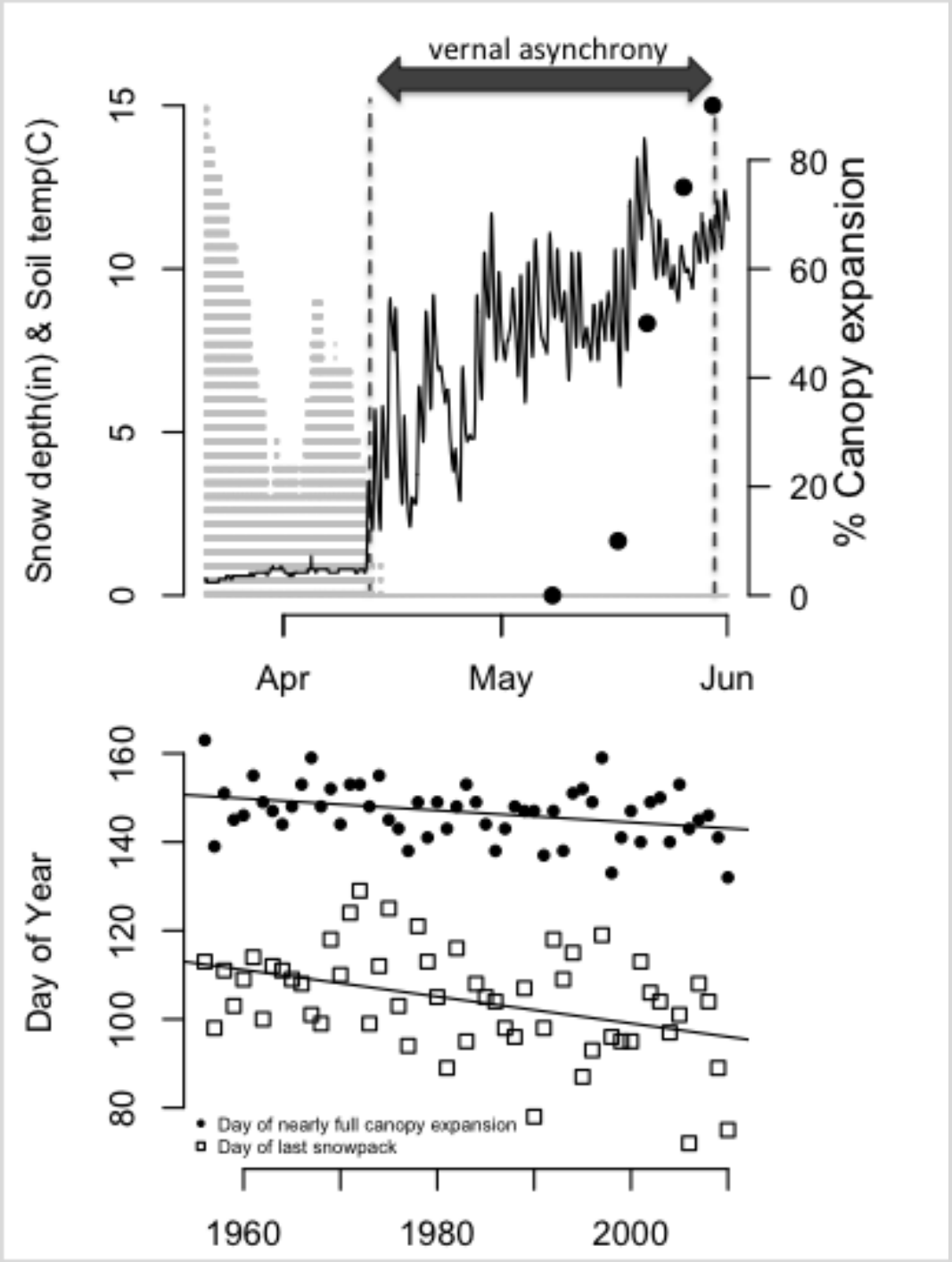



Low flows are decreasing and high flows are increasing

# Increases in Peak Stream Flow



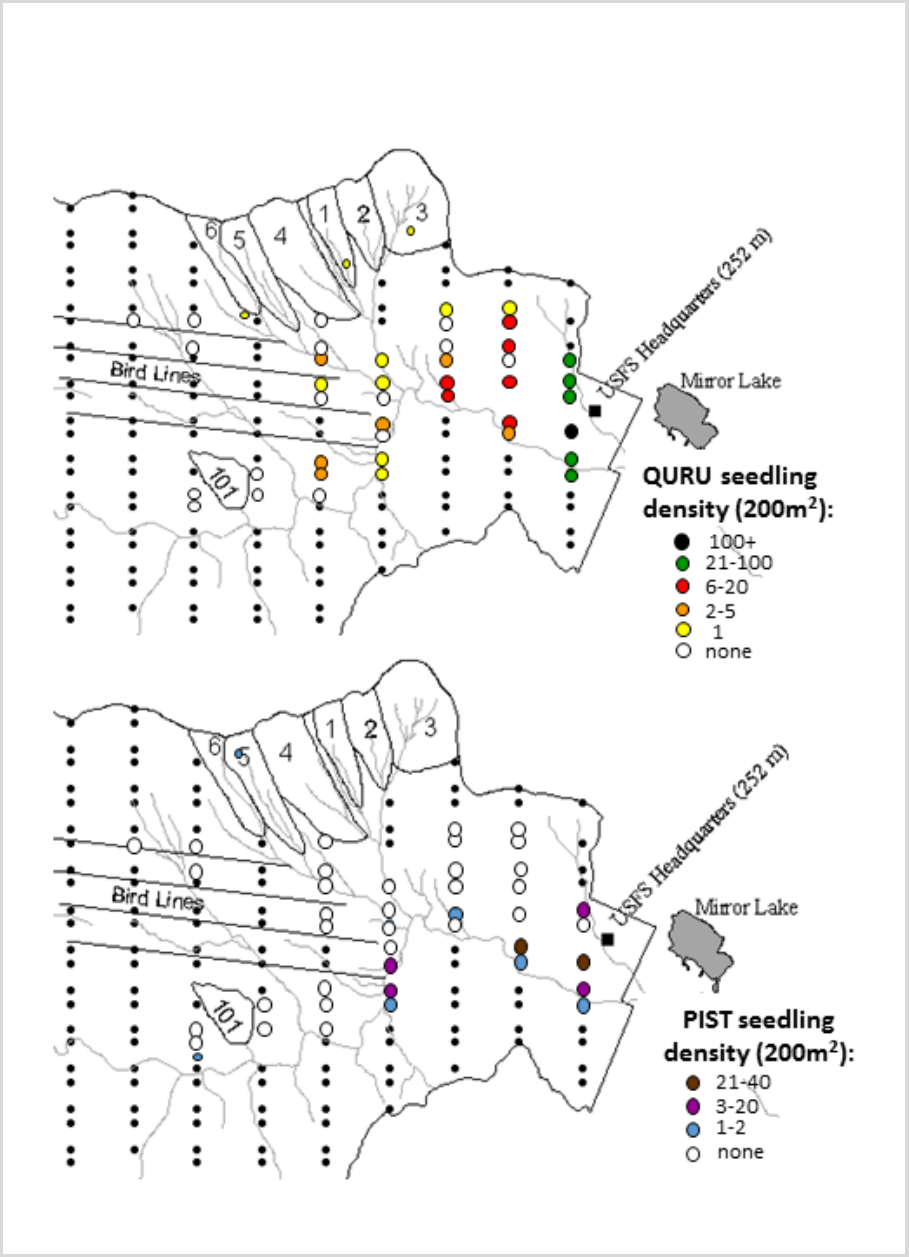

Peak flows are increasing

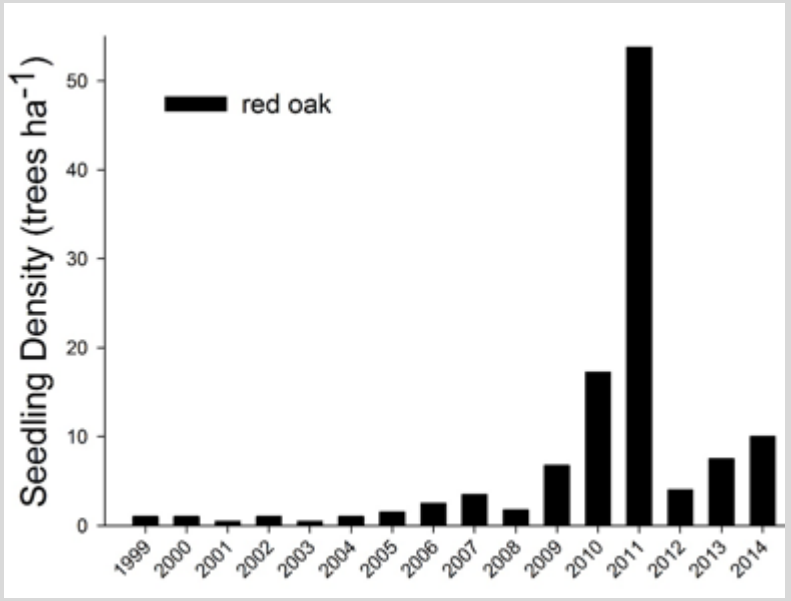


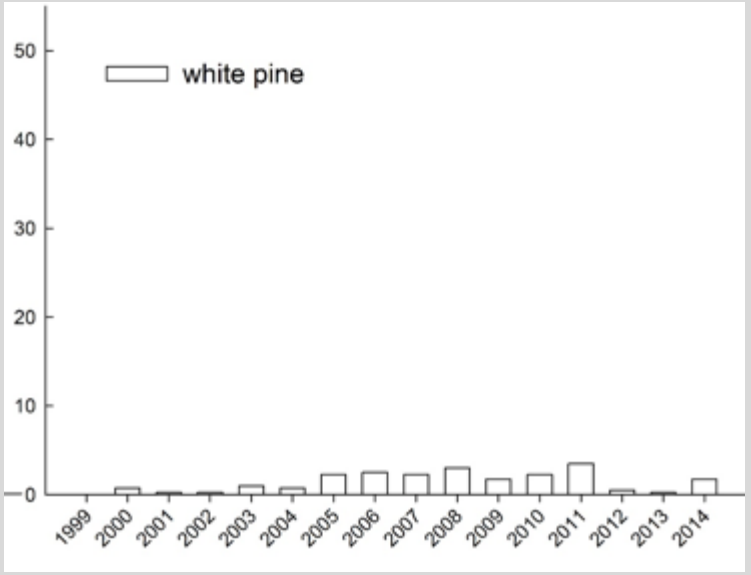

The period between the end of snowpack and the end of tree canopy expansion is increasing.

The vernal asynchrony

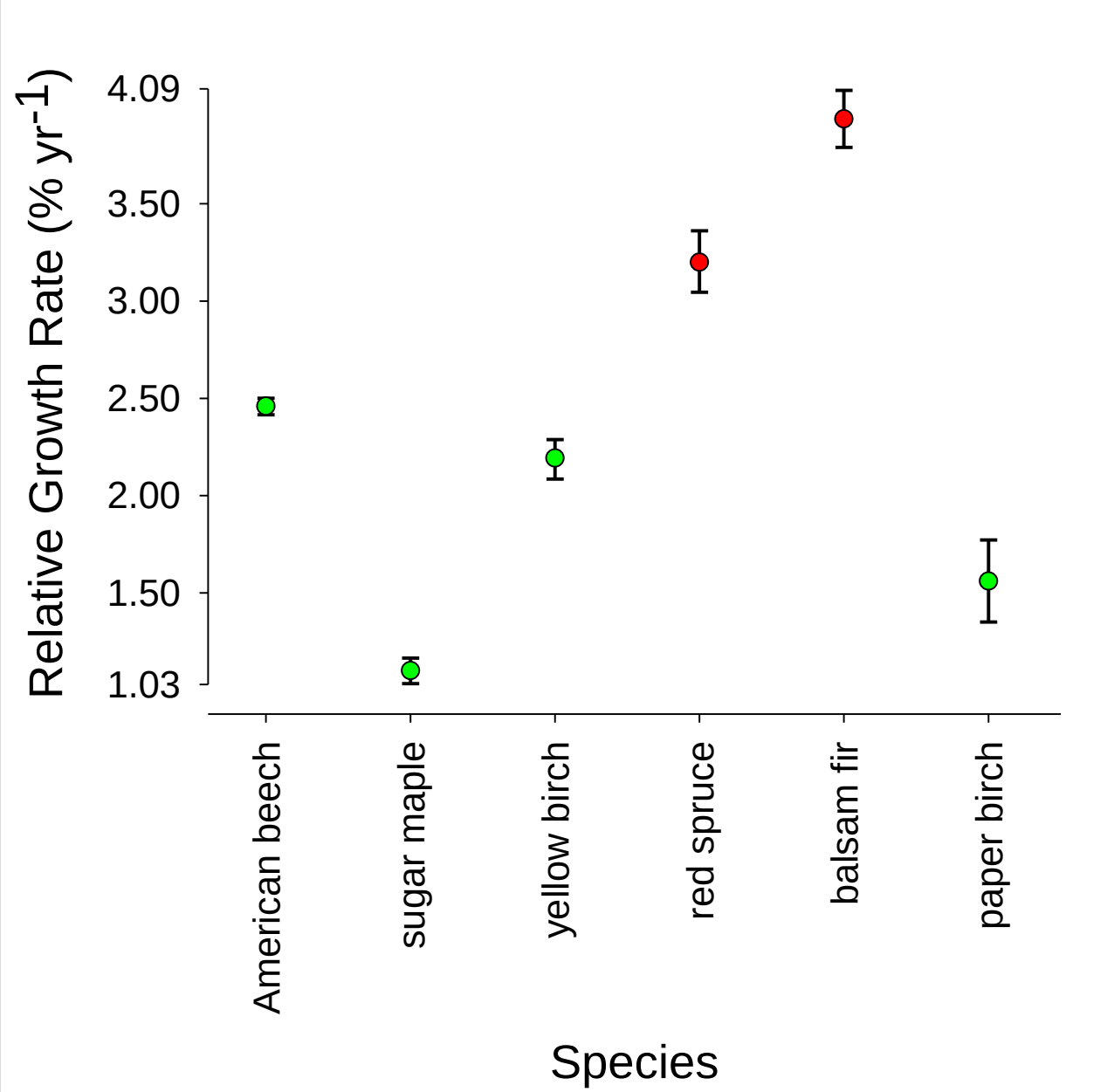
Groffman et al (2012)




Battles unpublished




Relative growth rate of major tree species in W6.

Data from 2007 to 2012

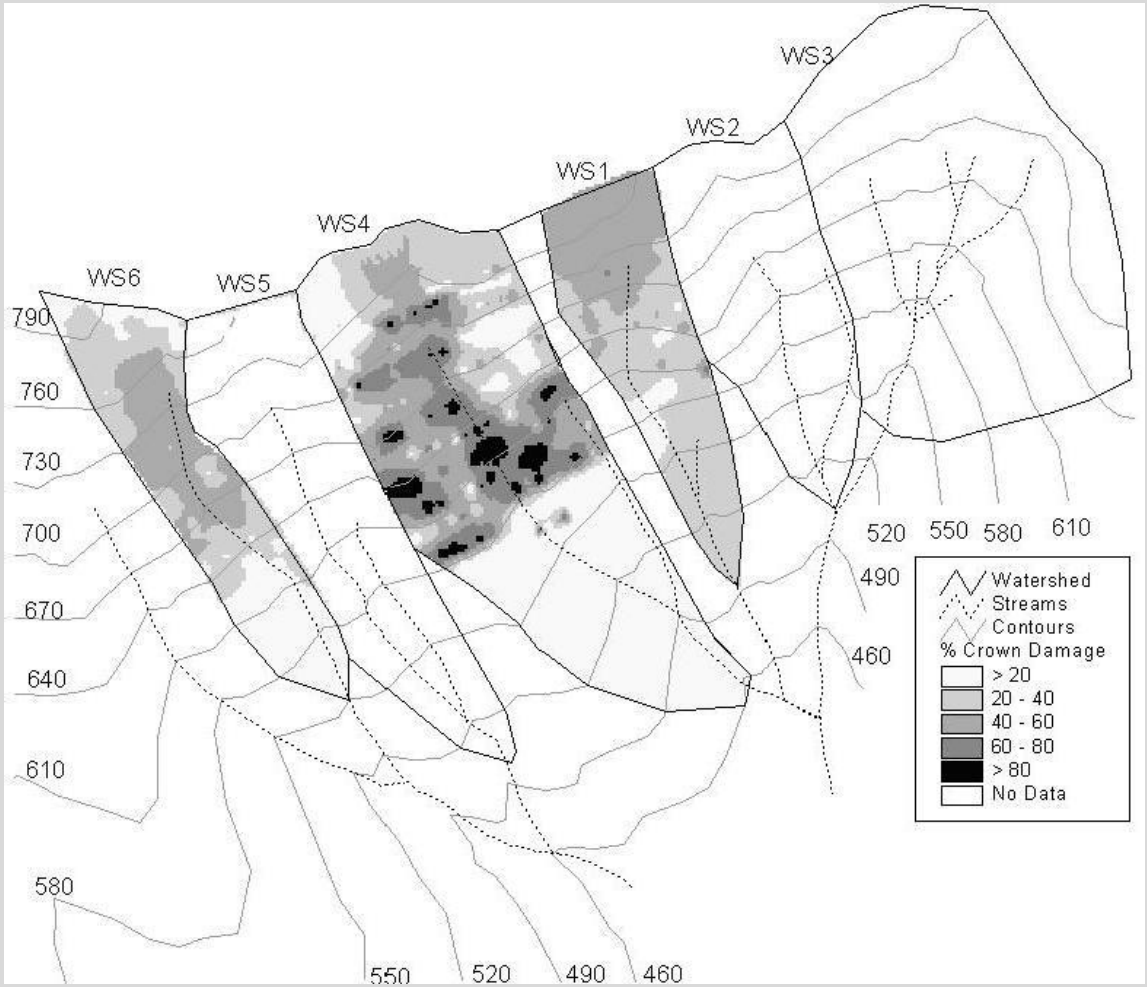
Red spruce and balsam fir are doing well; sugar maple is doing poorly

Battles unpublished

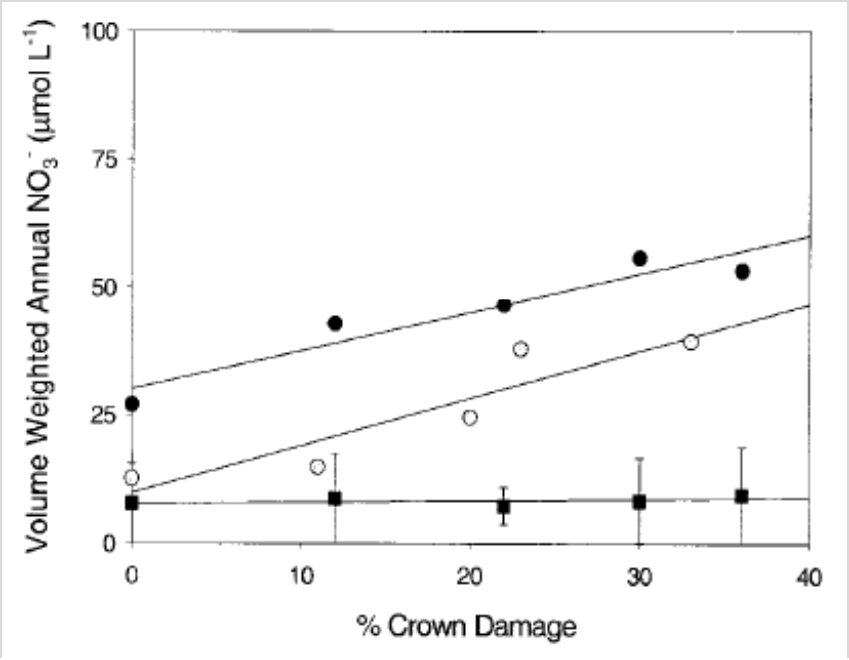
# Extreme Events

# “The Ice Storm” of 1998

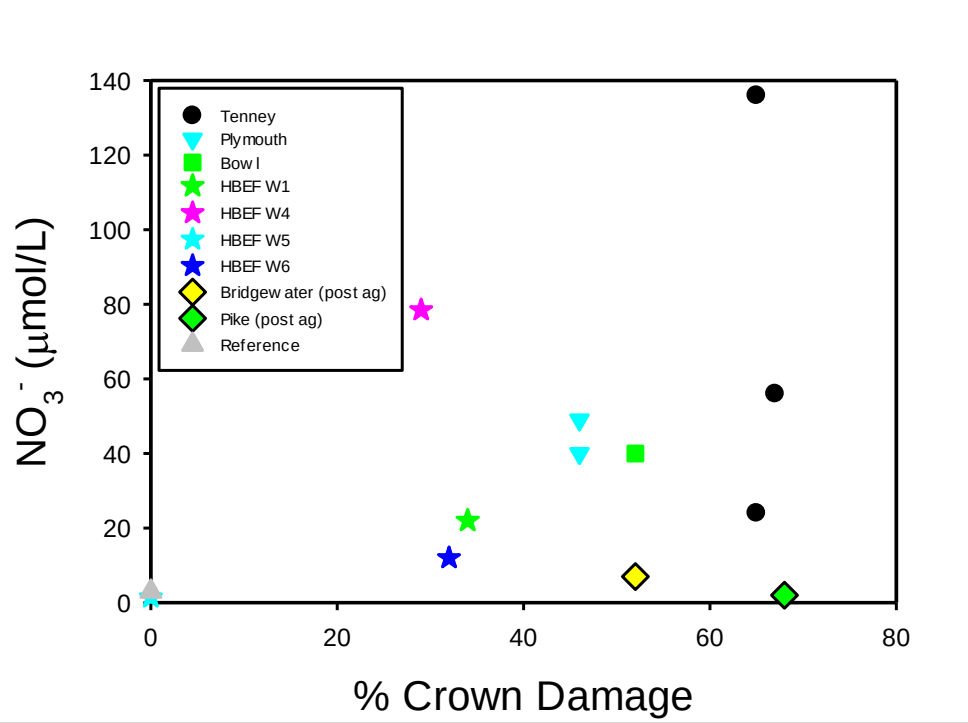
- Jan 4 – 10, 1998
- Northeastern US and southeastern Canada
- > 100,000 $km^2$ (40,000 $mi^2$)
- 7.8- 13 cm (3.1 – 5.1 in) ice
- ~ $3 Billion
- 44 fatalities




W5 ~ 15 y - stems flexible, too small to tip up root systems
W4 ~ 25 y - stems less flexible, break or permanently bend, large enough to tip up collateral damage with big stems taking down other trees downslope
W1, W6 ~ mature- damage mostly from downed branches, less collateral damage




a

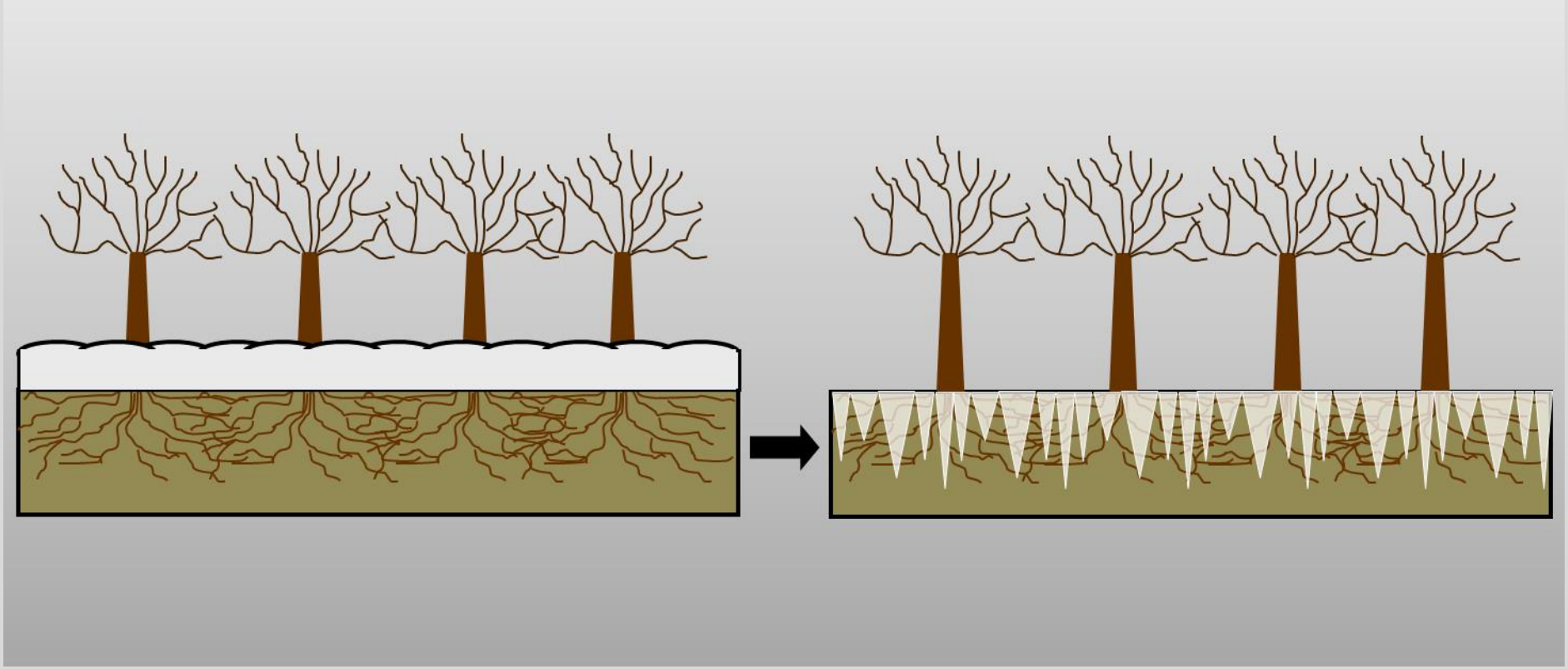



b

Annual stream nitrate concentrations with canopy crown damage for:
a) Hubbard Brook experimental watersheds; and
b) regional sites with Hubbard Brook watersheds

# Ice Storm Experiment

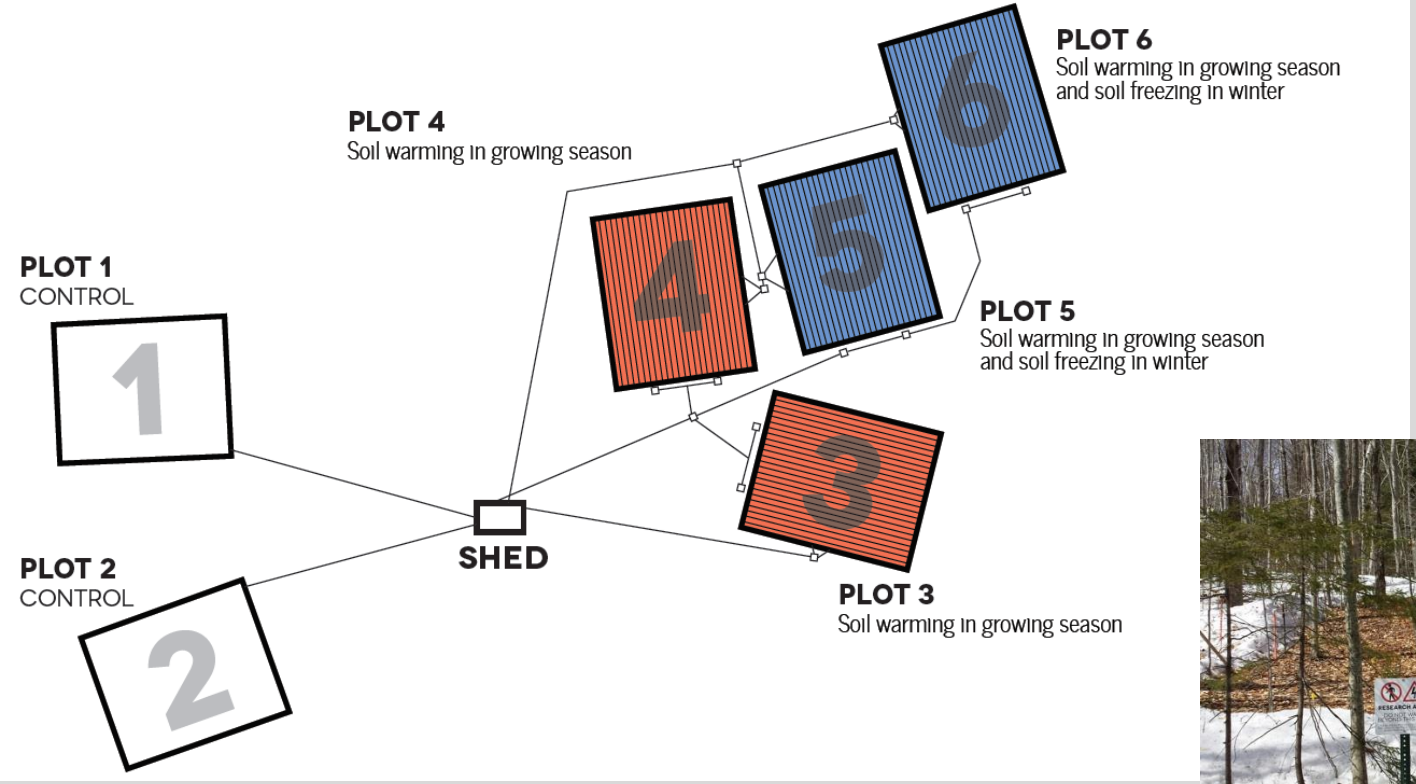
# Reduced Snow Pack Leads to Increase Soil Frost



# Climate Change Across Seasons Experiment (CCASE) at Hubbard Brook

14 X 11m$^2$ plots

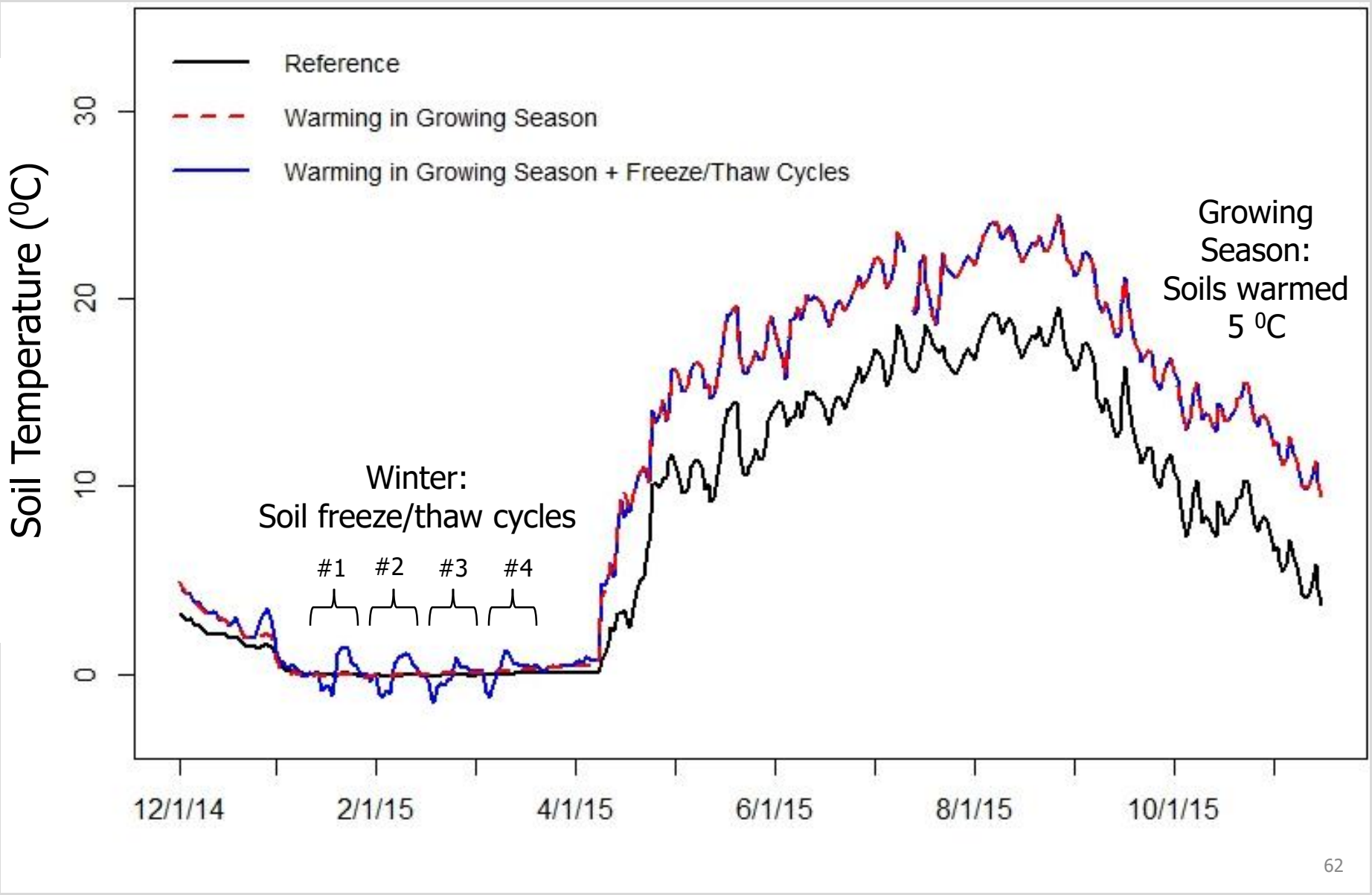
- 2 plots: reference
- 2 plots: soils warmed 5$^0$C in growing season
- 2 plots: soils warmed 5$^0$C in growing season and snow removed in winter to induce soil freeze/thaw cycles




Shoveled CCASE plot
Pam Templer

IR image of soil warming at CCASE- Mary Martin

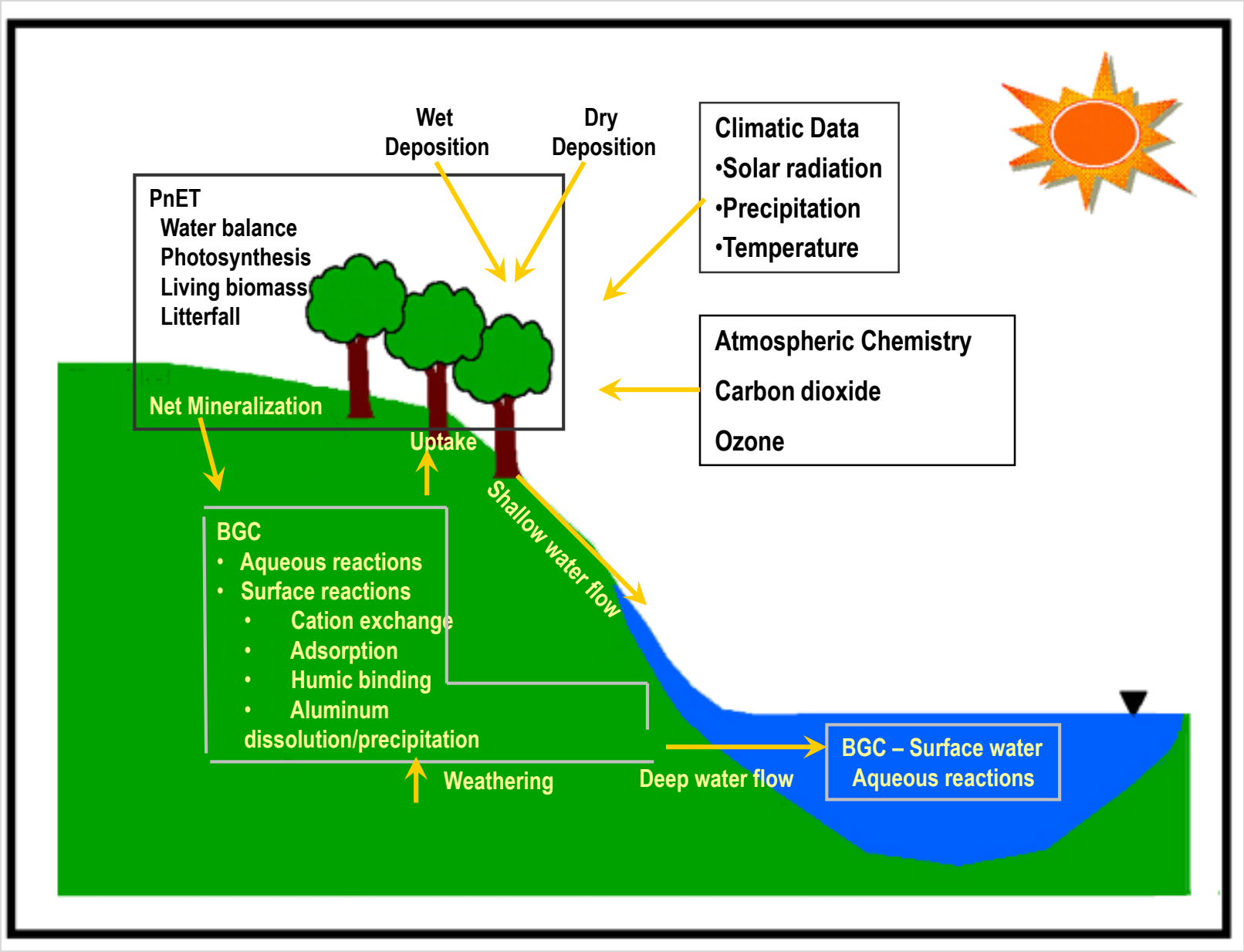
# Soil Temperatures at CCASE

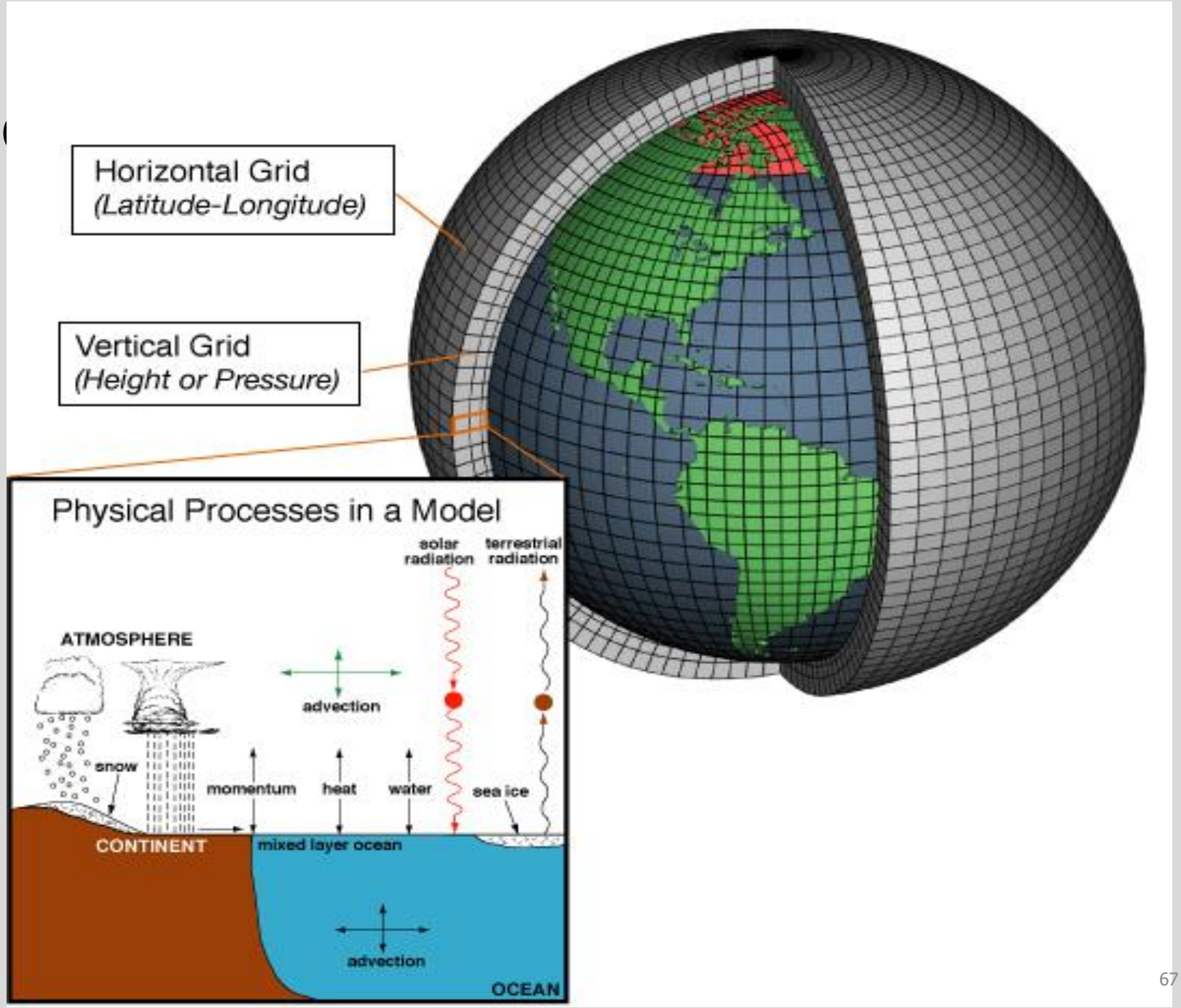


Troughs at DroughNet plot – Lindsey Rustad


08/11/2015

# PnET-BGC – Forest biogeochemical model




Horizontal Grid
(Latitude-Longitude)
Vertical Grid
(Height or Pressure)
Physical Processes in a Model
solar radiation
terrestrial radiation
ATMOSPHERE
advection
snow
momentum
heat
water
sea ice
CONTINENT
mixed layer ocean
advection
OCEAN

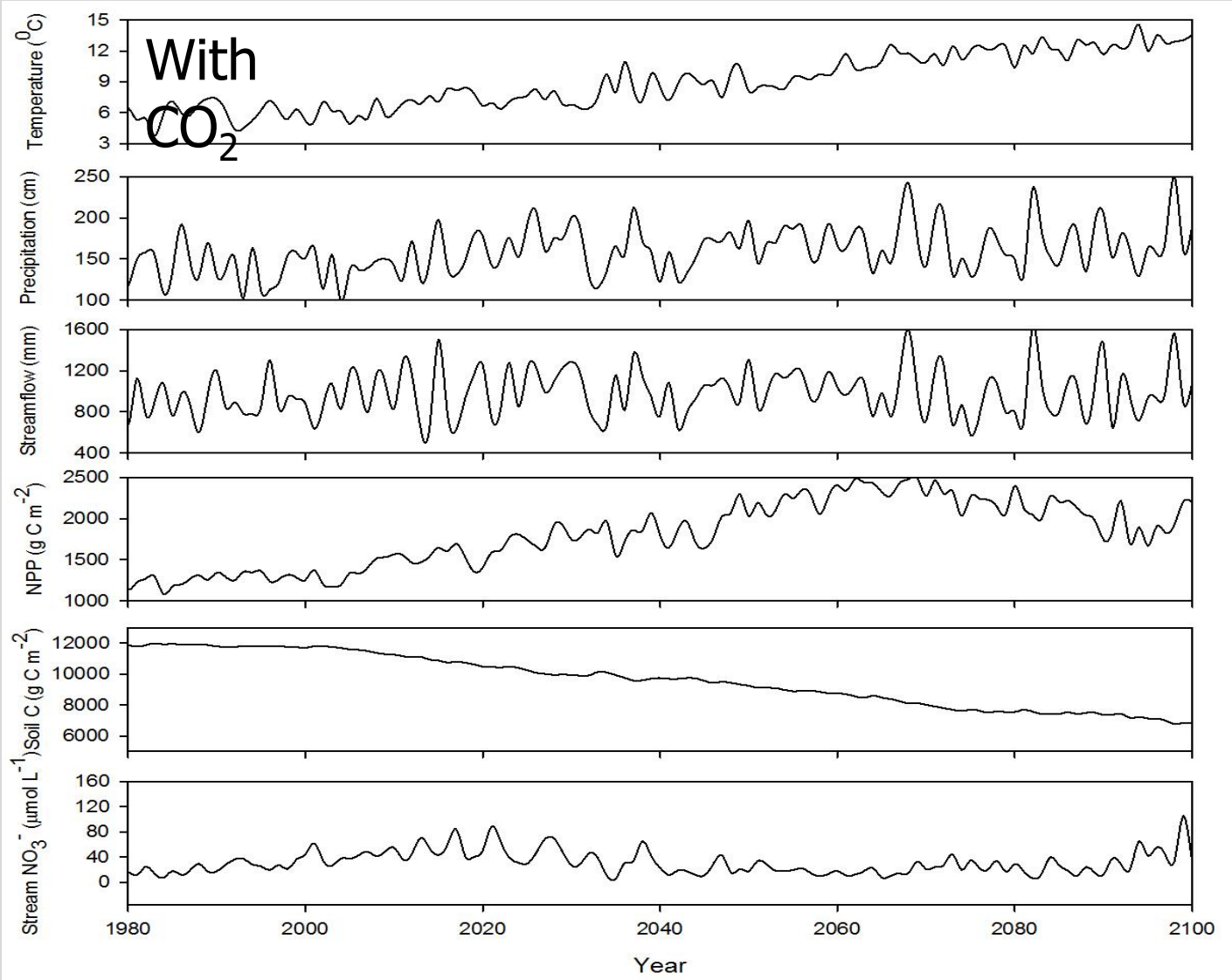
- **HadCM3: The United Kingdom Meteorological Office's Hadley Centre Climate Model, version 3,**
- **GFDL CM2.1: The U.S. National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory, and**
- **PCM: The National Center for Atmospheric Research's Parallel Climate Model.**

## Downscaling methods:

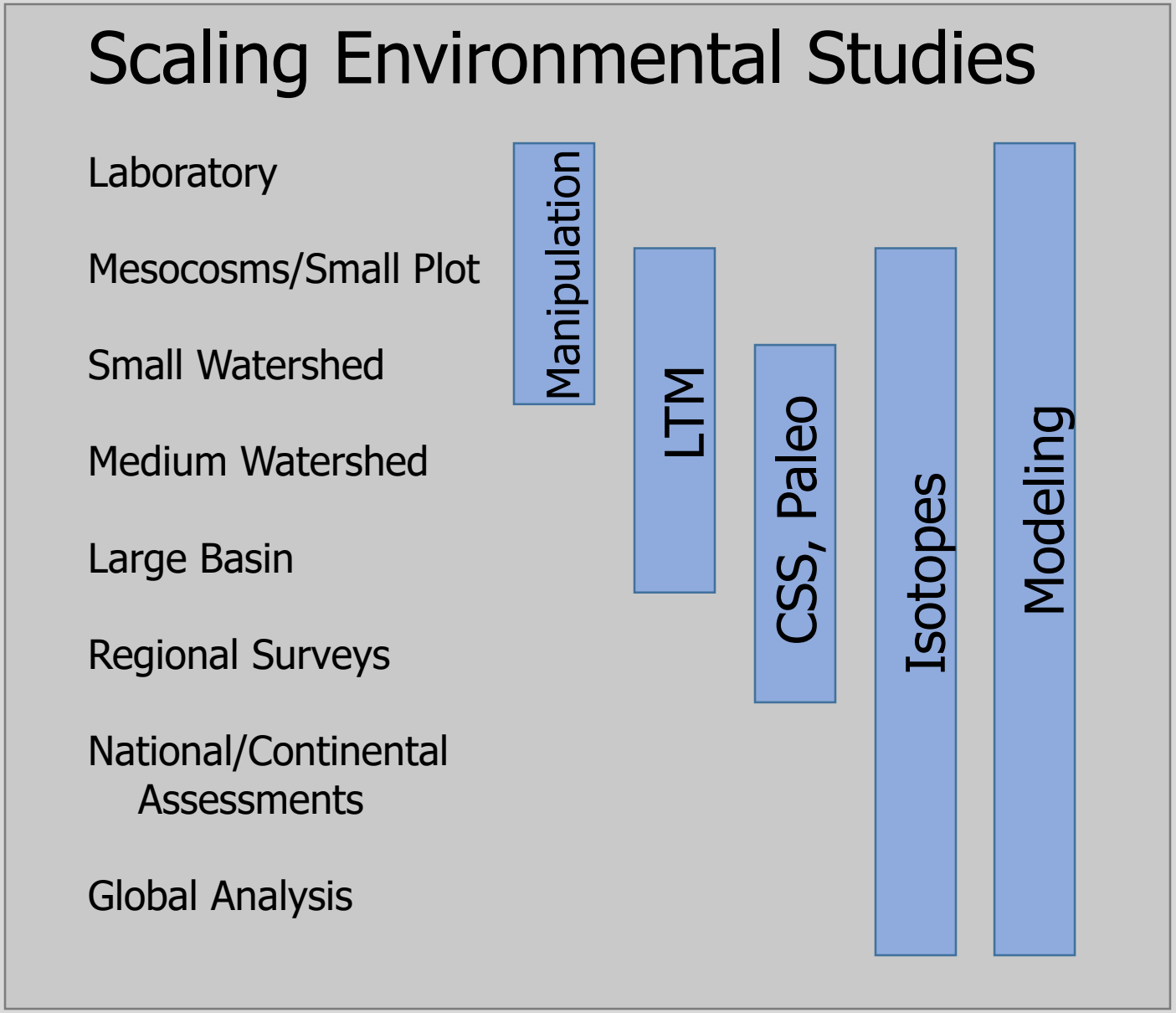
- **Dynamical:** e.g. Regional Climate Model (RCM).
- **Statistical (SD):** Use statistical relationships (usually some form of regression equation):

  - **Gridded** Quantile Mapping: Bias Correction-Spatial Disaggregation (BCSD)
  - **Station-based** Daily Asynchronous Regression

# Time Series HadGEM2-RCP8.5



# Scaling Environmental Studies



# Summary

- The small watershed approach is an effective tool to investigate biogeochemical processes, although it has limitations.
- Long-term measurements and experiments provide insight on ecosystem function, and are useful for testing models and generating hypotheses.
- Clear patterns of increases in air temperature and precipitation, and decreases in precipitation occurring as snow and snowpack accumulation are consistent with regional observations and future climate projections.
- Changing climate in the northern forest is manifested through increases in annual discharge and its timing, changes in species and maybe changes in nutrient dynamics.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