Critical Loads

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Background – What are Critical Loads?

- Definitions, biogeochemical basis, tools, approaches, limitations

Objectives – Why do we want (need) Critical Loads?

- How do we want to use these tools in the context of natural resource management in New York?

Methods – How are Critical Loads calculated?

- What is the policy context?
- How can the results be used?

Results –

- Some examples from the United States

What is a Critical Load –

The definition:

"Estimate of exposure to pollutants below which harmful effects on specified sensitive elements of the environment do not occur according to present knowledge"

(Nilsson & Grennfelt, 1988)

How was the concept developed?

Developed in Europe for nitrogen and sulfur deposition, used in European negotiations to establish emissions control standards.

Why are Critical Loads used?

Based on the idea that control strategies for acidification and eutrophication in Europe should be effects-driven.

How are Critical Loads of pollutant deposition determined – the steps:

1. Identify the **disturbance** produced by atmospheric deposition of the pollutants (acidification, eutrophication, etc.)

2. Identify the **receptors** subject to the disturbance (forests, waters, crops, etc.)

3. Identify the **biological indicators** to be protected within each receptor (individual organism, populations, community characteristics, etc) and determine the ***critical indicator responses*** that define biological damage

4. Identify the **chemical variables** that control the responses of the biological indicators and determine the ***critical chemical limits*** at which the critical indicator responses occur

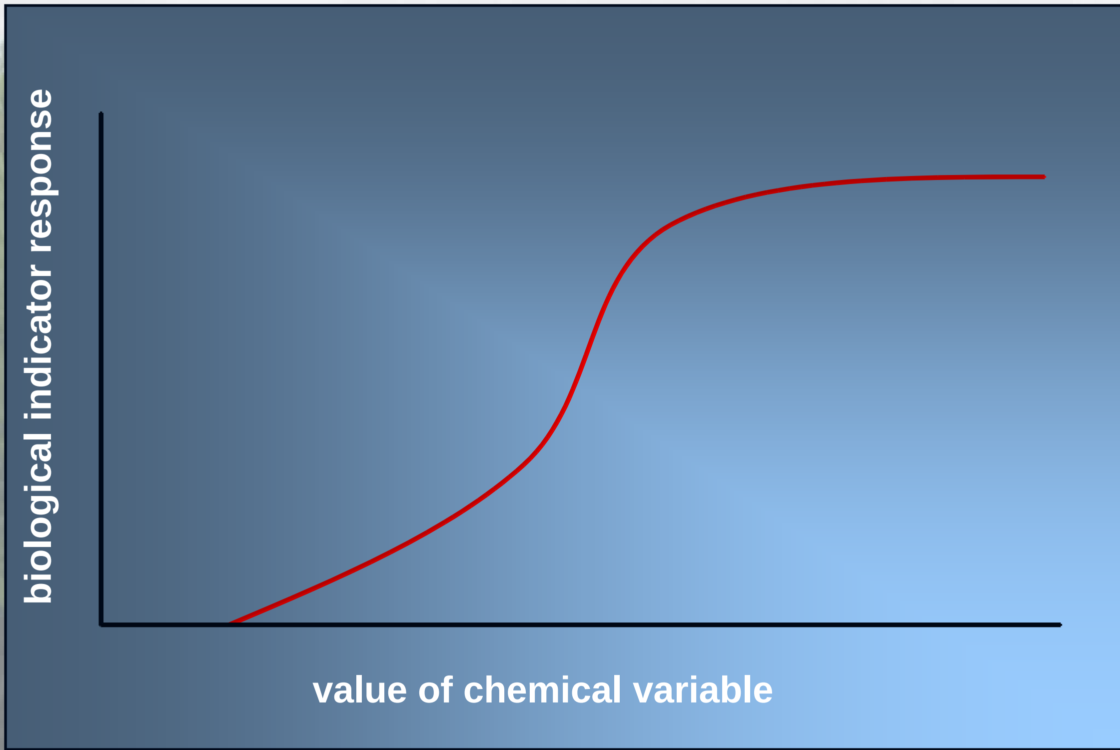
5. Identify the **atmospheric pollutants** that control the pertinent chemical variables (SO4, NO3, NH4, ozone, particulates, etc) and determine the ***critical pollutant loads*** at which the chemical variables reach their critical limits

Why do we want Critical Loads?

1. Promote recovery to point where harmful effects no longer occur
   - example: Adirondack lakes, Catskill streams
2. Prevent future acidification and associated harmful effects
   - example: Adirondack soils and associated vegetation
3. Head off effects associated with future nitrogen saturation
   - example: episodic stream acidification
4. Integrate knowledge of effects from multiple pollutants
   - example: NOx, NH_4, S, Hg
5. Set targets, develop management goals
   - example: when have we accomplished recovery?

Determining Critical Loads – the steps

1) Disturbance	Acidification				Eutrophication	
2) Receptor	Forest		Lake		Grassland	Lake
3) Biological indicator	Sugar Maple	Norway Spruce	Brook trout	Fish species richness	Species diversity	Primary productivity
4) Chemical variable	Soil % Base Saturation	Soil Ca/Al ratio	Lakewater ANC	Lakewater ANC	Soil C/N	Lakewater NO3
5) Atmospheric pollutant	SO4, NO3, NH4	SO4, NO3, NH4	SO4, NO3, NH4	SO4, NO3, NH4	NO3, NH4	NO3, NH4



Response Function

Biological Indicator is a function of Chemical Variable

Biological Indicator Responses

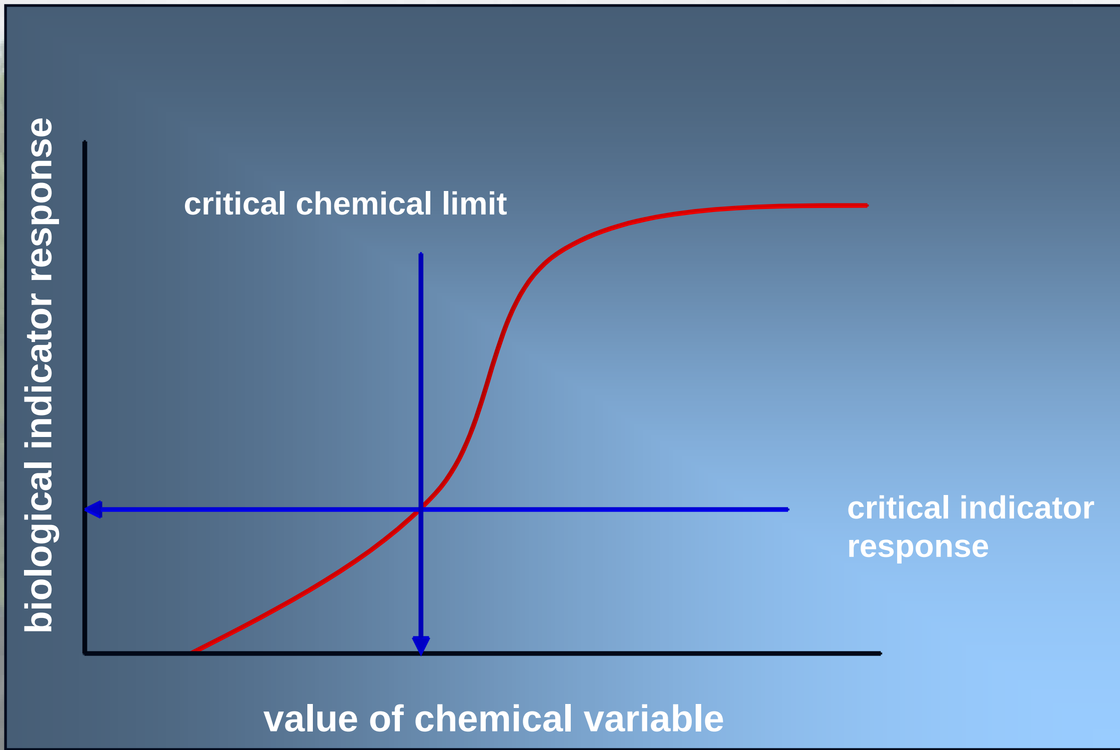
Death of organisms
Condition of individuals
Reproductive success

Loss of species
Community productivity

Chemical Variables

ANC, pH, NO3, Al
Base saturation, Ca/Al
Ozone

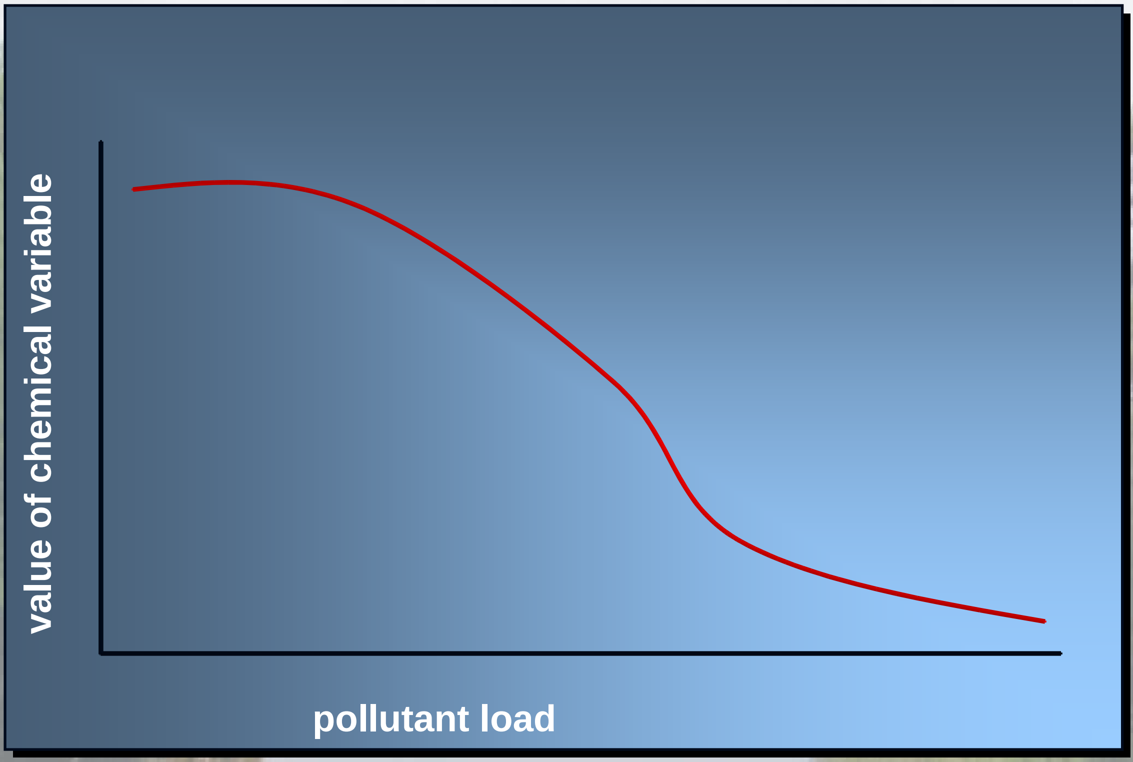
Annual averages
Seasonal extremes



Response Function

Biological Indicator is a function of Chemical Variable

Biological Indicator Responses	Chemical Variables
Death of organisms	
Condition of individuals	ANC, pH, NO3, Al
Reproductive success	Base saturation, Ca/Al
	Ozone
Loss of species	
Community productivity	Annual averages
	Seasonal extremes



Response Function

Chemical Variable is a function of Pollutant Load

Chemical Variables

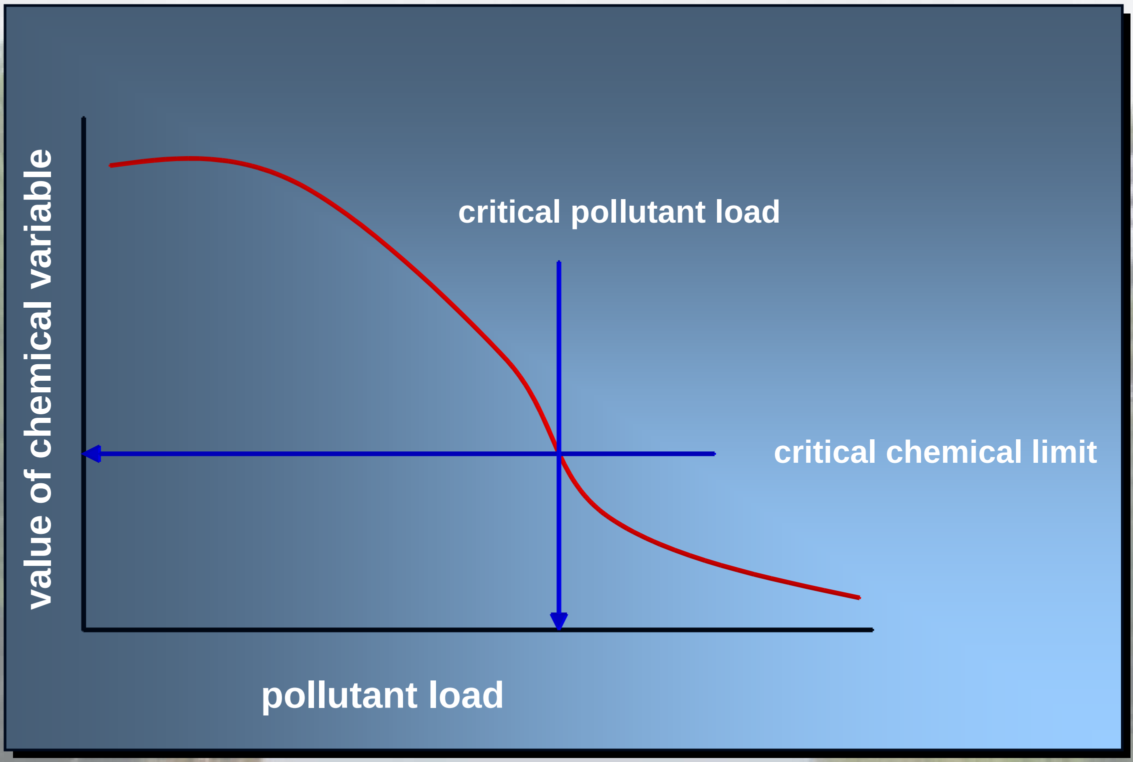
ANC, pH, NO3, Al
Base saturation, Ca/Al
Ozone

Annual averages
Seasonal extremes

Pollutant Load

S, N
Hg, NOx, SO2

Annual averages
Seasonal patterns



Response Function

Chemical Variable is a function of Pollutant Load

Chemical Variables

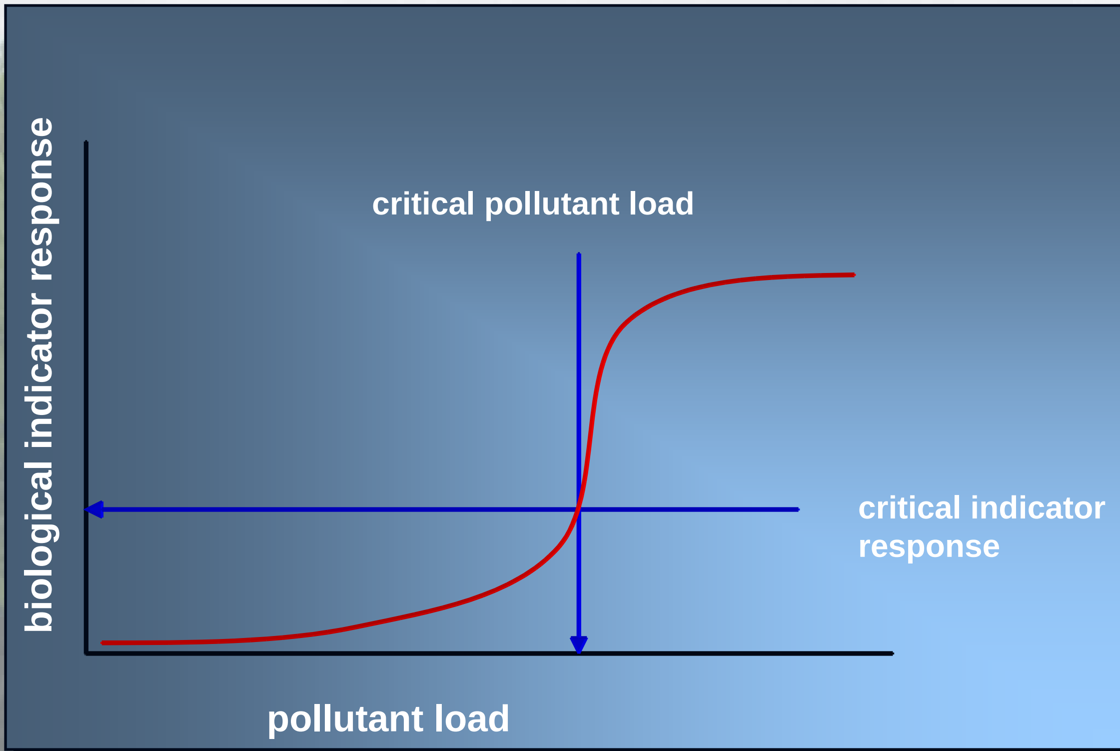
ANC, pH, NO3, Al
Base saturation, Ca/Al
Ozone

Annual averages
Seasonal extremes

Pollutant Load

S, N
Hg, Nox, SO2

Annual averages
Seasonal patterns



Combined Response Function

Biological Indicator is a function of Pollutant Load

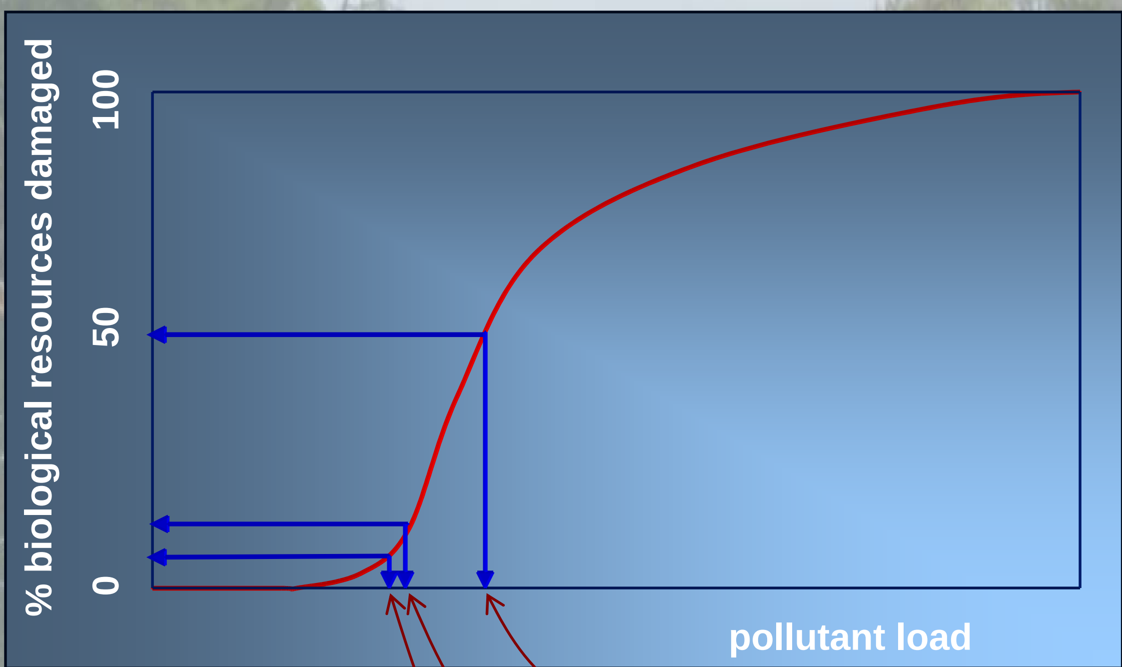
Biological Indicator Responses	← Chemical Variables	← Pollutant Load
Death of organisms Condition of individuals Reproductive success	ANC, pH, NO3, Al Base saturation, Ca/Al Ozone	S, N Hg, NOx, SO2
Loss of species Community productivity	Annual averages Seasonal extremes	Annual averages Seasonal patterns

How are Critical Loads of pollutant deposition determined – some examples

1) Disturbance	Acidification				Eutrophication	
2) Receptor	Forest		Lake		Grassland	Lake
3) Biological indicator	Sugar Maple	Norway Spruce	Brook trout	Fish species richness	Species diversity	Primary productivity
critical indicator response	Failure to reproduce	Seedling death	Presence absence	Species loss	Species loss	Excess productivity
4) Chemical variable	Soil % Base Saturation	Soil Ca/Al ratio	Lakewater ANC	Lakewater ANC	Soil C/N	Lakewater NO3
critical chemical limit	10%	1.0	0 ueq/L	50 ueq/L	20	10 umol/L
5) Atmospheric pollutant	SO4, NO3, NH4	SO4, NO3, NH4	SO4, NO3, NH4	SO4, NO3, NH4	NO3, NH4	NO3, NH4
critical pollutant load	???	???	???	???	???	???

How are Critical Loads of pollutant deposition determined – additional considerations

6. Evaluate the effects of **spatial heterogeneity** within the receptor on the response functions (geology, soils, landscape morphology, microclimatology, vegetation, etc.) and determine the ***cumulative resource responses*** for the critical pollutant loads within the receptor



Cumulative Resource Response to Pollutant Load

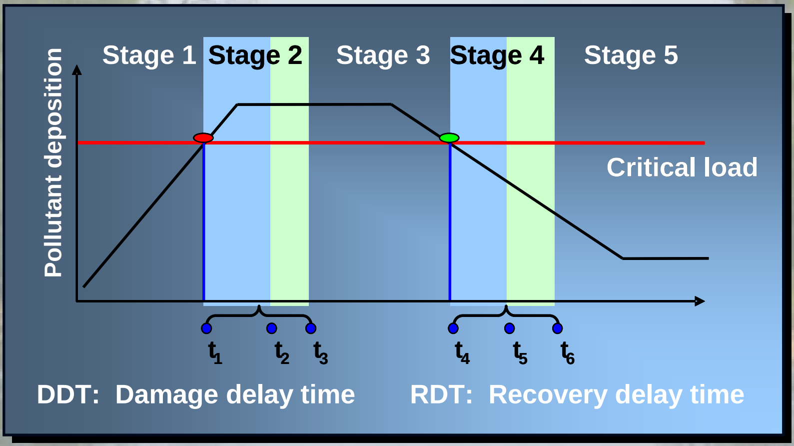
% biological resources damaged

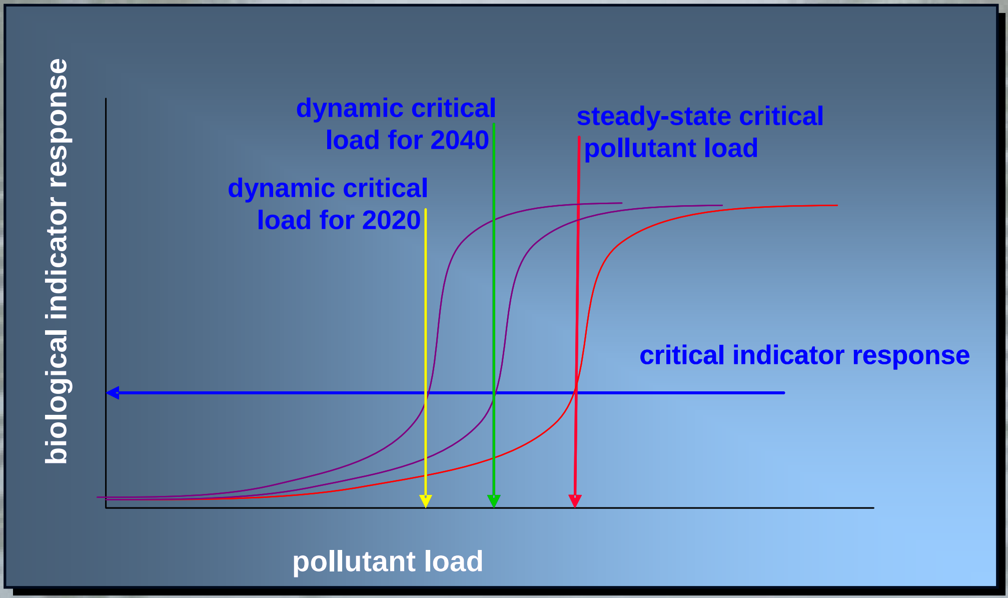
= % sites (streams, plots etc.) within receptor for which the biological indicator response *exceeds* the critical indicator response

- **Critical load for protection of 50% of resources**
- **Critical load for protection of 90% of resources**
- **Critical load for protection of 95% of resources**

How are Critical Loads of pollutant deposition determined – additional considerations

7. Evaluate the **response time-scales and lags** of the biological indicators and chemical variables (soil lags, population dynamics, recruitment, etc.) and differentiate between **steady-state and dynamic critical loads** of a pollutant



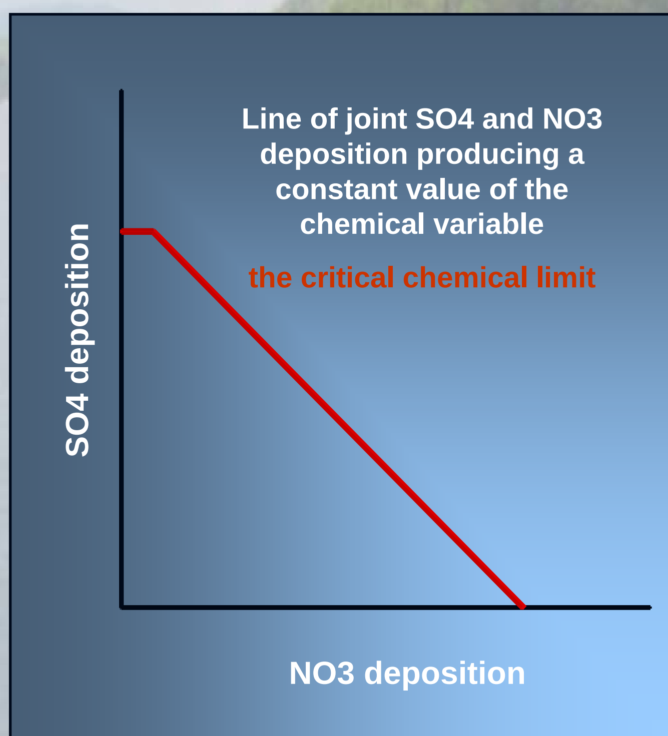


How are Critical Loads of pollutant deposition determined – additional considerations

8. Evaluate the **interaction of multiple pollutants** producing the same disturbance in a receptor (S and N acidification, NO_3 and NH_4 eutrophication, etc.) and determine the **multi-pollutant critical loads** at which chemical variables reach their critical limits

Some disturbances are driven by the deposition of more than one pollutant because the effects of the pollutants on the chemical variable in the receptor are the same

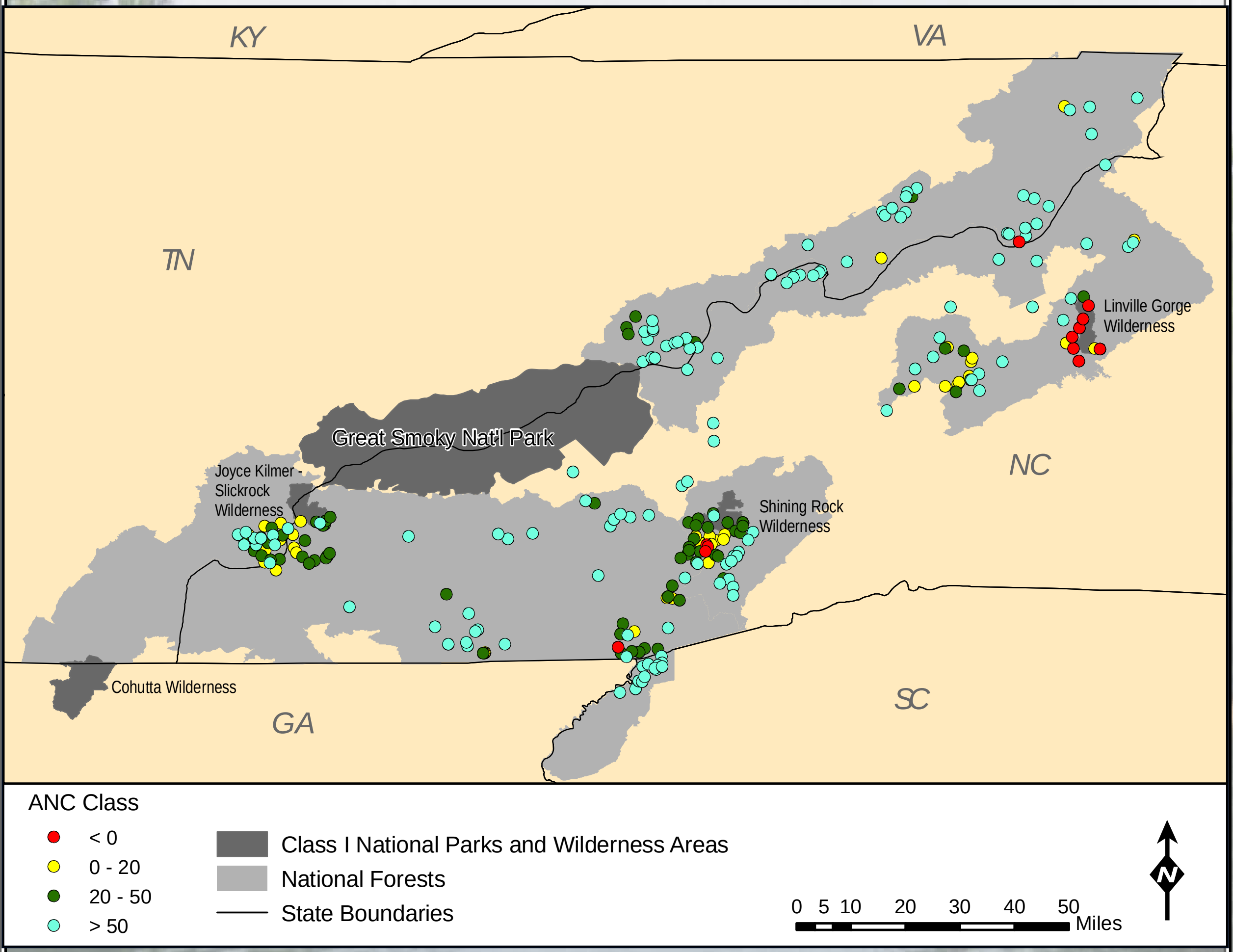
1) Disturbance	Acidification
2) Receptor	Lake
3) Biological indicator	Brook trout
4) Chemical variable	Lakewater ANC
5) Atmospheric pollutant	SO_4, NO_3, NH_4

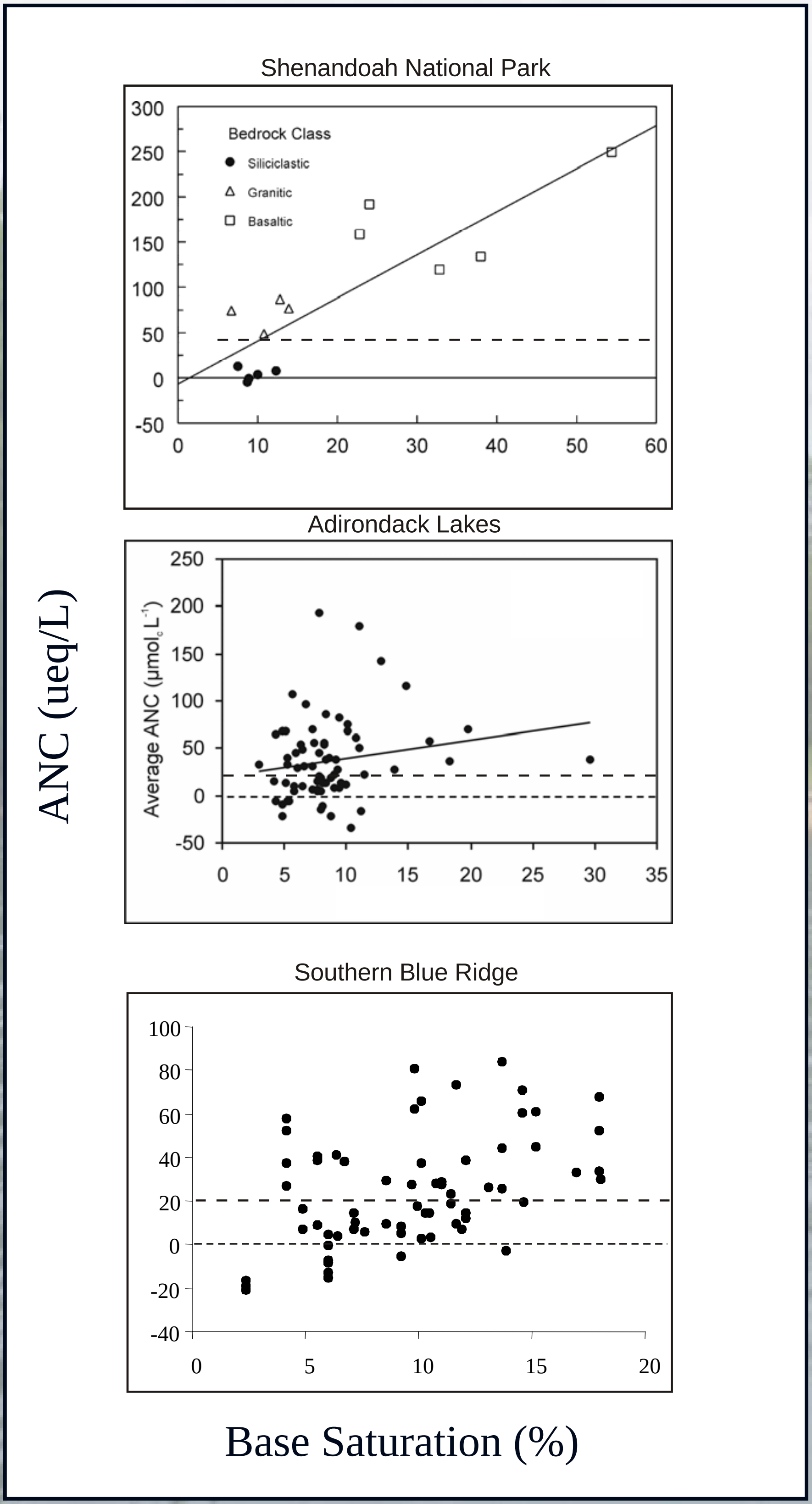


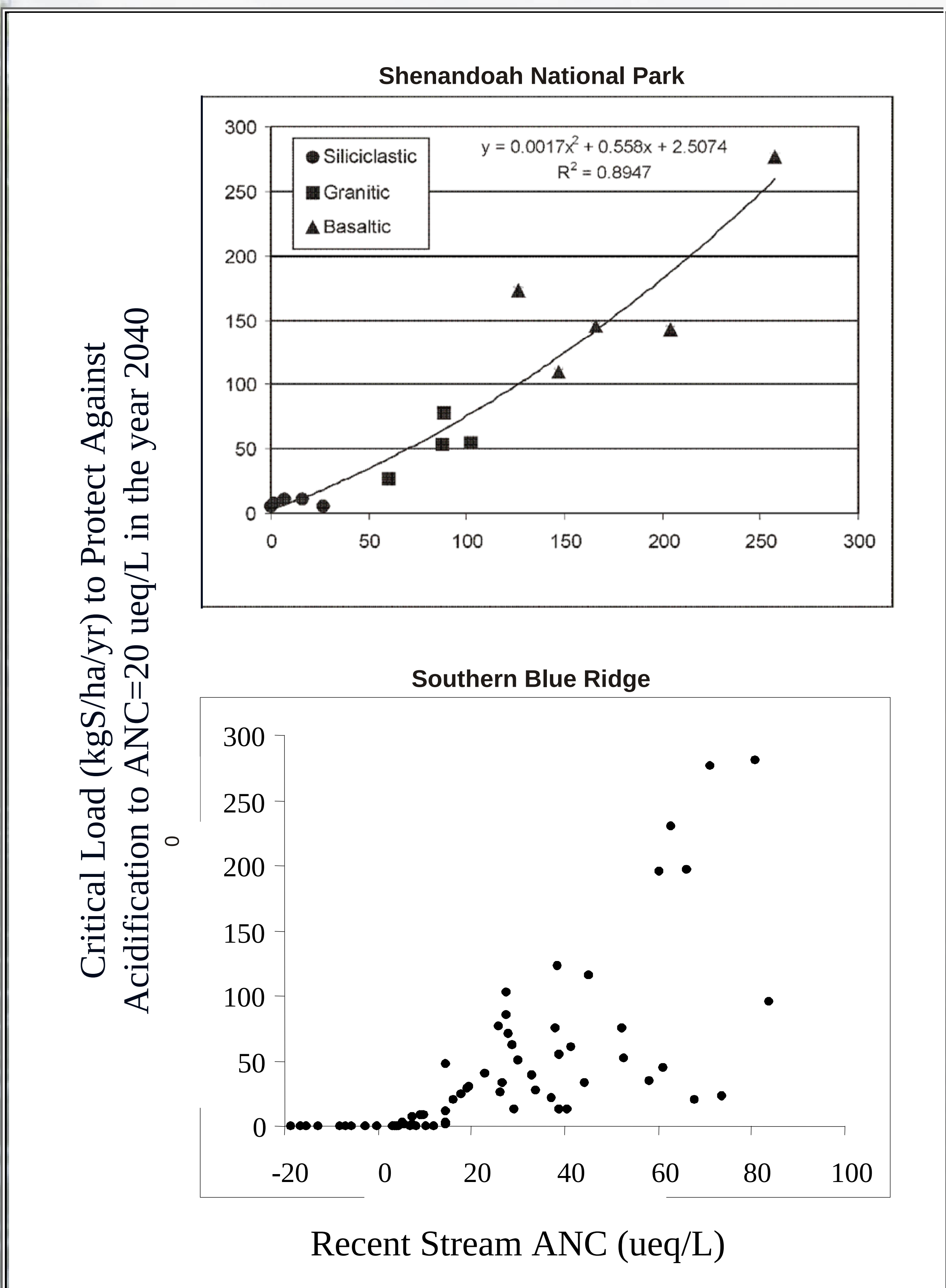
How do Science, Policy and Society Interact Concerning Critical Loads?

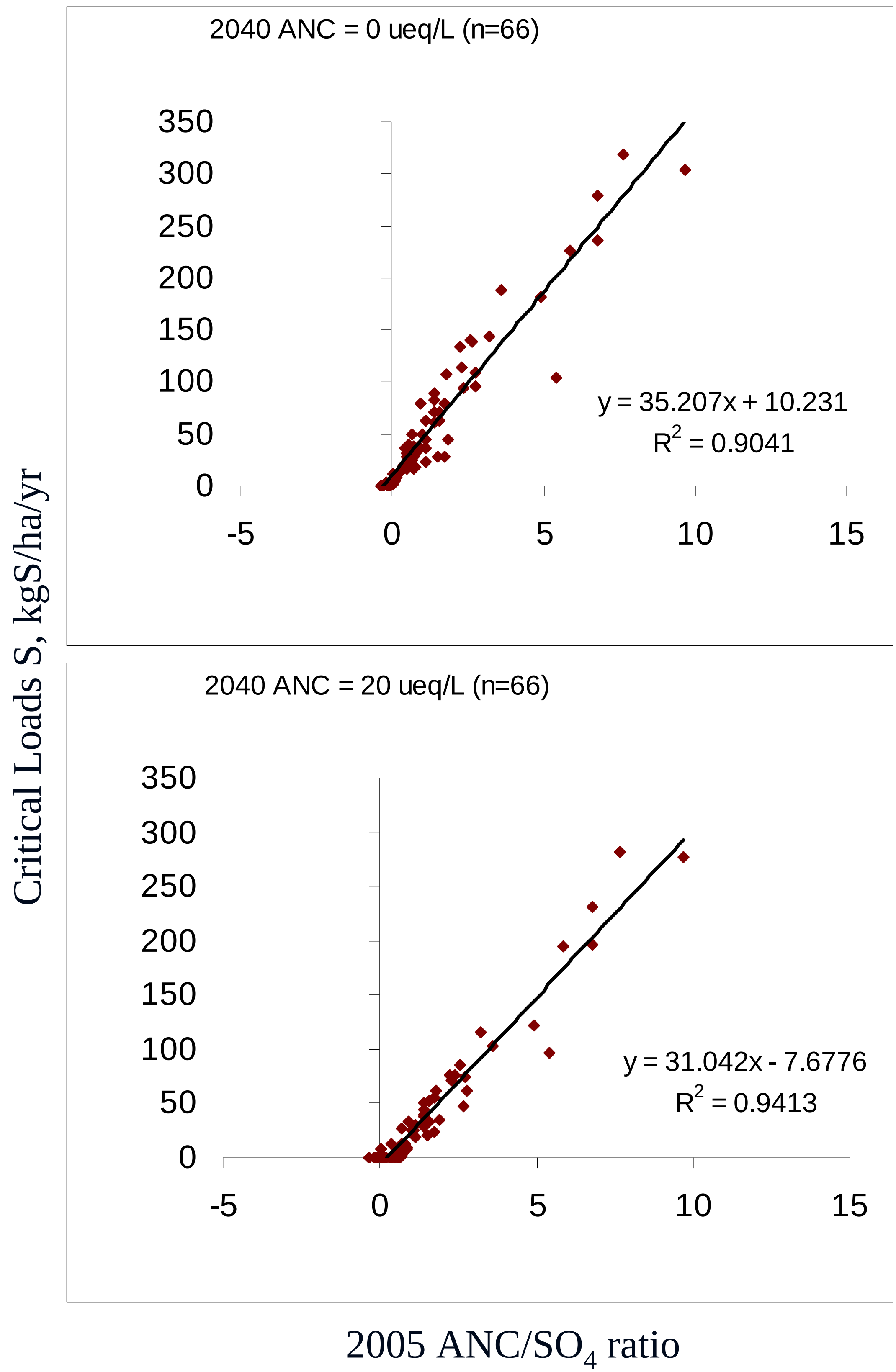
We must determine each of the following:

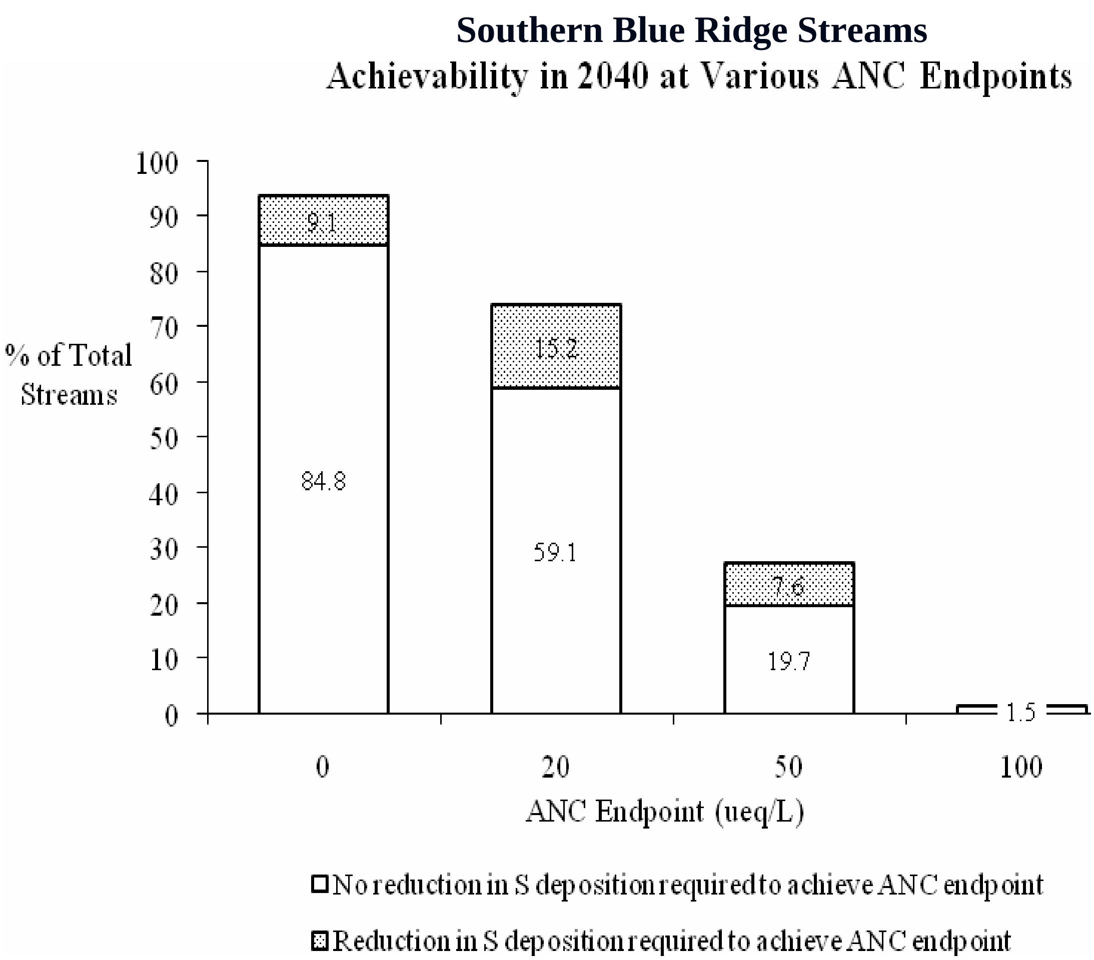
1. Disturbance produced by atmospheric deposition of pollutants
2. Receptors subject to the disturbance
3. Biological indicators and critical indicator responses (social decision)
4. Chemical variables and critical chemical limits
5. Atmospheric pollutants and critical pollutant load for different time periods
6. Level of protection desired (political/social decision)
7. Time at which protection is desired (political/social/economic decision)
8. Multi-pollutant management approach (political/economic decision)

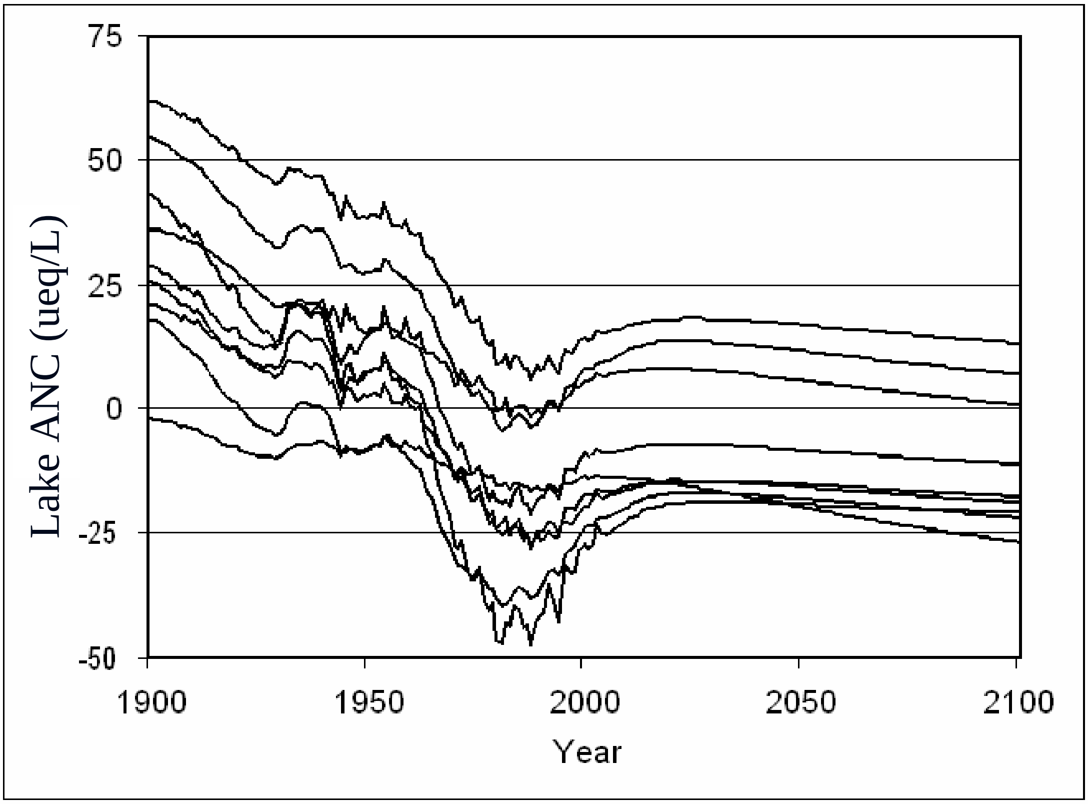

KY
VA
TN
NC
SC
GA
Great Smoky Nat'l Park
Joyce Kilmer - Slickrock Wilderness
Shining Rock Wilderness
Linville Gorge Wilderness
Cohutta Wilderness
ANC Class
< 0
0 - 20
20 - 50
> 50
Class I National Parks and Wilderness Areas
National Forests
State Boundaries
0 5 10 20 30 40 50
Miles
N

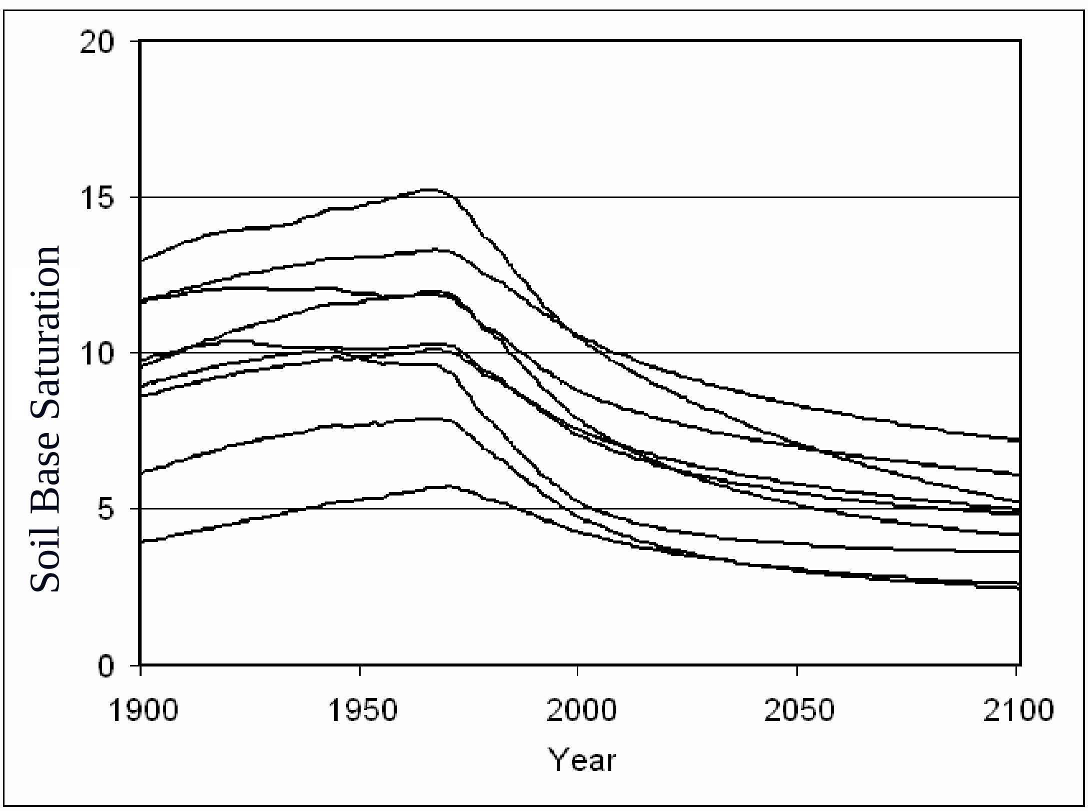

Shenandoah National Park
Bedrock Class
Siliciclastic
Granitic
Basaltic
300
250
200
150
100
50
0
-50
0
10
20
30
40
50
60
Adirondack Lakes
Average ANC (µmol$_c$ L^{-1})
250
200
150
100
50
0
-50
0
5
10
15
20
25
30
35
Southern Blue Ridge
100
80
60
40
20
0
-20
-40
0
5
10
15
20
ANC (ueq/L)
Base Saturation (%)

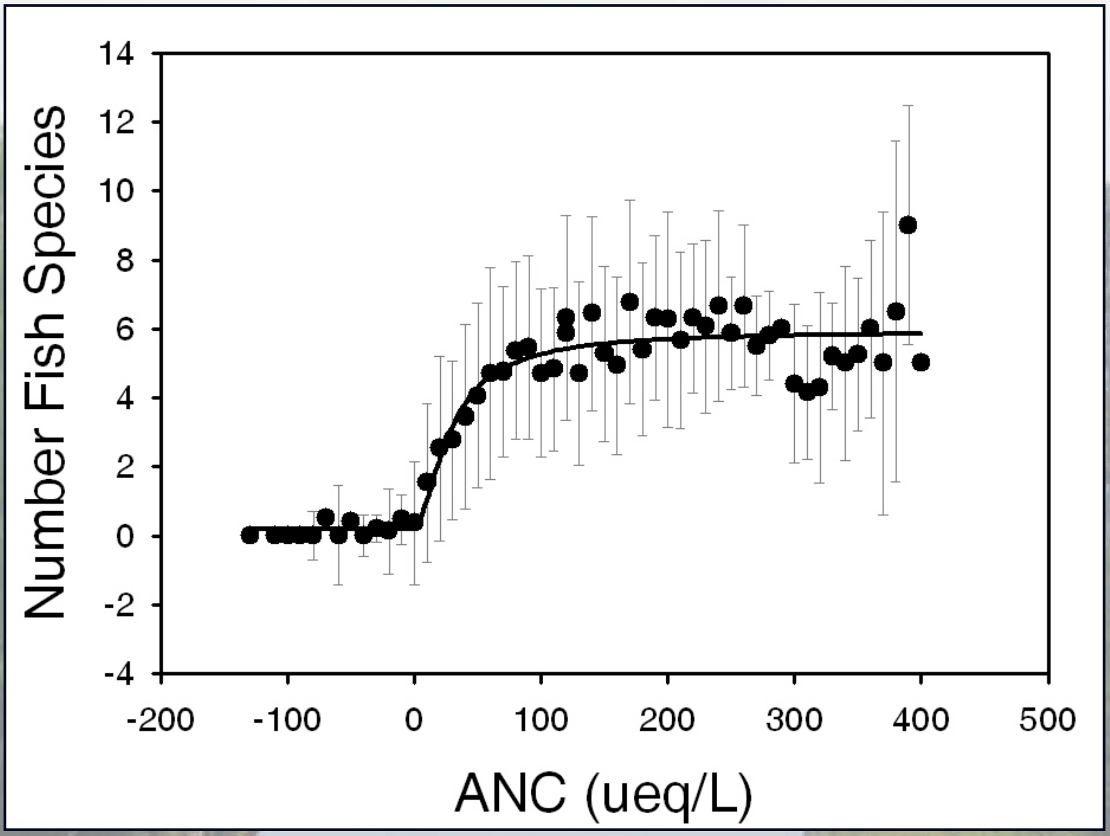

Shenandoah National Park
y = 0.0017x2 + 0.558x + 2.5074
R2 = 0.8947
Siliciclastic
Granitic
Basaltic
300
250
200
150
100
50
0
0
50
100
150
200
250
300
Southern Blue Ridge
300
250
200
150
100
50
0
-20
0
20
40
60
80
100
Critical Load (kgS/ha/yr) to Protect Against Acidification to ANC=20 ueq/L in the year 2040
Recent Stream ANC (ueq/L)


2040 ANC = 0 ueq/L (n=66)
350
300
250
200
150
100
50
0
-5
0
5
10
15
y = 35.207x + 10.231
R2 = 0.9041
2040 ANC = 20 ueq/L (n=66)
350
300
250
200
150
100
50
0
-5
0
5
10
15
y = 31.042x - 7.6776
R2 = 0.9413
Critical Loads S, kgS/ha/yr
2005 ANC/SO4 ratio

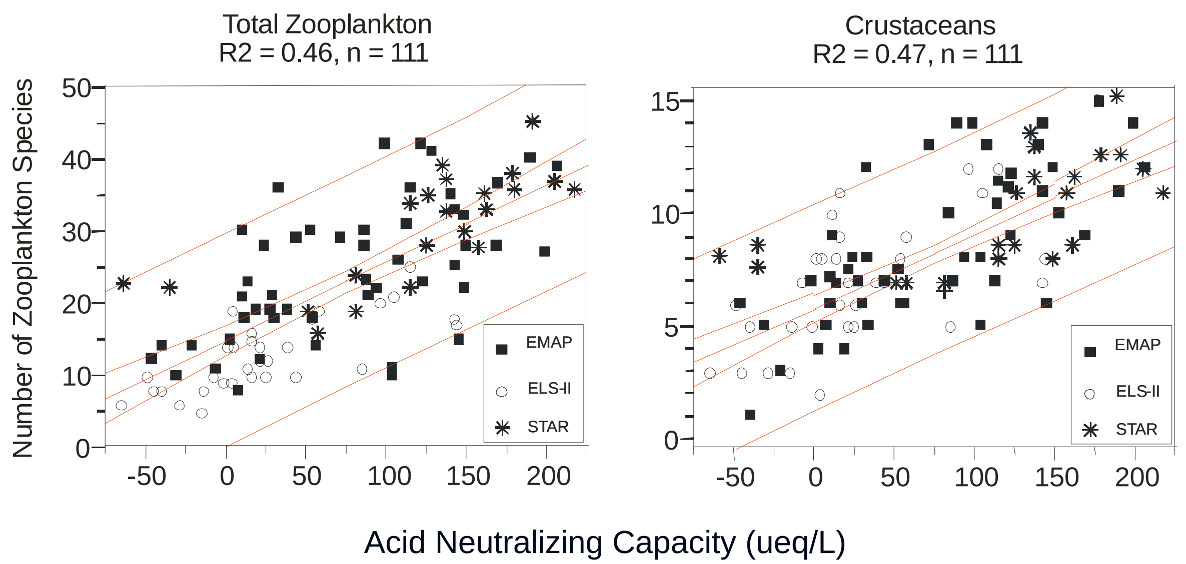

Southern Blue Ridge Streams
Achievability in 2040 at Various ANC Endpoints
% of Total Streams
100
90
80
70
60
50
40
30
20
10
0
9.1
84.8
15.2
59.1
7.6
19.7
1.5
0
20
50
100
ANC Endpoint (ueq/L)
No reduction in S deposition required to achieve ANC endpoint
Reduction in S deposition required to achieve ANC endpoint

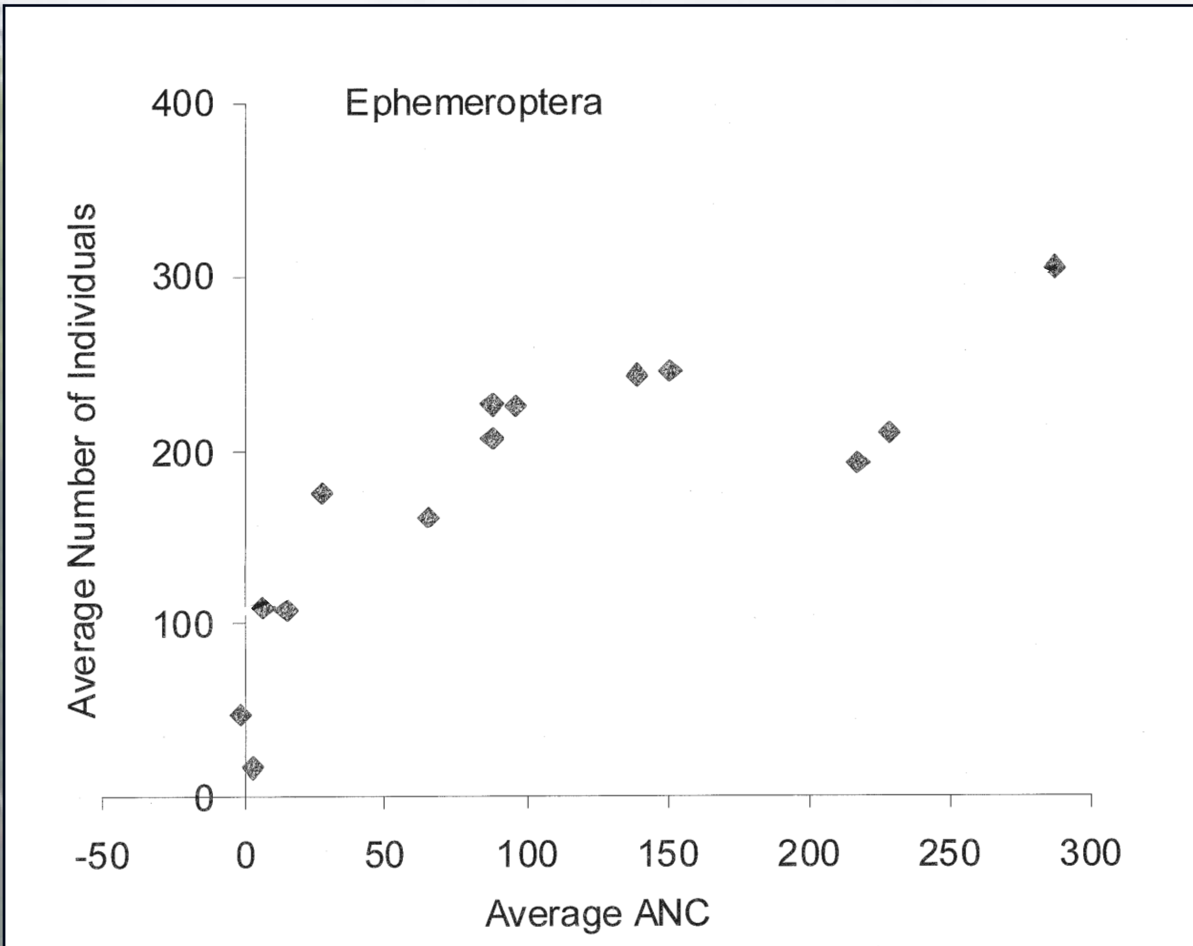

Lake ANC (ueq/L)
75
50
25
0
-25
-50
1900
1950
2000
2050
2100
Year


Soil Base Saturation
20
15
10
5
0
1900
1950
2000
2050
2100
Year


Number Fish Species
14
12
10
8
6
4
2
0
-2
-4
-200
-100
0
100
200
300
400
500
ANC (ueq/L)

Total Zooplankton Richness versus Lakewater ANC




Ephemeroptera
Average Number of Individuals
400
300
200
100
0
-50
0
50
100
150
200
250
300
Average ANC