

Factors Controlling the Critical Loads and Target Loads of SO_4^{2-} , NO_3^- and NH_4^+ in Watersheds of the Great Smoky Mountains National Park

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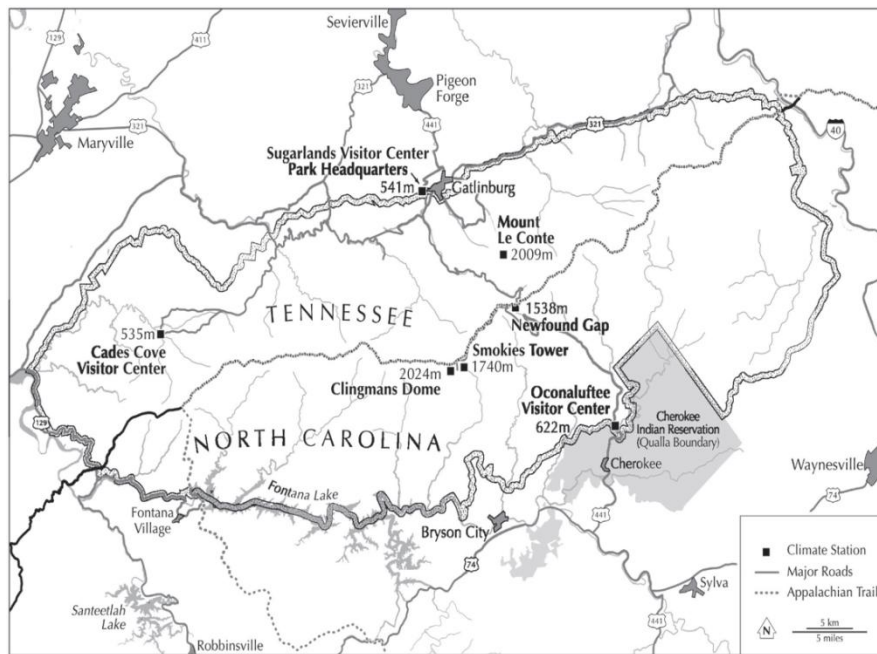


Outline

- Background
- Objectives
- Approach
- Results
 - Examples of model simulations for GRSM watersheds
 - Analysis of historical acidification and recovery
 - Comparison between GRSM and the Adirondacks
 - Park-wide extrapolation
- Conclusions

Great Smoky Mountains National (GRSM) Park

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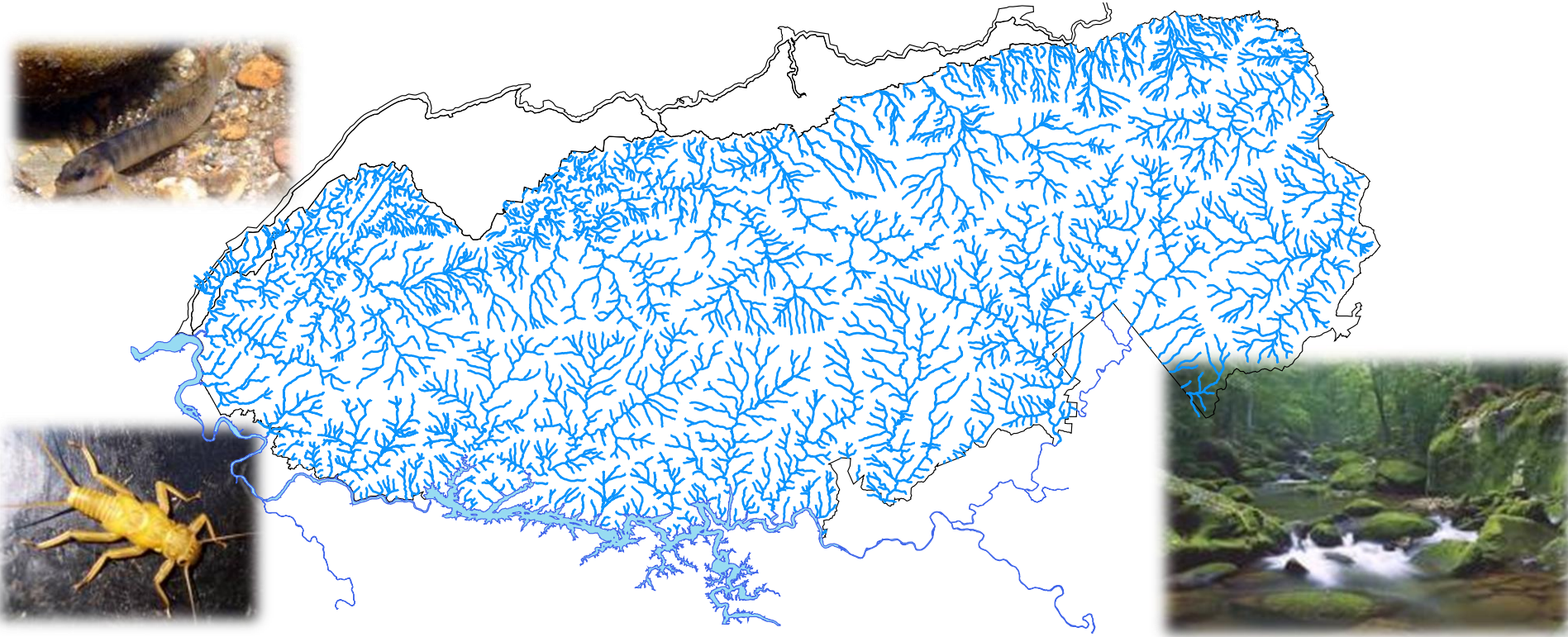
GRSM Water Resources

Streams: 3,404.4 km of streams (~2,115.5 miles) ranging from 1st – 6th order

Wetlands: Hundreds of riverine, pond, forest/shrub and emergent wetlands that are each ecologically significant and typically host rare communities and species (USFWS)

Fish: Over 60 species in 12 different families – includes 3 Federal T&E species

Aquatic Invertebrates: Over 900 species with 14 species new to science

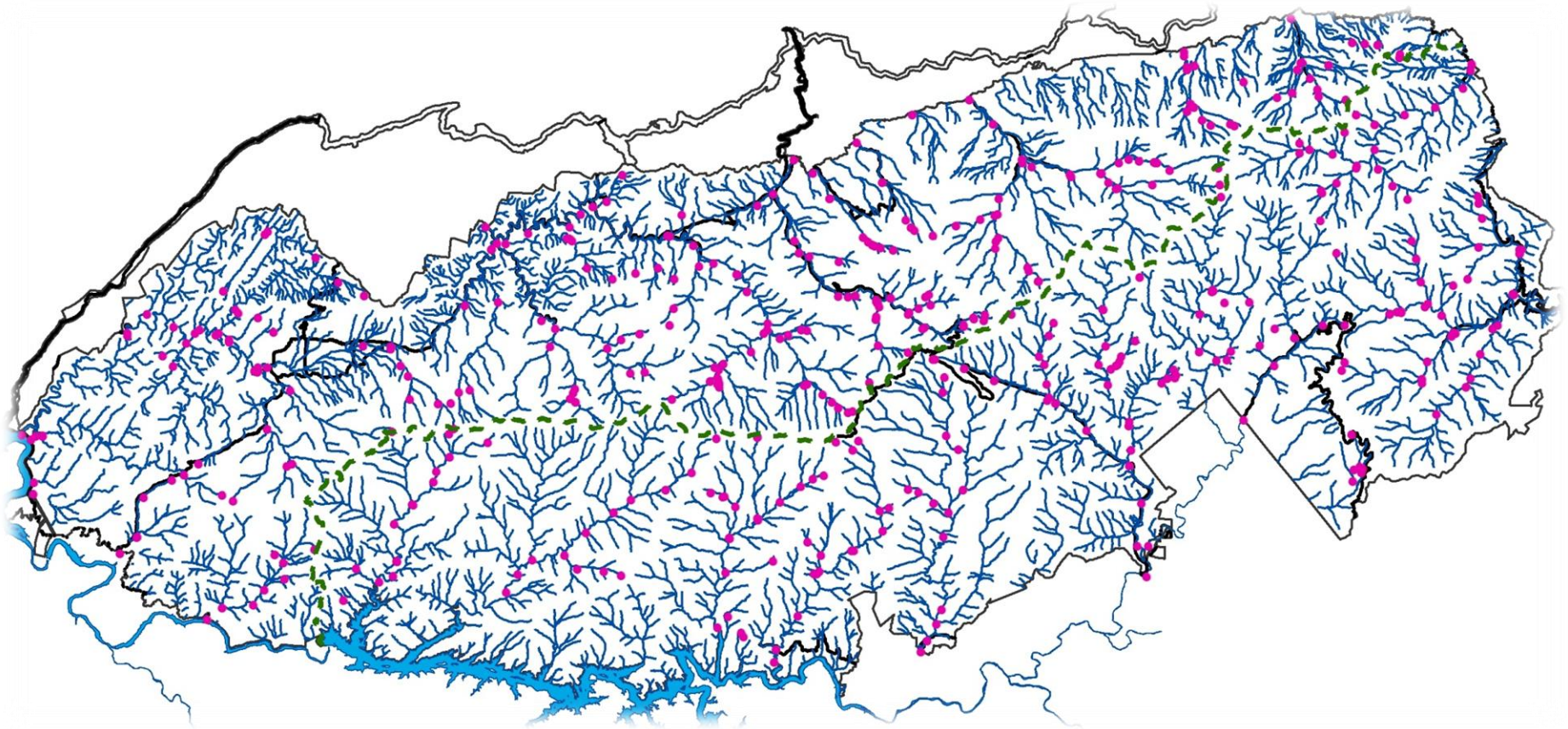


GRSM Parkwide Water Quality Sampling Design

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1993 Water Quality Monitoring Plan

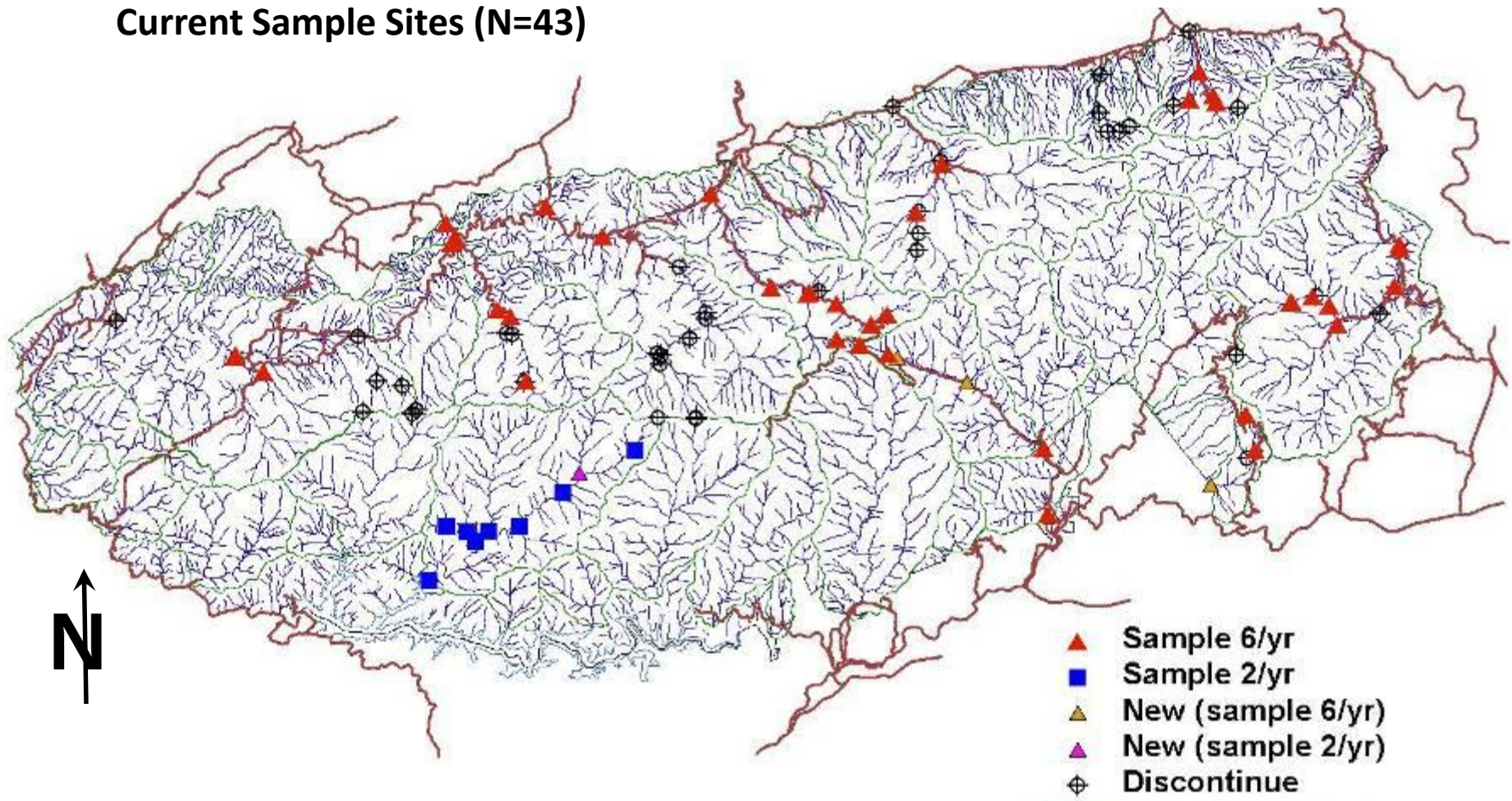
Original Sample Sites (N=367)



GRSM Parkwide Water Quality Sampling Design

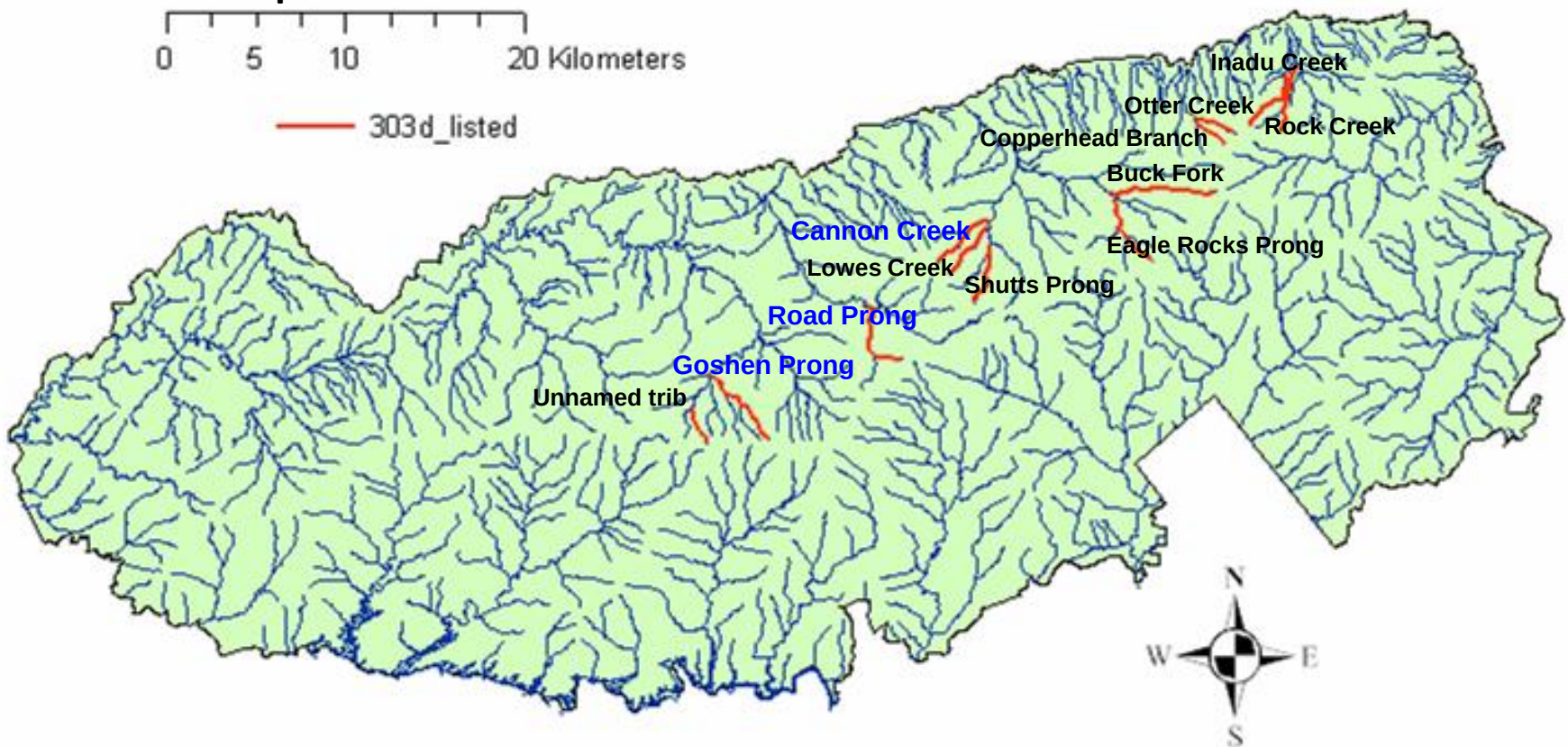
Reduced to 32 sites bi-monthly in 8 watersheds and 11 sites bi-annually in one watershed (Hazel Creek) (Odom 2003).

Current Sample Sites (N=43)



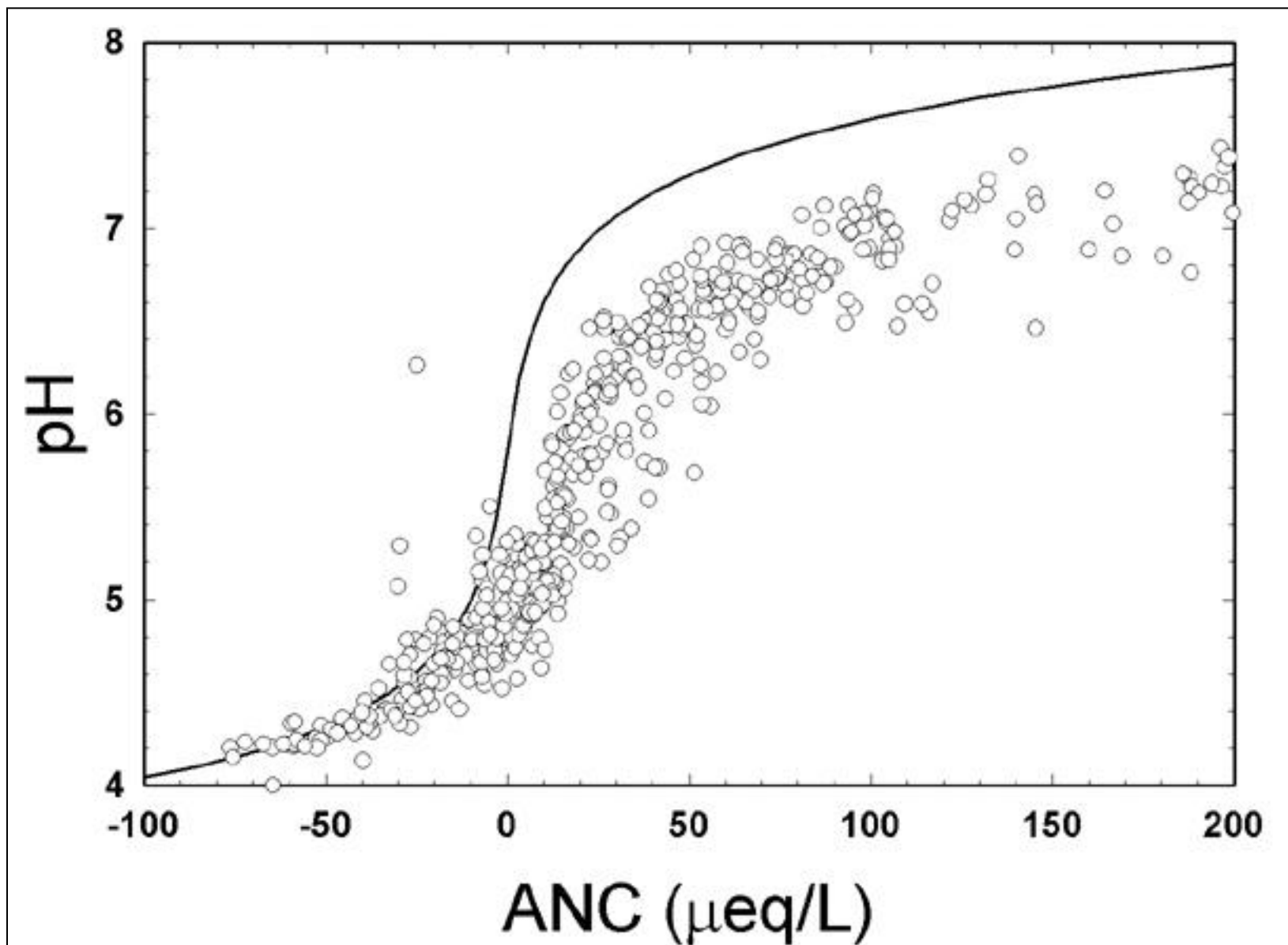
Stream Chemistry Results and Trends 303d Listing

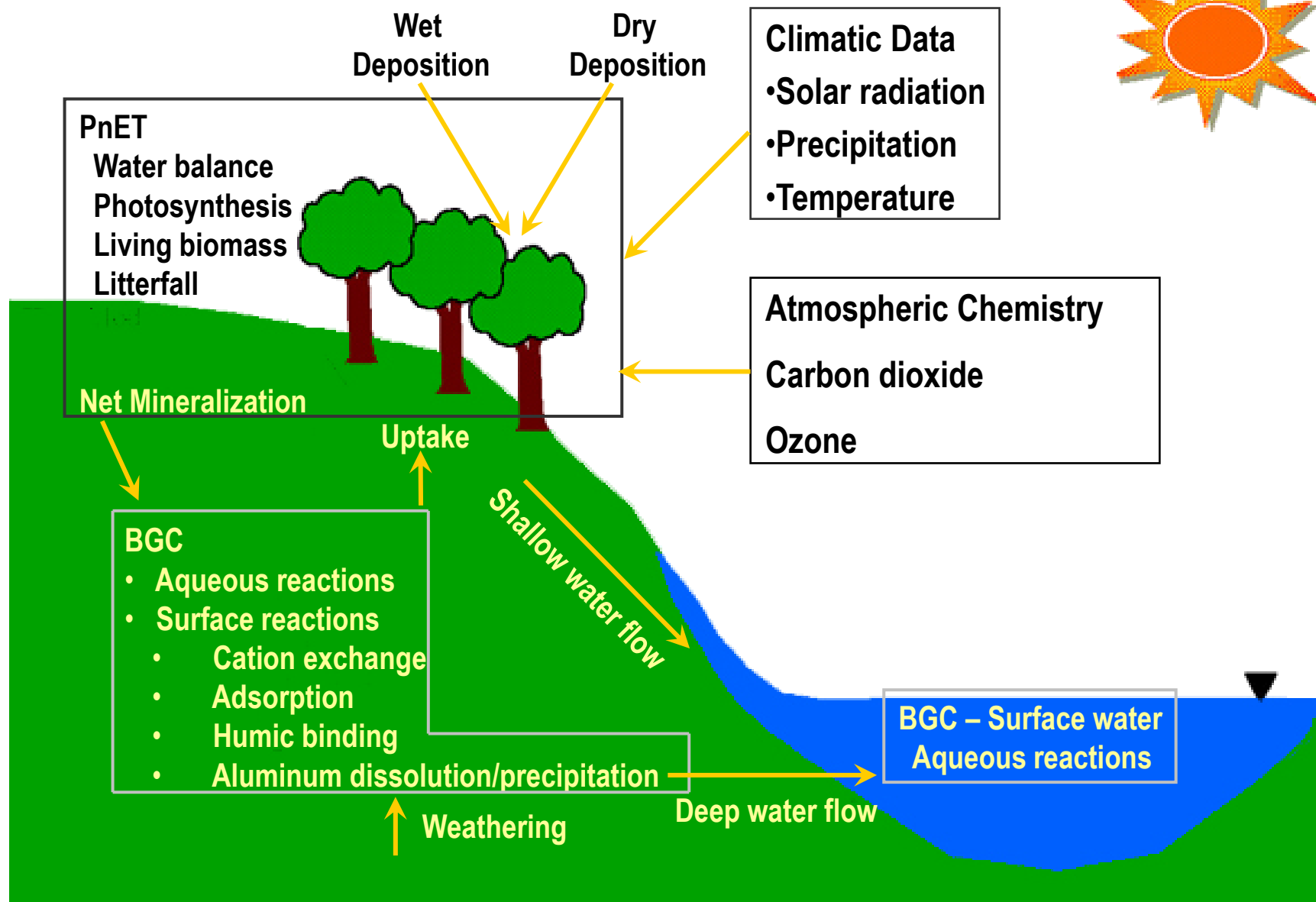
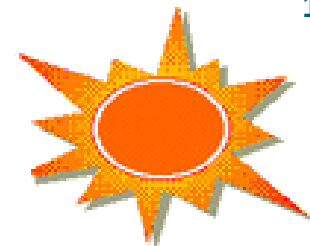
- In 2006, 12 streams representing 42 miles (67km) were listed on the Tennessee 303d list due to low stream pH (<6.0)
- Identified & listed only streams outside of Anakeesta influence
- 3 impaired streams modeled



Objectives

- To assess the response of streams and soils in the GRSM to past and potential future changes in the acidic deposition.
- To establish the Target Loads (TL) and Critical Loads(CL) for N and S deposition for watersheds of the GRSM.
- To explore the factors that control the critical loads in the GRSM.
- Inform the process to develop a Total Maximum Daily Load (TMDL) for acidity for the GRSM and elsewhere.





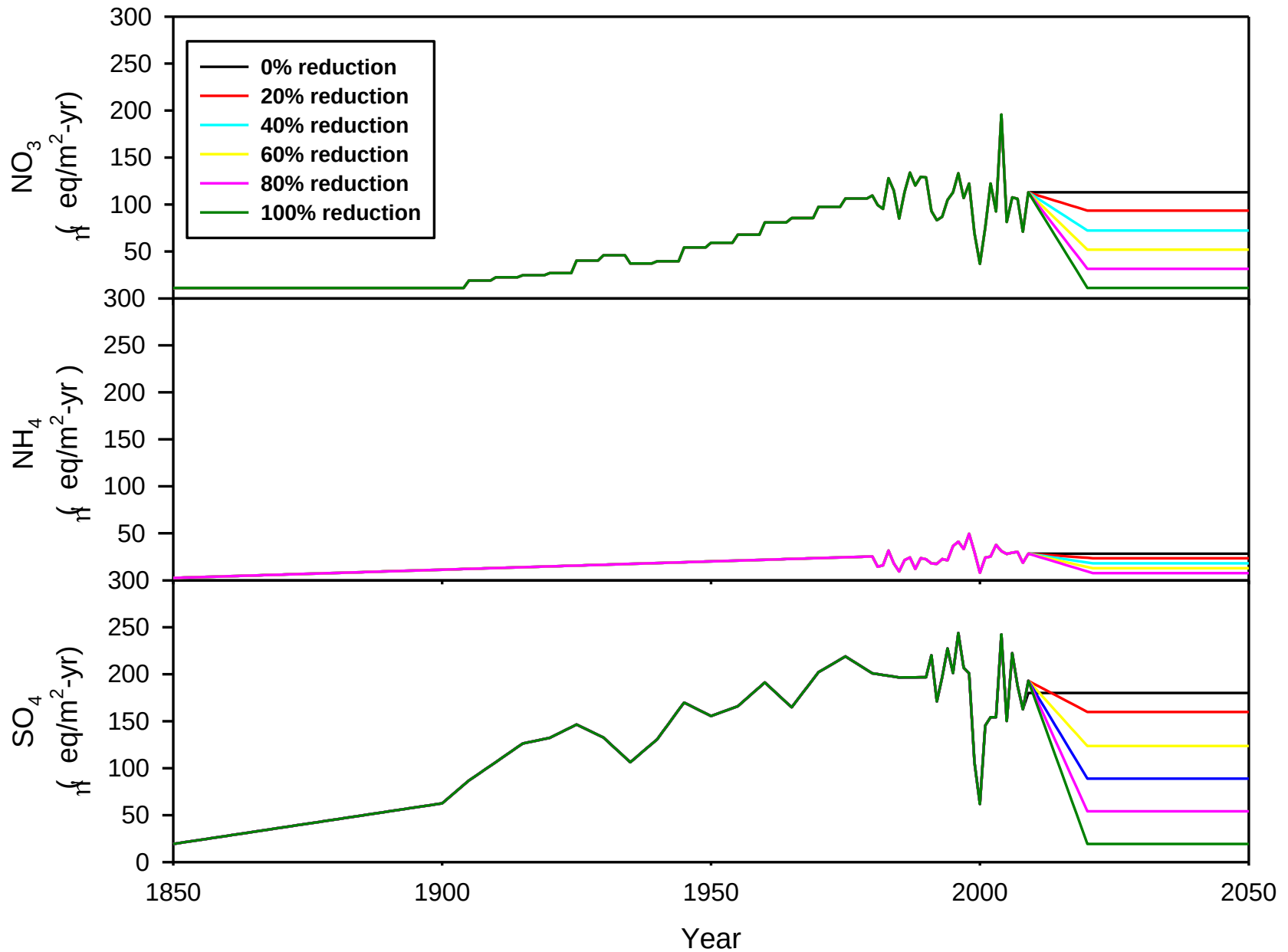
Data Sets Used to Apply PnET-BGC

Meteorological data	• Air temperature (max & min) (°C) • Precipitation (cm) • Solar radiation (mmol/m²-s)
Deposition data	• Wet deposition • CASTNet (Dry to wet ratio) • Throughfall (Dry to wet ratio)
Vegetation data	• Vegetation type • Disturbance history
Soils data	• Exchangeable cations • Adsorbed sulfate • Soil properties (soil, mass, WHC, CEC)

PnET-BGC Model Outputs

Surface water	• Discharge • chemistry (SO_4^{2-}, NO_3^-, NH_4^+, DOC, Ca, Al...) • Solute fluxes
Soil	• Concentrations (SOC, N, Ca, Al...) • Soil pools • Soil transfers (cation exchange, anion adsorption, mineralization, nitrification, plant uptake...)
Vegetation	• Biomass (foliage, wood, roots, NPP, NEP) • Vegetation pools (C, N, Ca...) • Vegetation transfers (litter fall, nutrient uptake, foliar leaching...)

Different scenarios for Noland Divide Watershed



Approach: The Criterion of Choosing Different Sites in GRSM

Study sites in block units

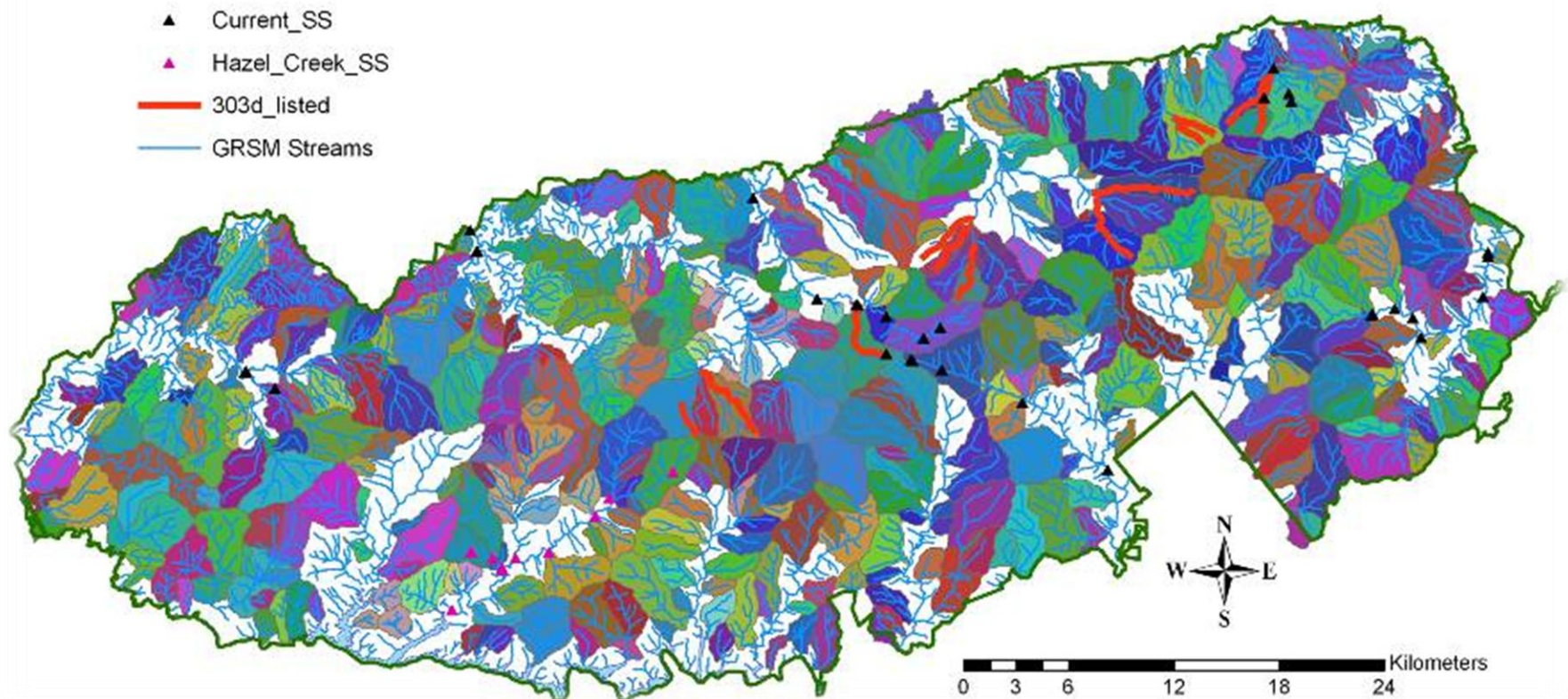
Block	Basin Area km ² (ac)	Elevation m (ft)	Anakeesta
1	<10 (<2471)	<1000 (3281)	>10%
2	<10 (<2471)	>1000 (3281)	>10%
3	<10 (<2471)	<1000 (3281)	None
4	<10 (<2471)	>1000 (3281)	None
5	10-20 (2471-4942)	<1000 (3281)	>10%
6	10-20 (2471-4942)	>1000 (3281)	>10%
7	10 -20 (2471-4942)	<1000 (3281)	None
8	10 -20 (2471-4942)	>1000 (3281)	None

Watershed Block Design for Monitoring

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- Stratified GRSM watersheds into block design based upon: watershed size ($<10 \text{ km}^2$ or $10\text{-}20 \text{ km}^2$), elevation ($>$ or $< 1,000\text{m}$) and percent Anakeesta (0% or $>10\%$)
- Block design captured nearly 80% of watersheds (remainder <1 or $>20\text{km}^2$)

GRSM Block Watersheds



Biophysical and Chemical Characteristics¹⁶ of Different Watersheds

	Elevation m (ft)	Watershed areas km ² (ac)	Disturbance	Vegetation	NO ₃ ⁻ (μeq/L)	ANC (μeq/L)
Noland Divide	1798 (5899)	0.174 (43)	Balsam Woolly Adelgid	SF	44.3	4.3
Indian Camp Creek	1205 (3953)	6.31 (1559)	Land disturbance	HD	42.1	16.9
Walker Camp	1168 (3832)	4.24 (1048)	None	HD	38	-13.3
Goshen Prong	1046 (3432)	7.29 (1801)	Logging	HD	21.2	19.3
Lost Bottom	1000 (3281)	5.15 (1273)	Land disturbance	HD	7.7	59.2
Left Prong Anthony	909 (2982)	1.61 (398)	None	SF	23.4	35.4
Pretty Hollow	903 (2963)	11.18 (2763)	Land disturbance	HD	16.6	46.1
Cosby Creek	783 (2569)	5.78 (1428)	Land disturbance	HD	38.2	36.8
Sugar Fork	780 (2559)	2.14 (529)	Land disturbance	HD	3.7	86.3
Cannon Creek	751 (2464)	4.19 (1035)	Land disturbance	HD	20.6	17.1
Thunderhead	664 (2178)	11.26 (2782)	Fire	HD	14.4	33.2
Mill Creek	545 (1788)	10.92 (2698)	Land disturbance	HD	56.1	17

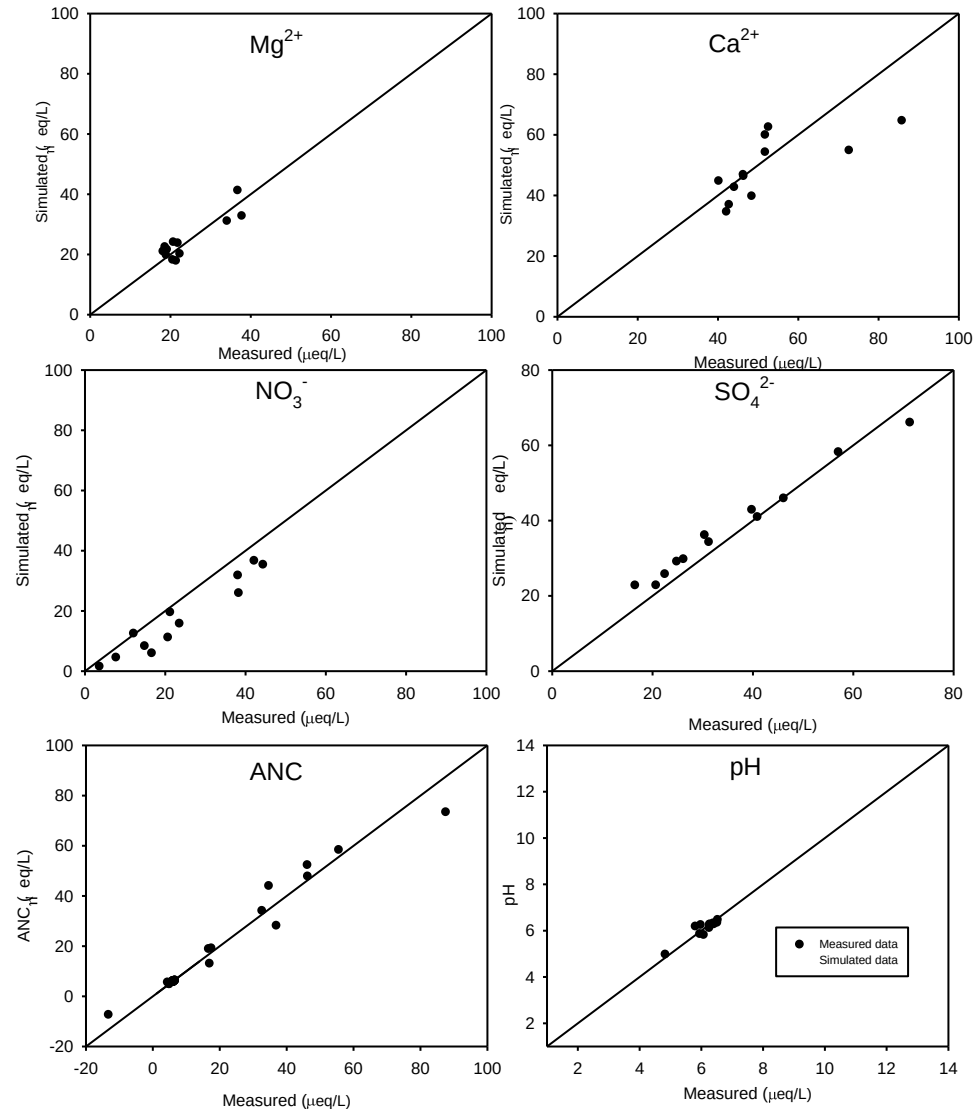
Site	Elevation (m)	Area (km ²)	Vegetation	%Anakeesta	Length of record	ANC (µeq/L)	Impaired
Noland Divide	1798	0.174	SF	No	1991-2008	24.8	
Indian Camp Creek	1205	2.17	HD	No	1993-2003	17.82	303d
Walker Camp	1168	10.73	HD	81.89%	1994-2009	-13.85	
Goshen Prong	1046	7.29	HD	26.83%	1993-2003	20.78	303d
Lost Bottom	1000	5.15	HD	No	1994-2009	50.34	
Left Prong Anthony	909	1.61	SF	No	1994-2003	34.85	
Pretty Hollow	903	11.18	HD	No	1993-2003	47.03	
Cosby Creek	783	5.78	HD	No	1993-2009	37.33	
Sugar Fork	780	2.14	HD	No	1996-2009	90.32	
Cannon Creek	751	4.19	HD	0.64%	1994-2003	16.25	303d
Thunderhead	664	11.26	HD	34.73%	1994-2003	33.22	
Mill Creek	545	10.92	HD	No	1996-2009	46.08	

Testing and Evaluation of Model Performance

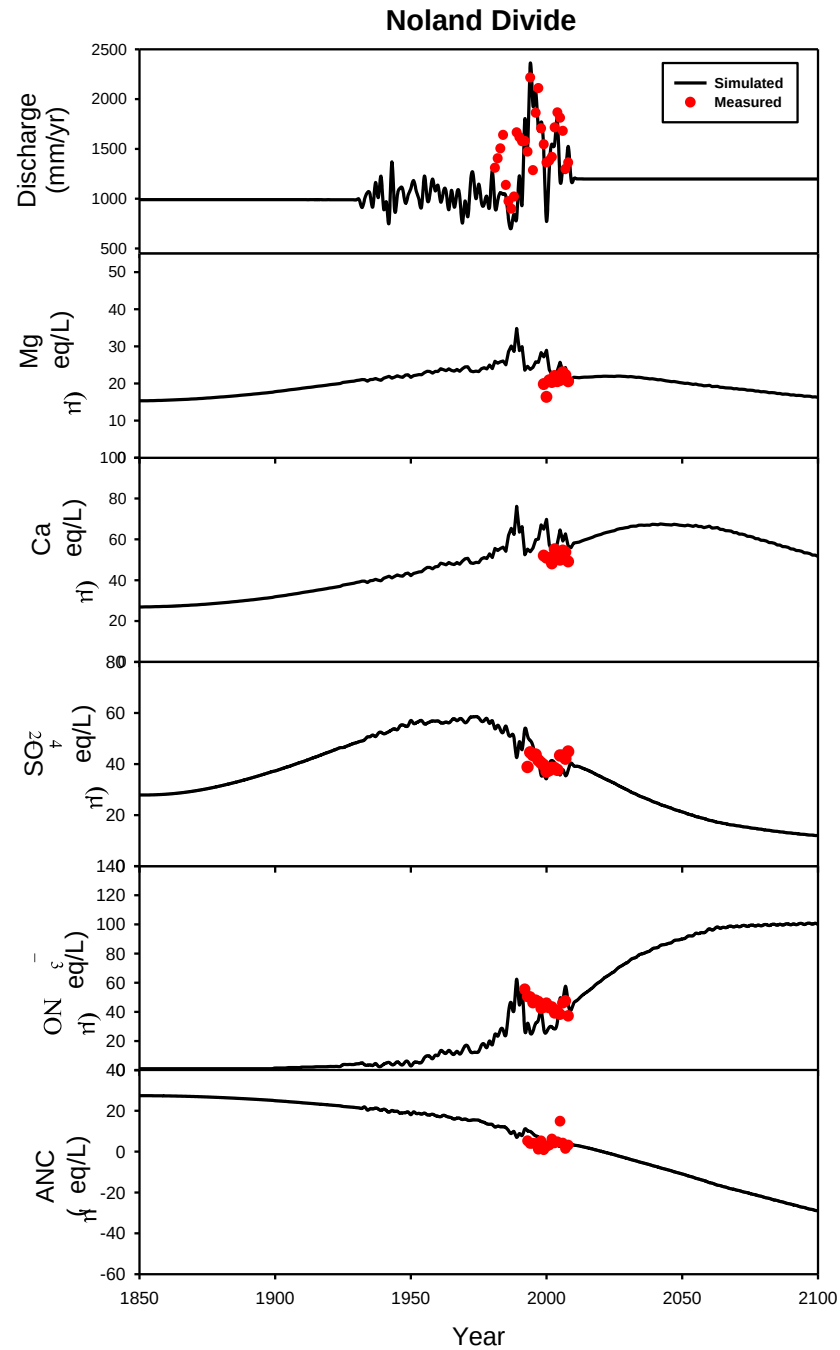
Comparison with measured values	• Discharge • Stream chemistry • Soil chemistry • Ecosystem biogeochemical measurements
Performance statistical metrics	• Normalized Mean Error (NME) • Normalized Mean Absolute Error (NMAE)
Sensitivity/uncertainty analysis	
Comparison with other models	• Comparison with MAGIC

Results: Model Performance

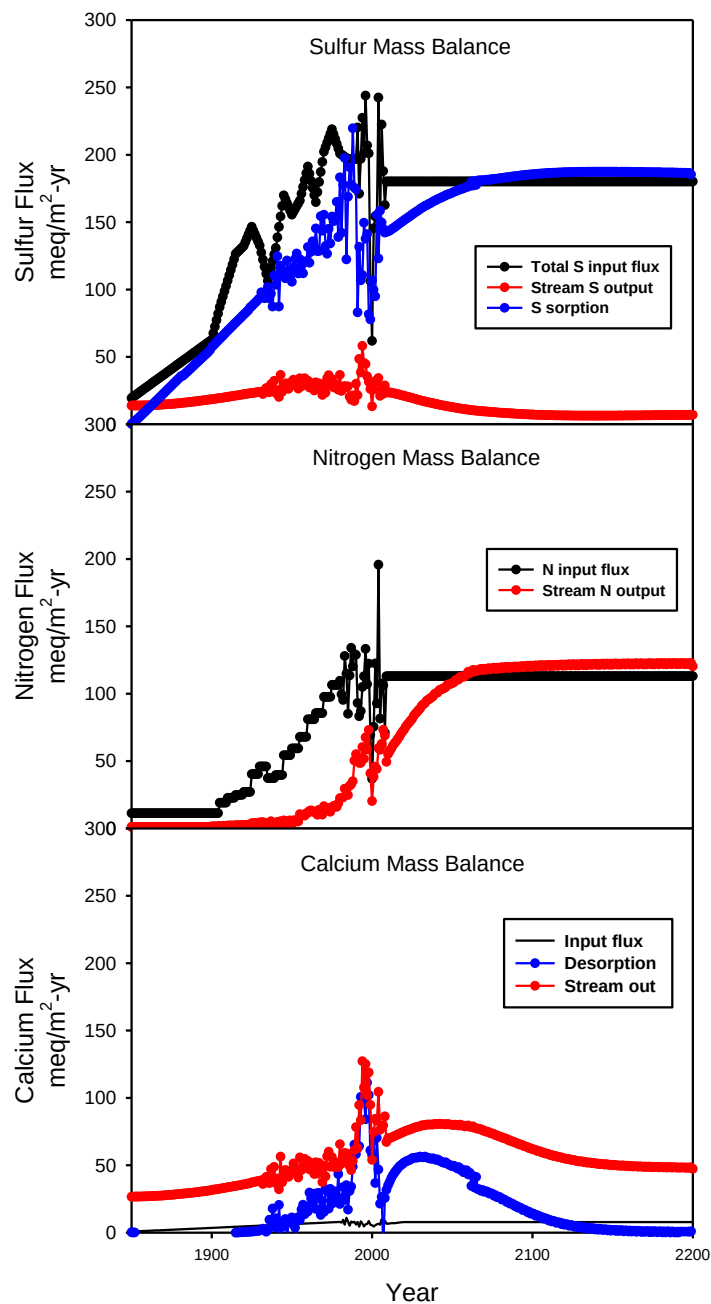
- No significant differences between measured to simulated (modeled) results



Results



Noland Divide Watershed



Model Predicted Element Fluxes (1993-2008)

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	NH ₄ -N (kg/ha-yr)	NO ₃ -N (kg/ha-yr)	SO ₄ -S (kg/ha-yr)	Ca (kg/ha-yr)
Deposition	4.08	14.3	29.1	1.31
Weathering	0	0	1.2	5.4
Mineralization	33.3	0	13.1	34.0
Nitrification	-23.6	23.6	0	0
Plant Uptake	-12.8	-31.8	-13.5	-48.8
Sorption		0	-19.8	12.5
Drainage losses	0	-7.6	-10.3	-18.5

Note: Positive=Input; Negative=Output

Comparison of Modeled and Measured Fluxes

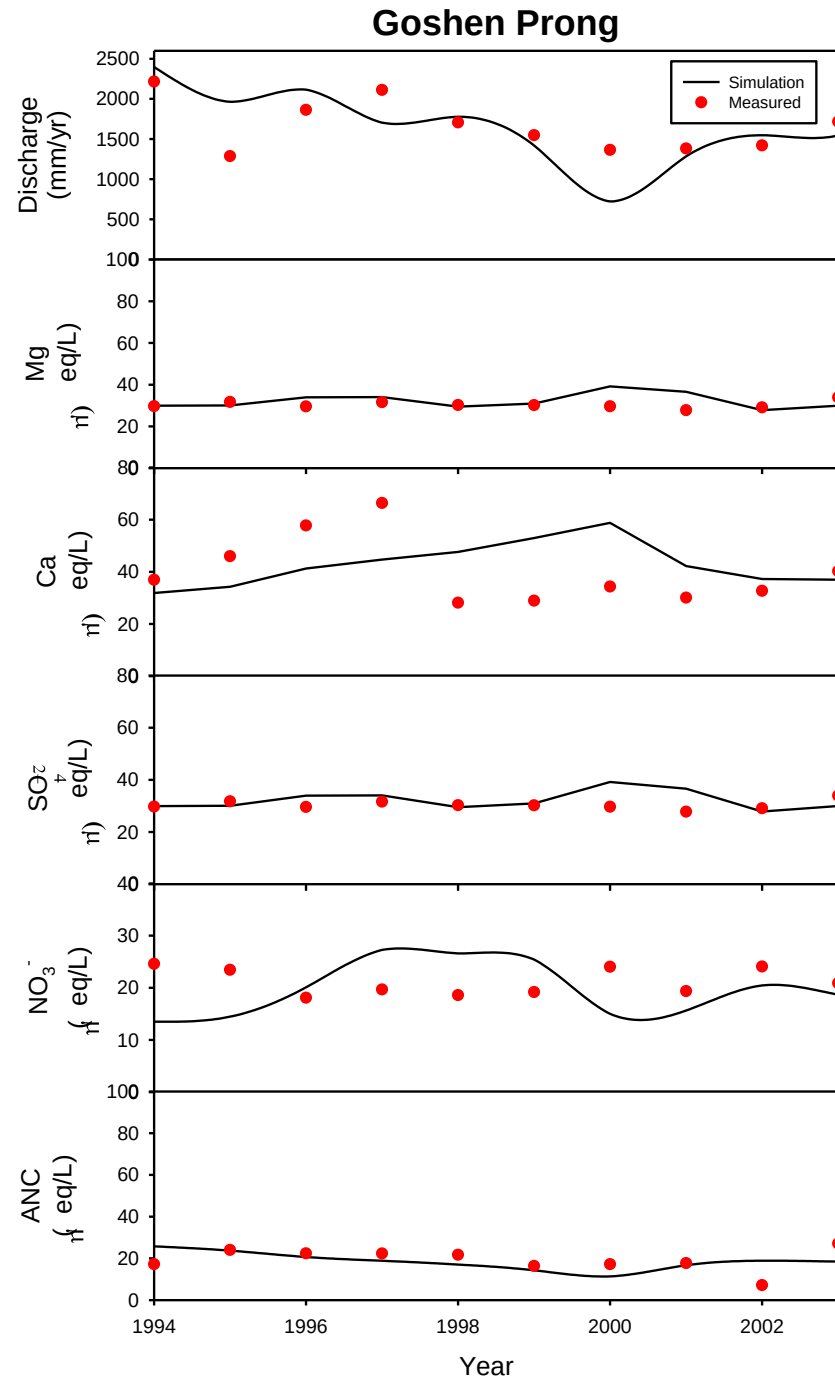
23

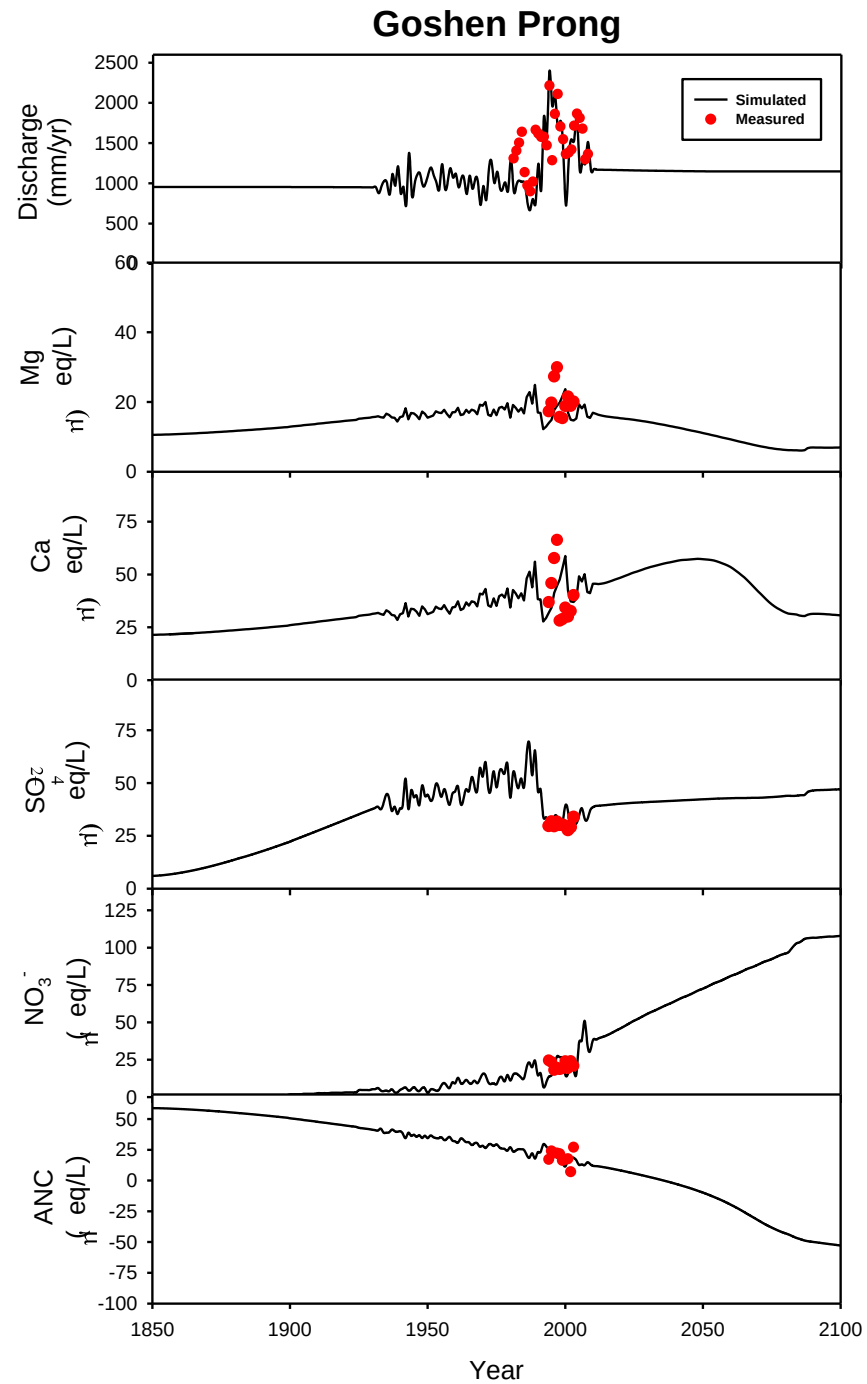
	NH ₄ -N (kg/ha-yr)			NO ₃ -N (kg/ha-yr)		
	IFS	UTM	Model	IFS	UTM	Model
Throughfall Deposition	0.28	4.2	4.08	16.8	12.5	14.3
Weathering			0	0		0
Mineralization			33.3			0
Nitrification			-23.6			23.6
Plant Uptake			-12.8	-26.4		-31.8
Sorption						0
Drainage losses		0.3	0		-9.92	-7.6

Comparison of Modeled and Measured Fluxes

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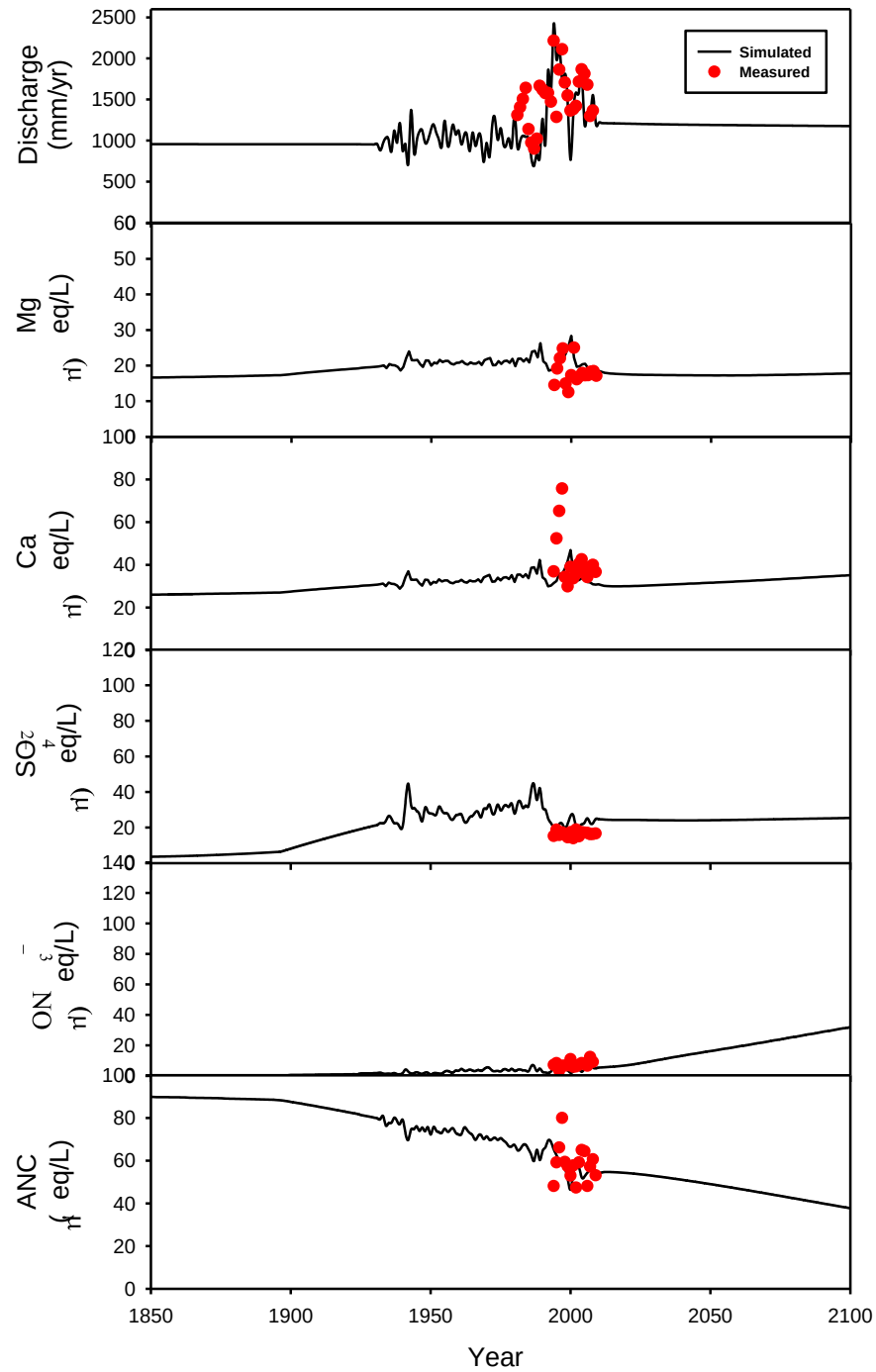
	SO ₄ -S (kg/ha-yr)			Ca kg/ha-yr)		
	IFS	UTM	Model	IFS	UTM	Model
Throughfall Deposition	40	32	29.1	18.76	18.0	17.6
Weathering			1.2	5.4		5.4
Mineralization			13.1			34.0
Nitrification			0			0
Plant Uptake	-3.5		-13.5	-8.65		-48.8
Sorption			-19.8			12.5
Drainage losses		-10.24	-10.3		-16.54	-18.5



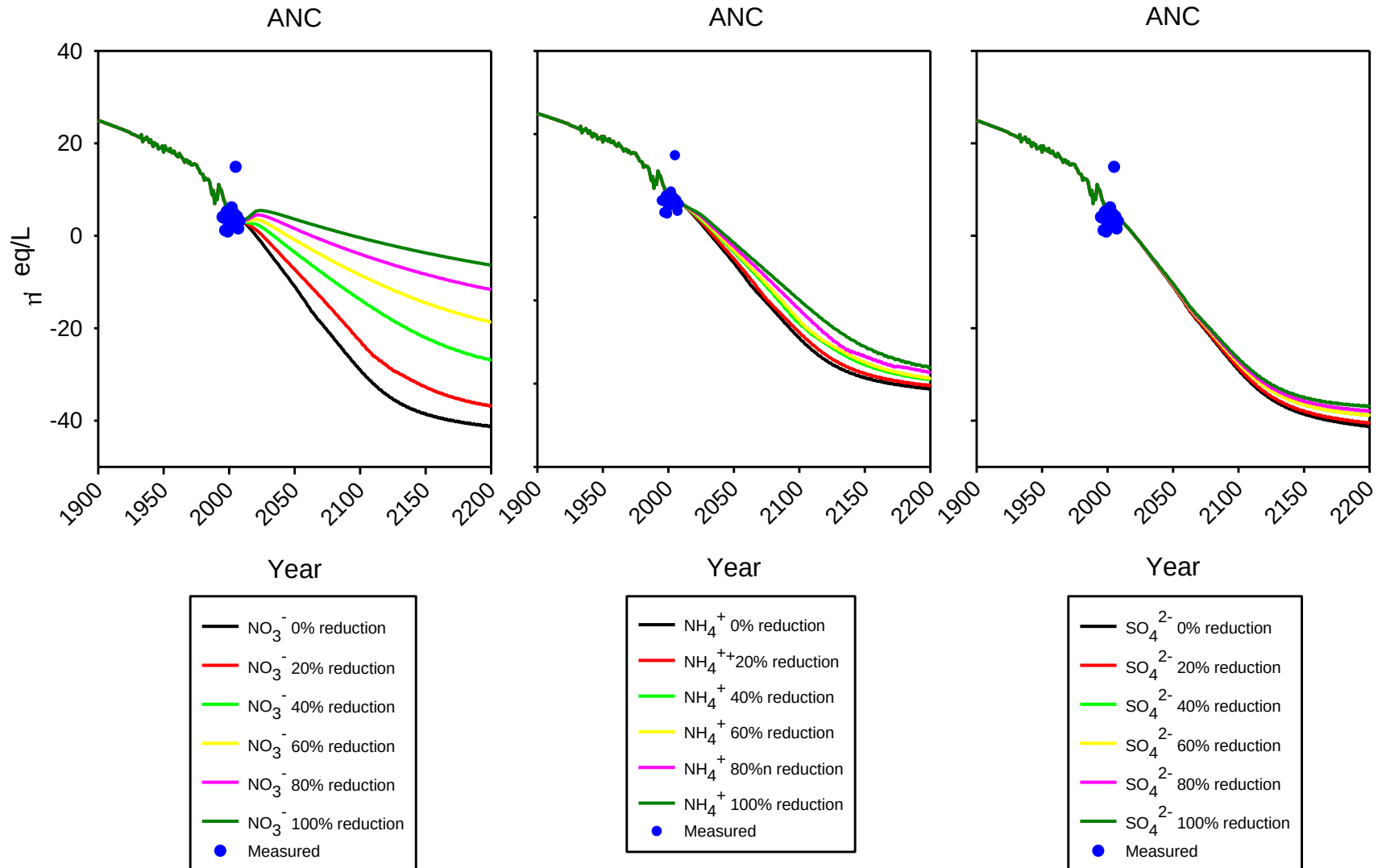


Lost Bottom

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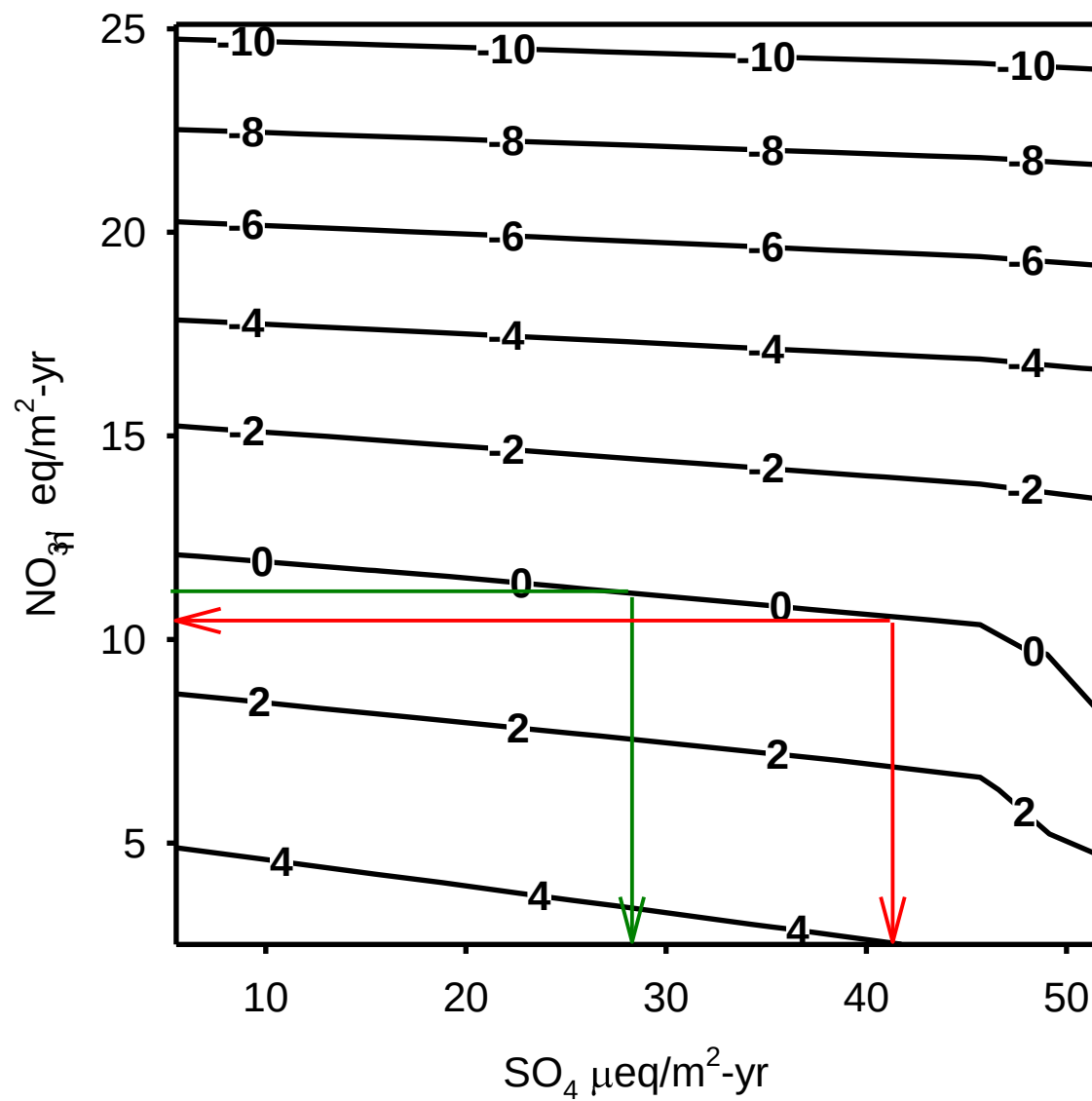


Result: Predictions of future response of stream ANC to different scenarios of nitrate, ammonium and sulfate deposition in Noland Divide Watershed



Target Load for Noland Divide(2050)

ANC Intervals ($\mu\text{eq/L}$)

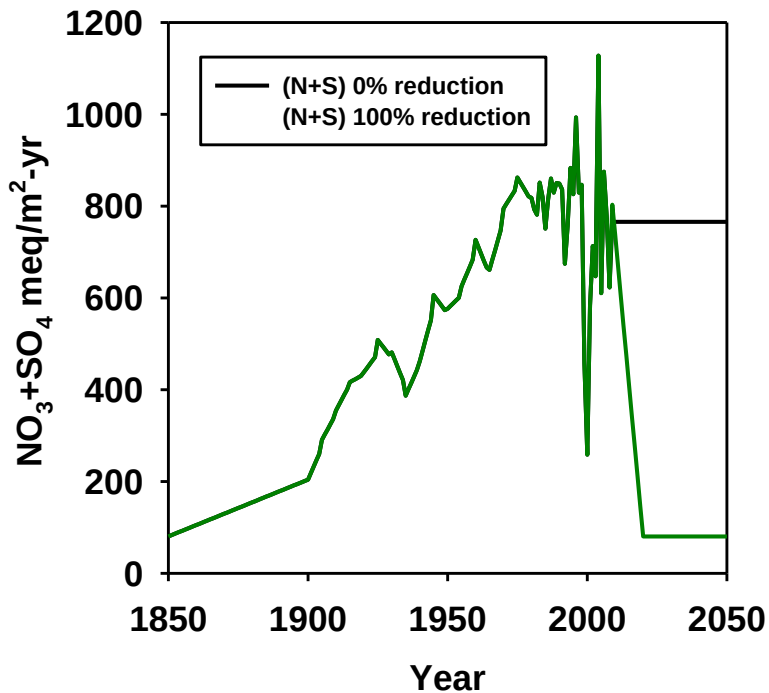


Differential ANC Response to Sulfate vs. Nitrate Deposition

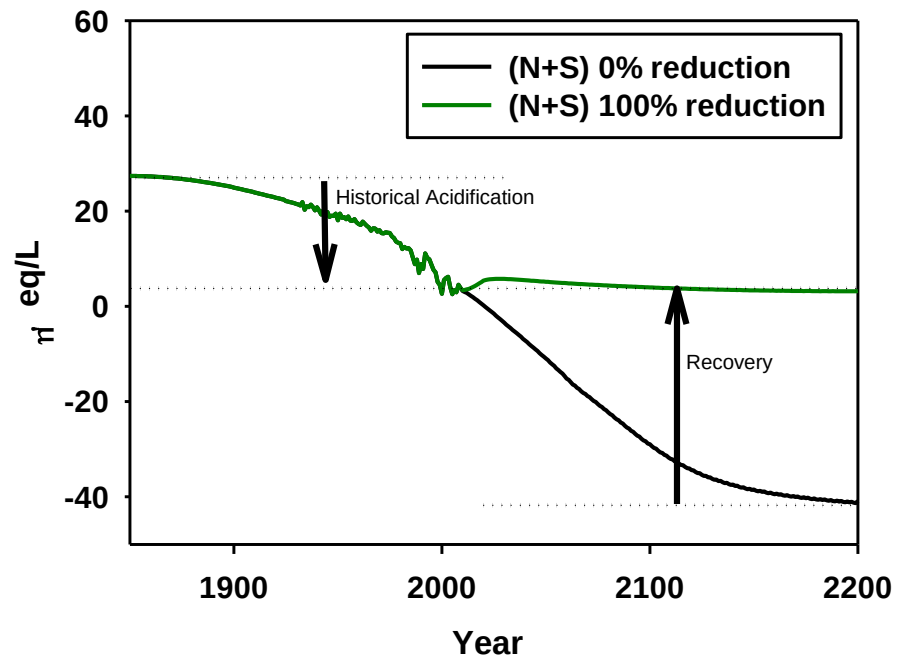
	$\frac{\Delta ANC(eq)}{\Delta SO_4^{2-}(eq)}$	$\frac{\Delta ANC(eq)}{\Delta NO_3^-(eq)}$
DCL₂₀₅₀	0.00058	0.22
CL₂₂₀₀	0.0041	0.52

Results

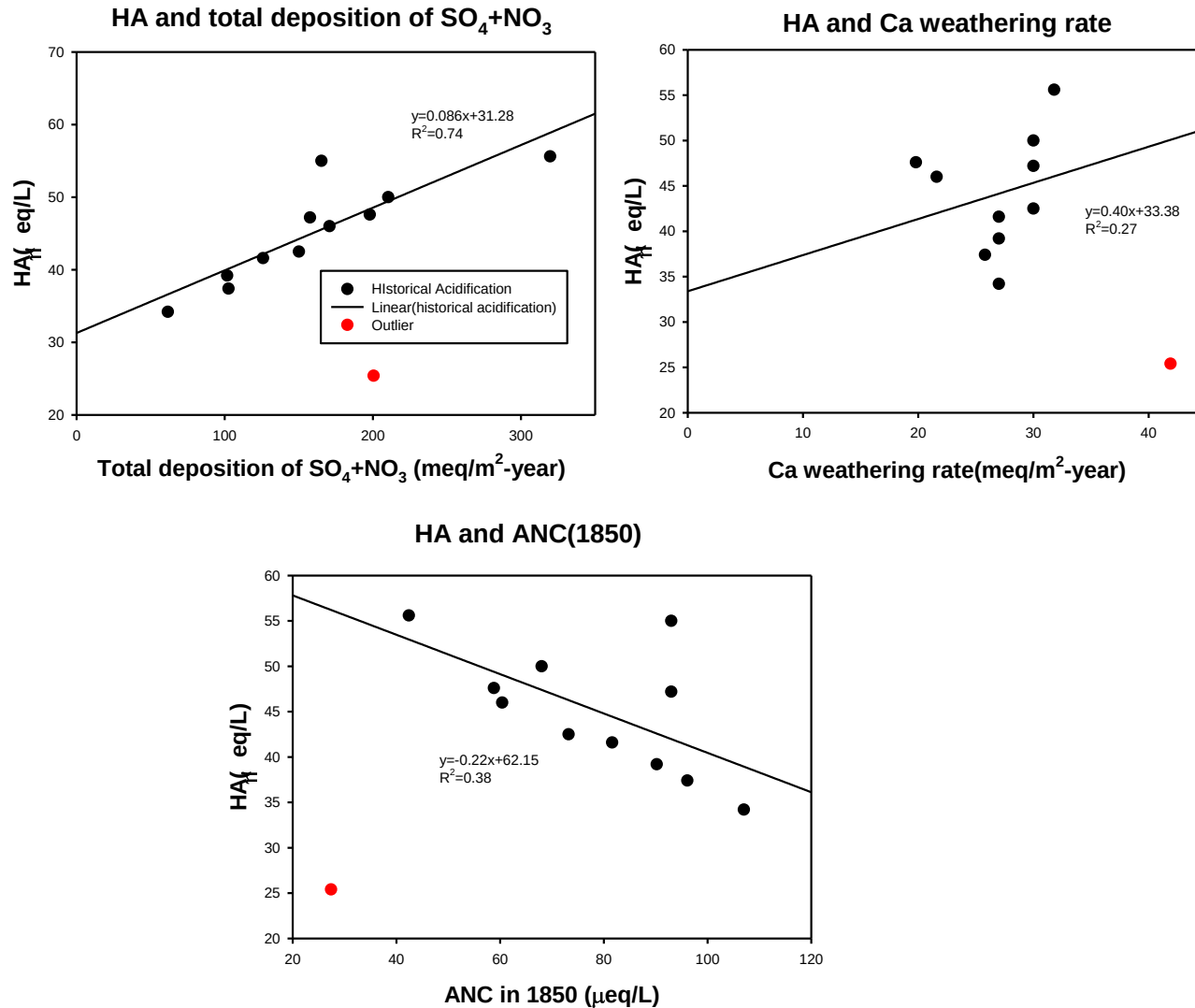
Total $\text{SO}_4 + \text{NO}_3$ deposition for NDW



ANC

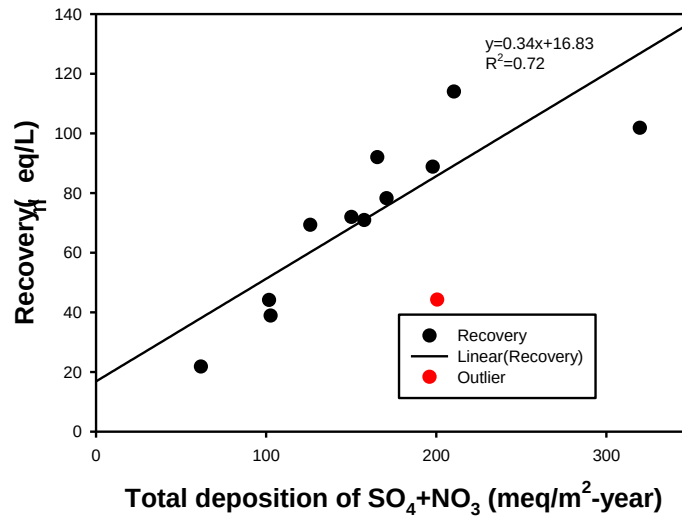


Historical Acidification

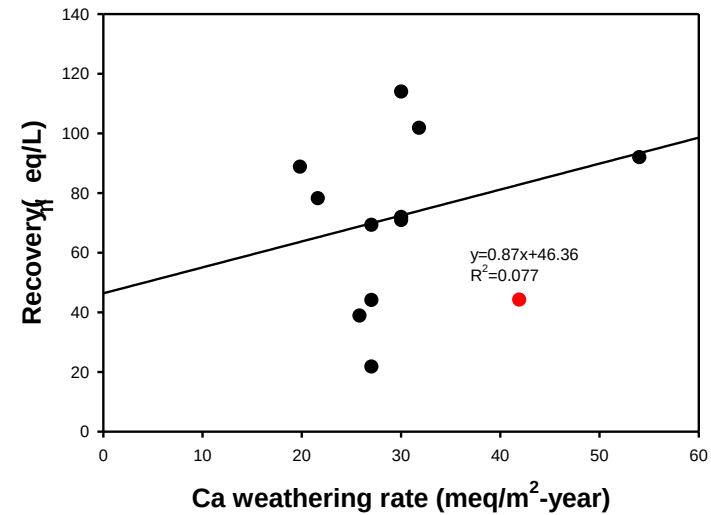


Recovery

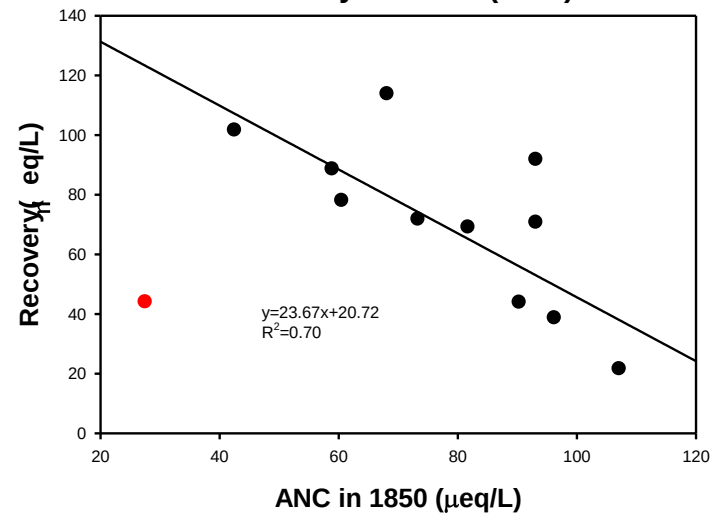
Recovery with the $\text{SO}_4 + \text{NO}_3$ 2010



Recovery with Ca weathering rate



Recovery and ANC(1850)



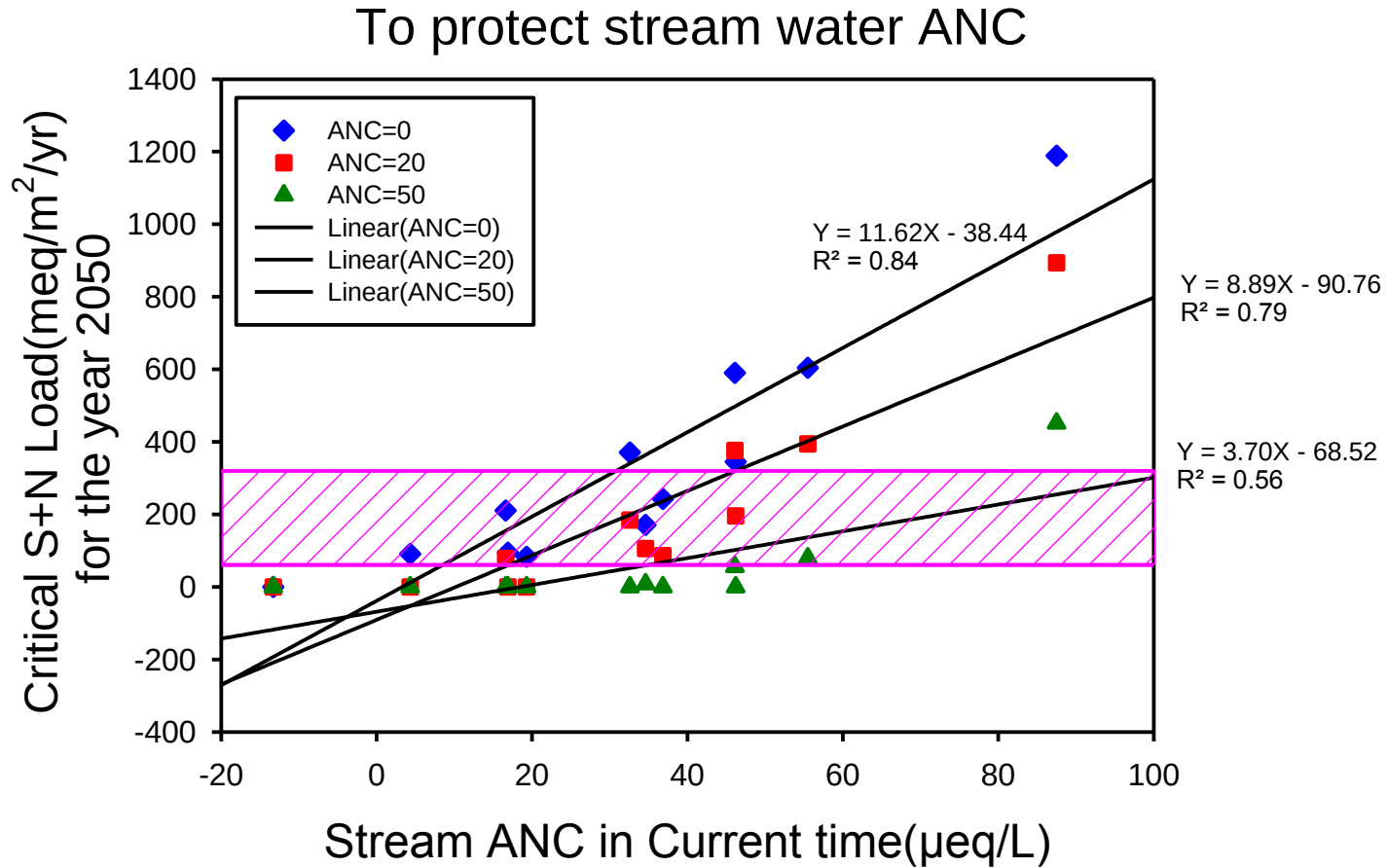
How Does the Recovery of GRSM Compare with Adirondack Watersheds?

Recovery Regions	Target load (2050)		Critical Load (2200)	
	$\frac{\Delta ANC (\mu eq L^{-1})}{\Delta SO_4^{2-} (meq m^{-2} yr^{-1})}$	$\frac{\Delta ANC (\mu eq L^{-1})}{\Delta NO_3^- (meq m^{-2} yr^{-1})}$	$\frac{\Delta ANC (\mu eq L^{-1})}{\Delta SO_4^{2-} (meq m^{-2} yr^{-1})}$	$\frac{\Delta ANC (\mu eq L^{-1})}{\Delta NO_3^- (meq m^{-2} yr^{-1})}$
Adirondack	0.6 (± 0.2)	-0.2 (± 0.1)	1.2 (± 0.4)	0.1 (± 0.18)
GRSM	0.3 (± 0.1)	0.7 (± 0.3)	0.6 (± 0.1)	1.9 (± 0.4)

Extrapolation of Future Deposition Projections Park-Wide

- Utilize empirical relationships from model results from 12 watershed study sites
- Utilize stream survey data for the GRSM

site	Current ANC ($\mu\text{eq/L}$)	ANC in 1850 ($\mu\text{eq/L}$)	Current Deposition ($\text{meq/m}^2\text{-yr}$)	Sulfate + Nitrate Deposition ($\text{meq/m}^2\text{-yr}$)	Sulfate + Nitrate Deposition ($\text{meq/m}^2\text{-yr}$)	Sulfate + Nitrate Deposition ($\text{meq/m}^2\text{-yr}$)
Target ANC				ANC=0 ($\mu\text{eq/L}$)	ANC = 20 ($\mu\text{eq/L}$)	ANC =50 ($\mu\text{eq/L}$)
Noland Divide	4.3	27.4	201	91	0	0
Goshen Prong	19.3	58.9	197	76	0	0
Cosby Creek	36.9	93.1	165	370	130	0
Lost Bottom Creek	59.2	89.8	103	600	390	80



Conclusions

- The stream ANC in the GRSM increases to a greater extent in response to decreases in NO_3^- deposition than to decreases in SO_4^{2-} or NH_4^+ .
- There is a relationship between historical acidification and potential watershed recovery with changes in NO_3^- plus SO_4^{2-} deposition and historical ANC (1850).

Conclusions

- Surface water ANC responds more to changes in NO_3^- deposition in the GRSM, but more to changes in SO_4^{2-} deposition in Adirondacks.
- A relationship exists between current ANC and the level of deposition needed to achieve a target ANC. This relationship could be utilized with stream survey data for the GRSM to develop a Park wide TMDL.

Future Activities

- Complete model testing for intensive study sites
- Model testing pH-ANC relationships
- Future scenario testing for TMDL sites
- Comparison of results with MAGIC results
- Extrapolation of model result to entire Park
- Project communication activities.

Questions?



