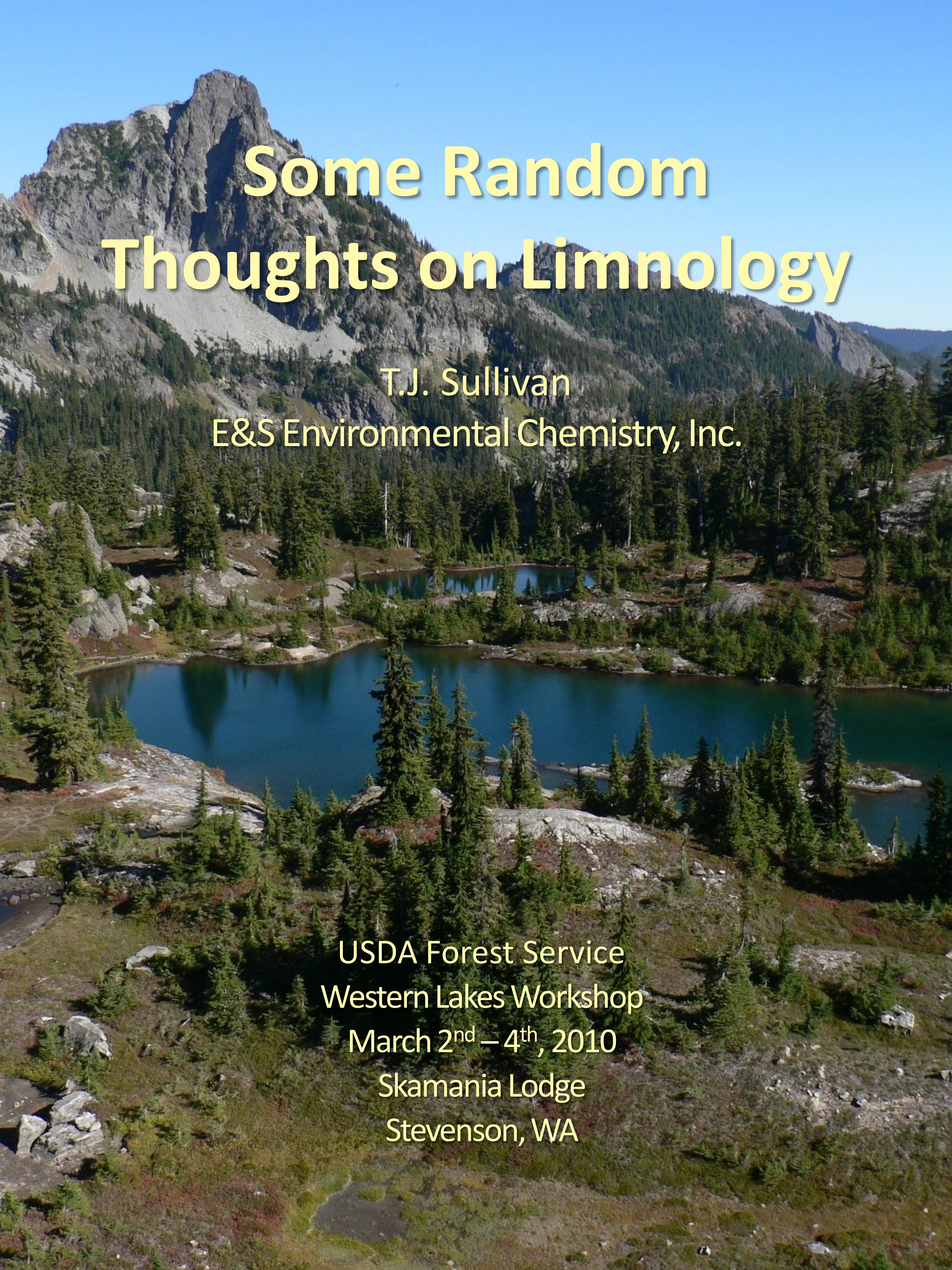

Some Random Thoughts on Limnology

T.J. Sullivan
E&S Environmental Chemistry, Inc.

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STUDY DESIGN

Major Issues to Consider

- Site selection
- When to sample
- What to bring into the field
- Logistics and mechanics of stream sampling
- Logistics and mechanics of lake sampling
- Will you measure discharge
- What to do after collecting the samples
- Proper documentation

What is the purpose of your sampling?

- Characterize the condition of a lake or stream.
- Survey the chemistry of water bodies across a forest or wilderness.
- Determine if water chemistry is changing over time.
- Quantify episodic changes in water chemistry.
- Determine whether, and to what extent, chemistry is affected by air pollution.
- Support modeling, management decisions, permitting, litigation.
- Other.

Common Management Issues for Forest Service Air Resources Program Staff, with Associated Field Study Approaches

Purpose

Determine whether one lake or stream, or a group of lakes or streams, is N-limited for algal growth

General Approach

Determine nutrient and chlorophyll *a* concentrations on multiple occasions during multiple years. Consider also nutrient (N, P) addition experiments.

Purpose

Quantify episodic excursions from base flow conditions

General Approach

Sample water and measure full ion chemistry during rainstorms, snowmelt

Purpose

Determine the distribution of lake or stream water chemistry across a forest

General Approach

Conduct a statistically based synoptic survey of lake or stream chemistry

Purpose

Quantify long-term changes in chemistry over time in a particular lake or stream

General Approach

Sample at least annually over a period of at least 8 years. Consider restricting sampling times to common hydroperiod

Purpose

Determine to what extent air pollution is currently affecting the water resources in a particular forest or wilderness

General Approach

Multiple approaches can contribute to this evaluation, as follows:

1. Characterize index chemistry for multiple waters expected to be highly sensitive
2. Conduct synoptic survey (preferably random) of waters
3. Use a dynamic watershed model to hindcast past changes in chemistry
4. Paleolimnology
5. Use a steady state or dynamic watershed model to quantify the critical load

A Well-Conceived Plan for Water Quality Sampling Should be:

- relevant to the intended beneficial uses
- specific with respect to sampling locations, depths, parameters, schedule, methods
- consistent with approved methods
- specific with respect to recommendations for data analysis, reporting, and flagging;
- designed to maintain continuity with past sampling efforts.

Examples of Questions That Could be Used to Guide Inventory, Characterization, and Monitoring Study Design

Inventory

- What is the distribution of lakewater ANC across high-elevation lakes in XYZ Wilderness Area?
- What is the annual average (or index) water chemistry of the most acid-sensitive streams in XYZ National Forest?
- What are the concentrations of stream water NO_3^- during snowmelt at selected long-term monitoring (LTM) locations in XYZ National Forest, and how do they compare with summer or fall index NO_3^- concentration in these streams?

Characterization

- What is the extent of episodic chemical change during the peak of snowmelt at selected stream sites?
- What landscape characteristics (i.e., lithology, soil type, elevation, ecoregion, stream order, etc.) are associated with the occurrence of streams having spring base flow ANC below 50 μeq/L within the XYZ National Forest?

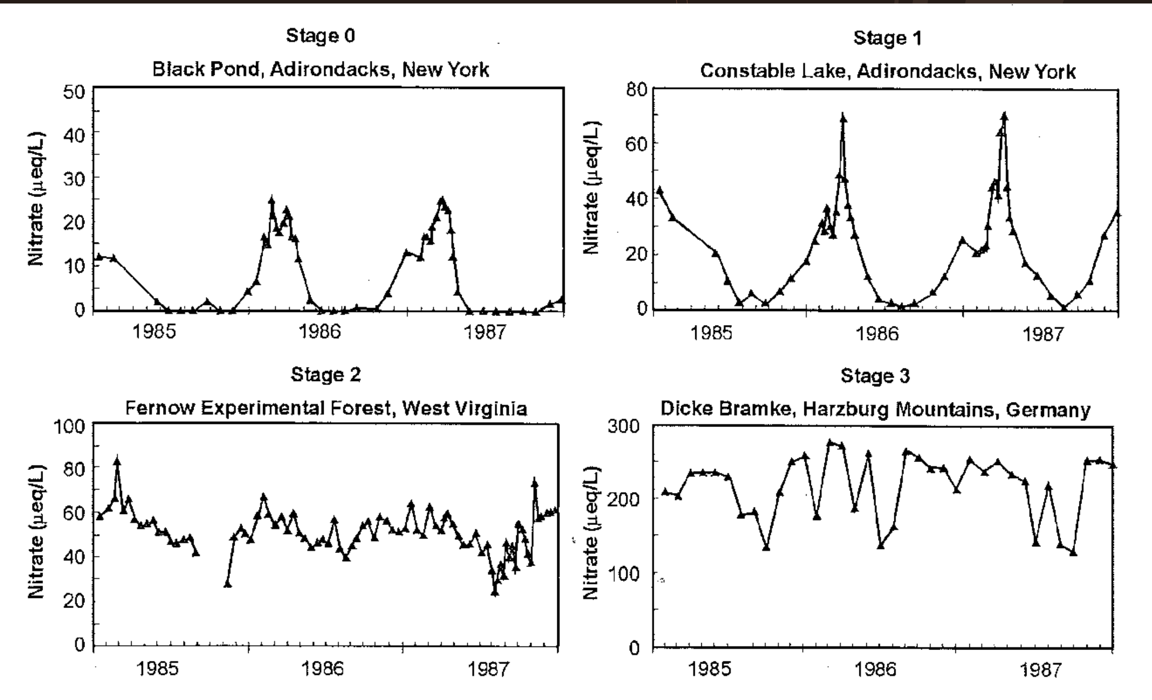
Monitoring

- What is the long-term trend in lakewater NO_3^- concentration for LTM sites in the Rocky Mountains over the period of monitoring since 1990, as measured during the summer index period, and what are the characteristics of the sites that show the largest increasing trends?
- Do long-term trends in spring base flow stream water Ca^{2+} concentrations in second- and third-order streams in XYZ Wilderness Area since 1990 suggest the potential for Ca-deficiency in the soils of higher elevation forests in this wilderness?

NITROGEN EFFECTS

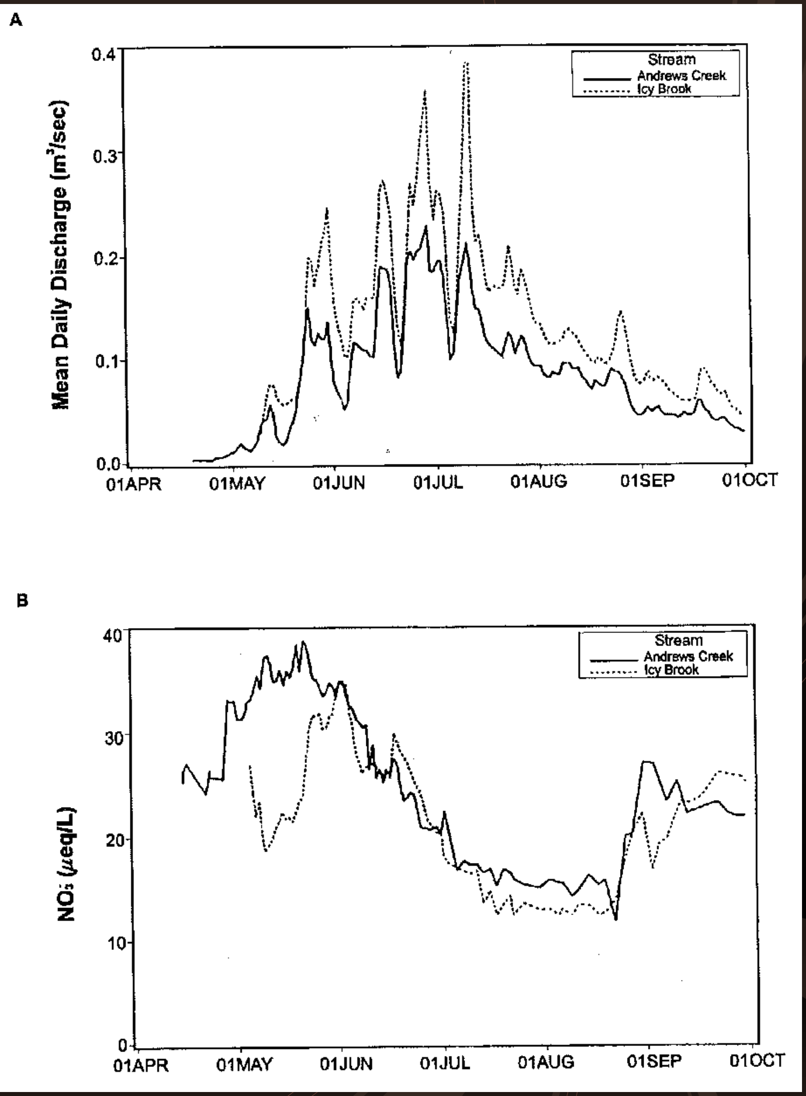
Acidification
Nutrient Enrichment

Example Stages of N Saturation



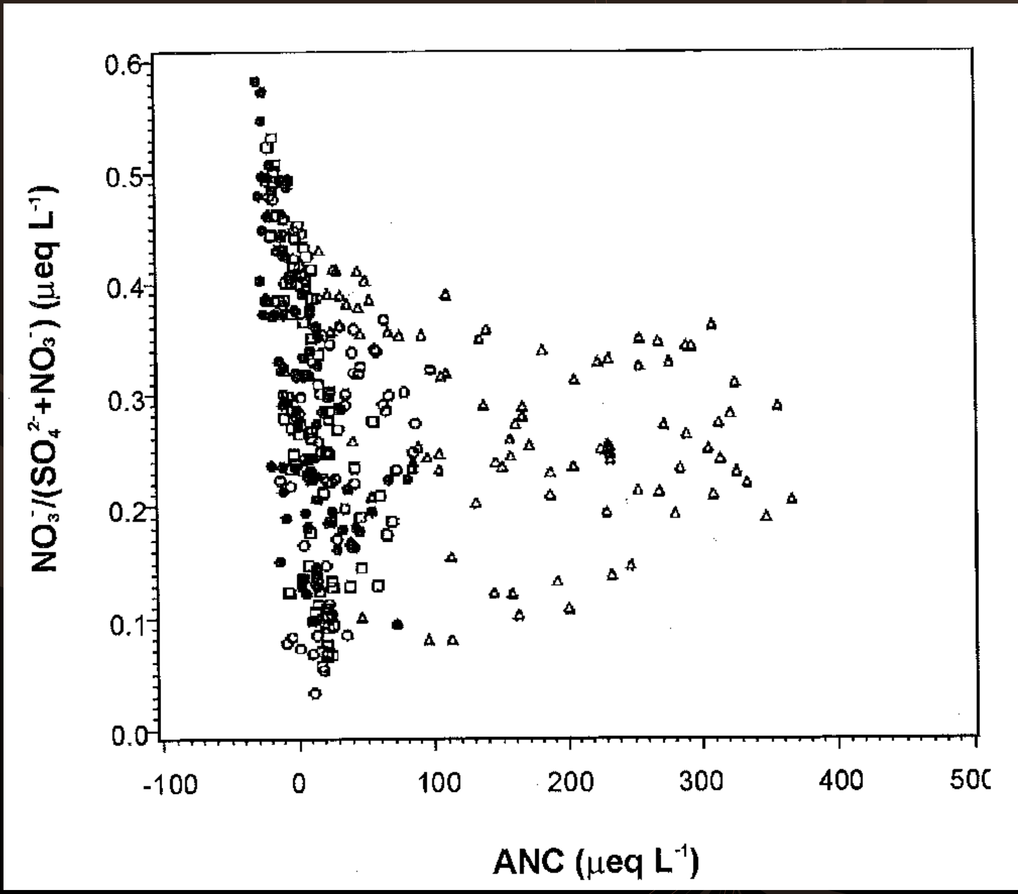
Example patterns of NO_3^- concentration in surface water at four sites at various stages of watershed N-saturation. (Source: Stoddard 1994)

Daily Discharge and Nitrate Concentration



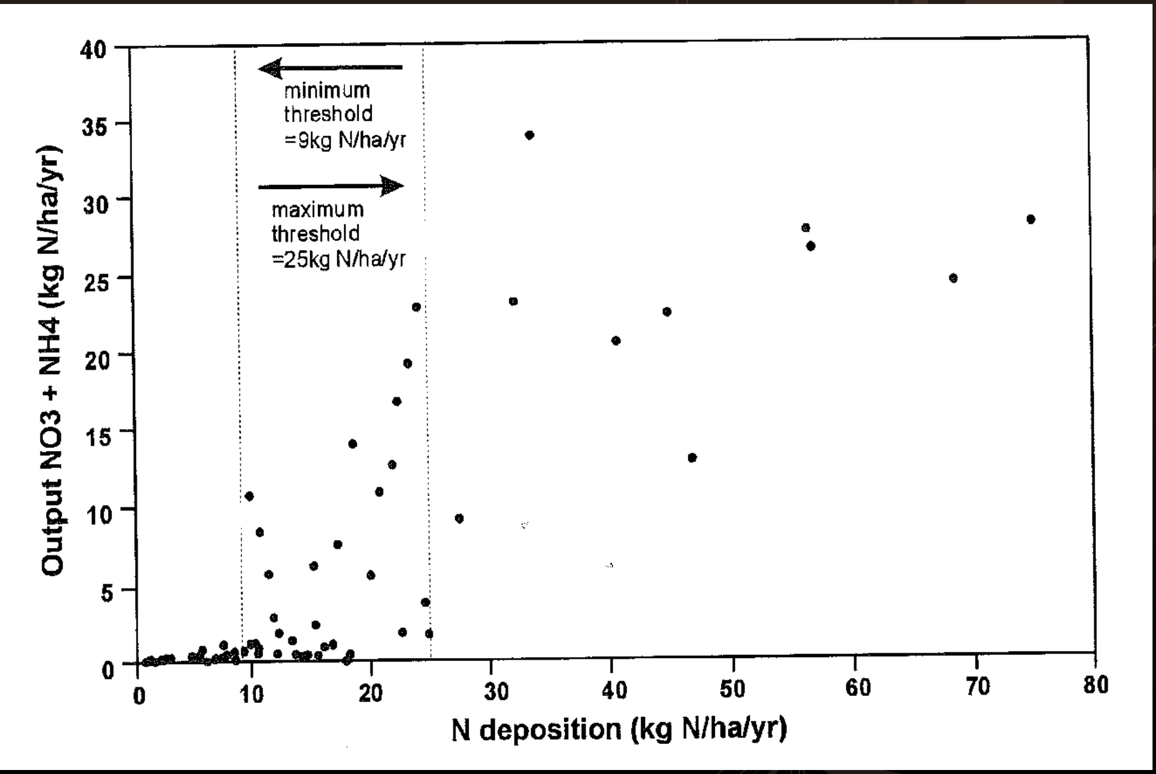
Daily discharge (A) and nitrate concentration (B) in Icy Brook and Andrews Creek within the Loch Vale watershed, Rocky Mountain National Park, in April-September 1992. (Source: Campbell et al. 1995) This graphic shows an approach for displaying data from repeated sampling of two streams for the purpose of documenting changes in NO_3^- concentration as snowmelt proceeds within a given year.

Relative Role of N in Acidity Status



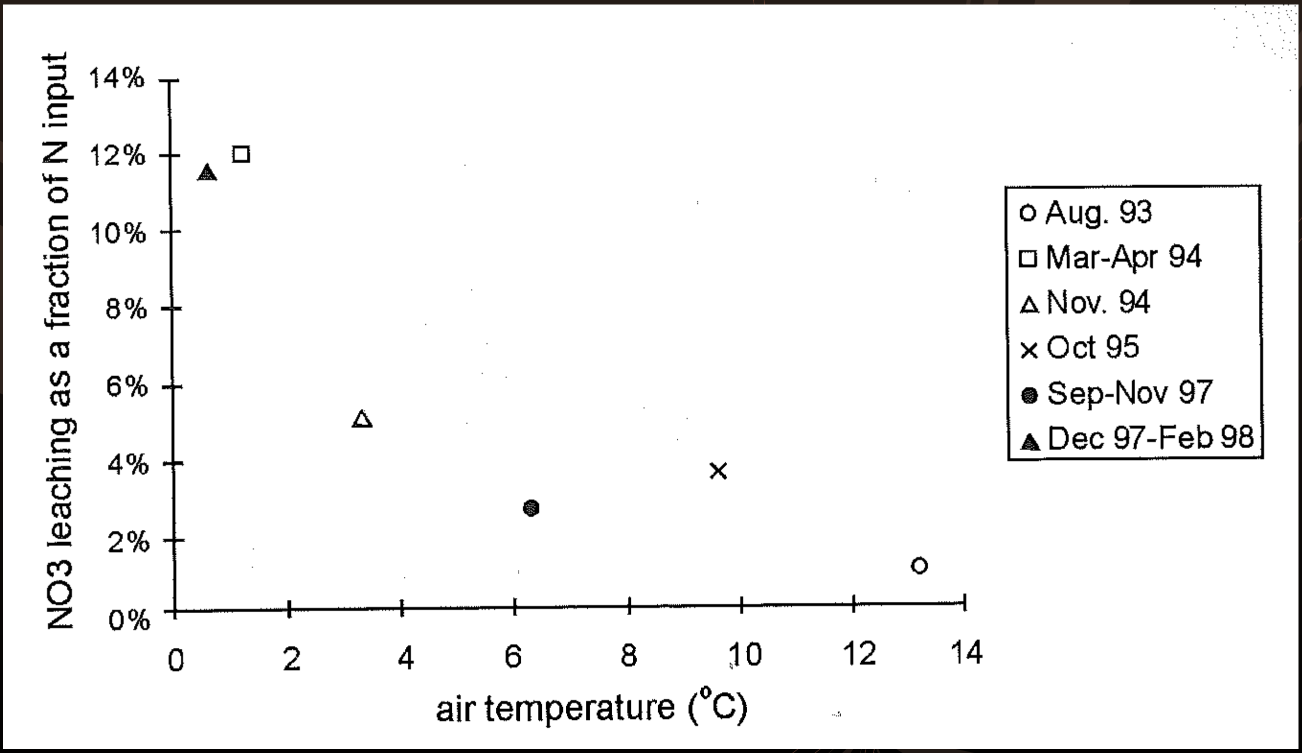
Ratio of NO_3^-:(SO_4^{2-} + NO_3^-) concentration versus ANC in streamwater samples collected during hydrological episodes in four streams included in the Adirondack region of EPA's Episodic Response Program (ERP). The different symbols on the graph represent different streams. (Source: Sullivan et al. 1997)

Nitrogen Outputs Versus N Deposition Inputs



Nitrogen outputs in soil water or stream water versus N deposition inputs throughout Europe. (Source: Dise and Wright 1995)

Relationship Between NO_3^- in Runoff and Air Temperature



Observed relationship between NO_3^- leaching loss in runoff and mean air temperature at an experimental watershed site at Gårdsjön, Sweden. Each point represents an average of data collected over a period of 14 to 90 days. (Source: Moldan and Wright 1998)

CRITICAL LOADS

Critical Load Matrix

	Acidification	Nutrient Enrichment
Water		
Soil and Vegetation		

Water Acidification Critical Loads

Steady State (SSWC)

Dynamic (MAGIC, PnET-BGC)

Sensitive Receptor	Lake Water
Chemical Criterion	ANC
Threshold (Critical Value)	0, 20, 50, 100 µeq/L

Water Nutrient Enrichment Critical Loads

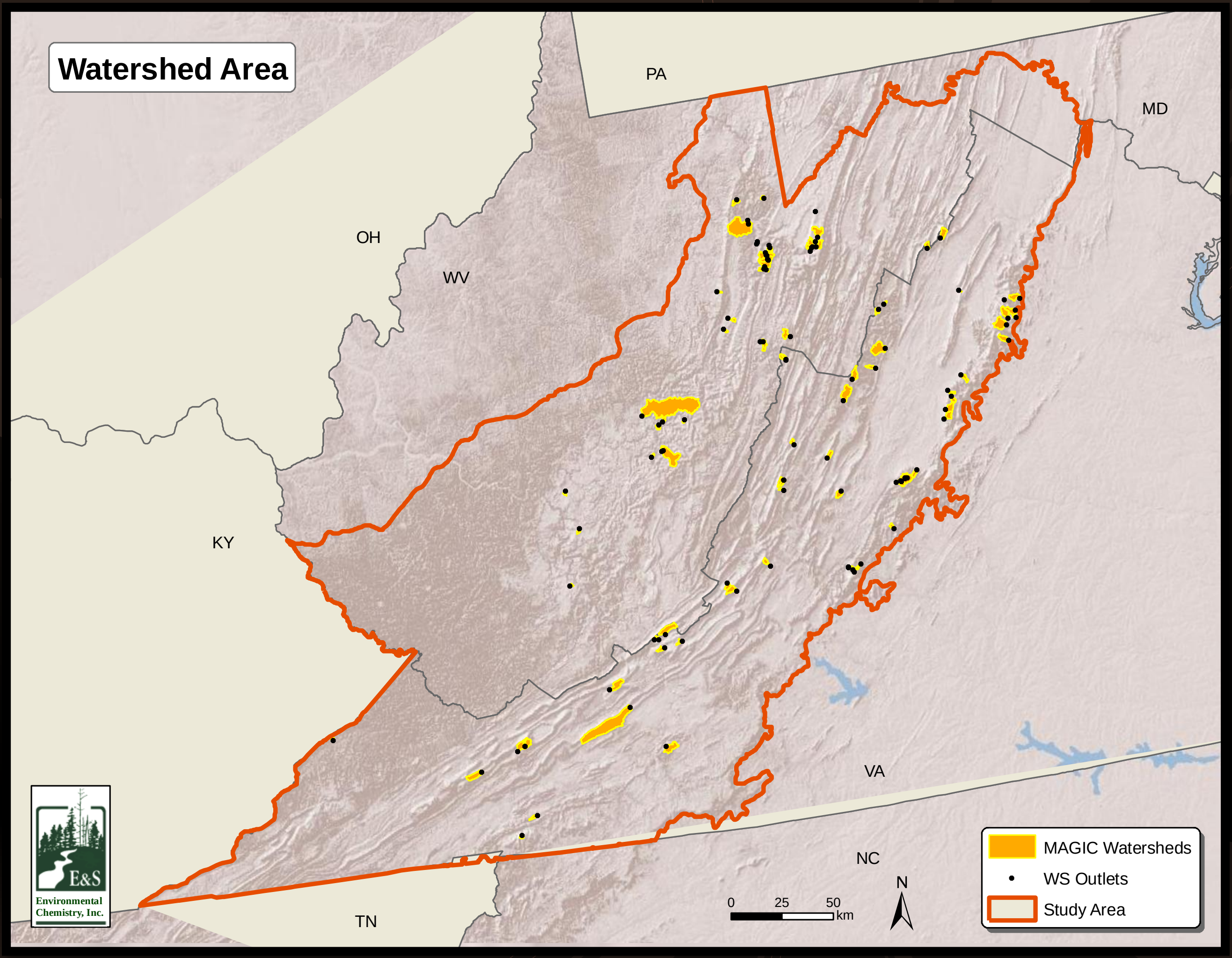
Dynamic (MAGIC, PnET-BGC)

Sensitive Receptor	Drainage Water
Chemical Criterion	NO_3^-
Threshold	?

Steady State Water Chemistry Model (SSWC)

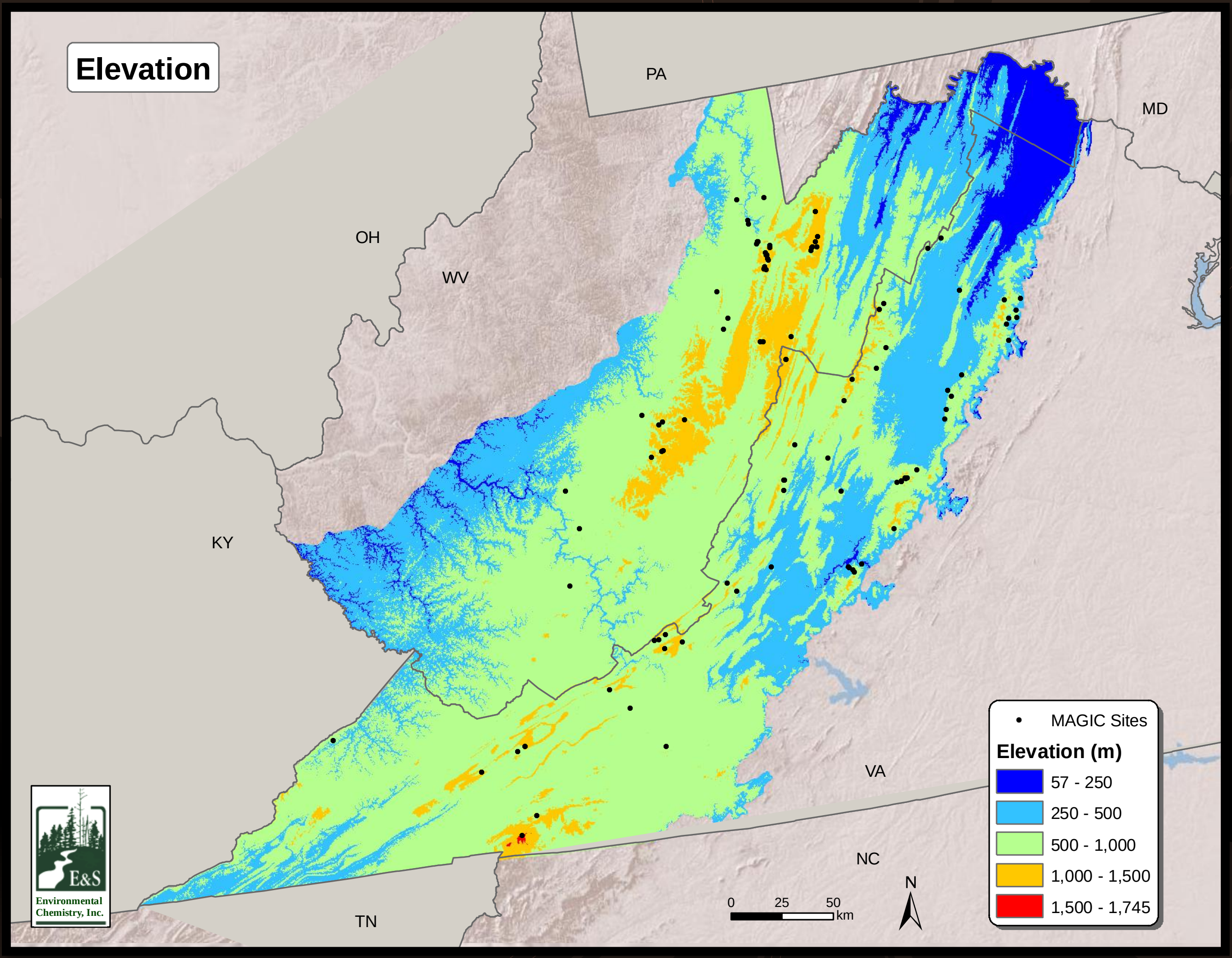
$$CL(A) = BC_{dep} + BC_{w} – Bc_{up} – ANC_{limit}$$

Stream Sampling Locations



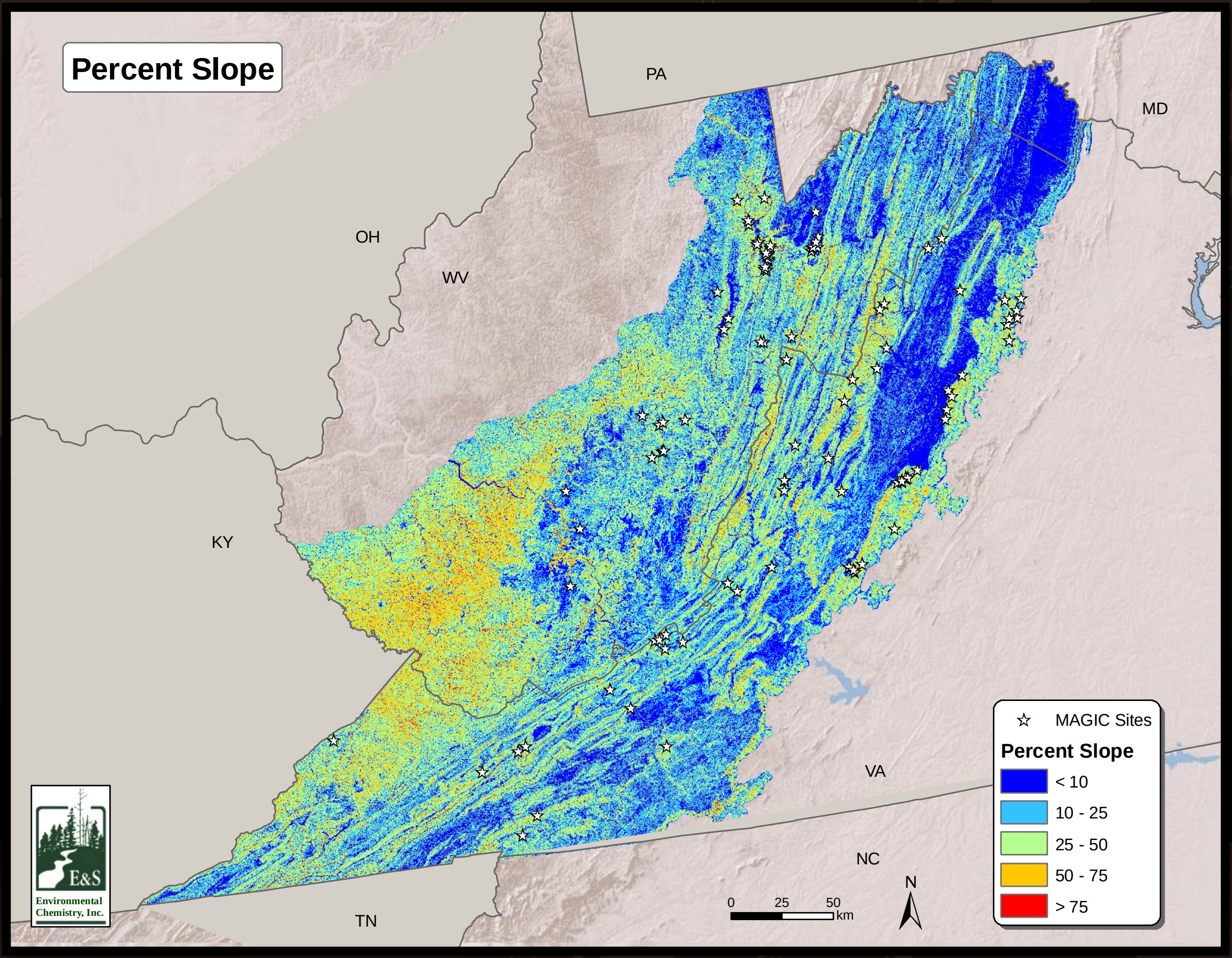
Stream sampling locations and associated watersheds for sites modeled with MAGIC.

Elevation Pattern



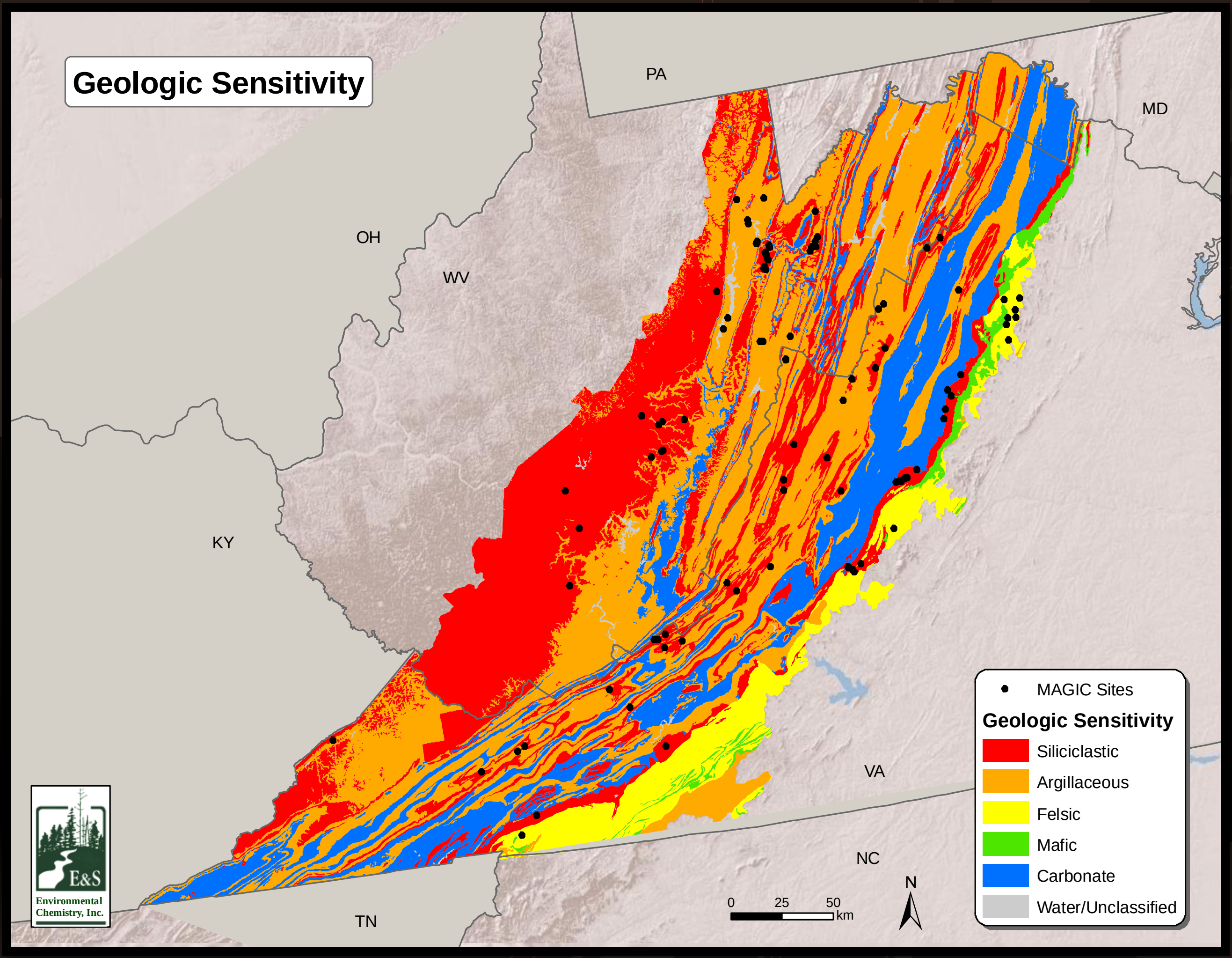
Elevation pattern across the study area. Also shown are MAGIC model sampling sites.

Spatial Pattern in Percent Slope



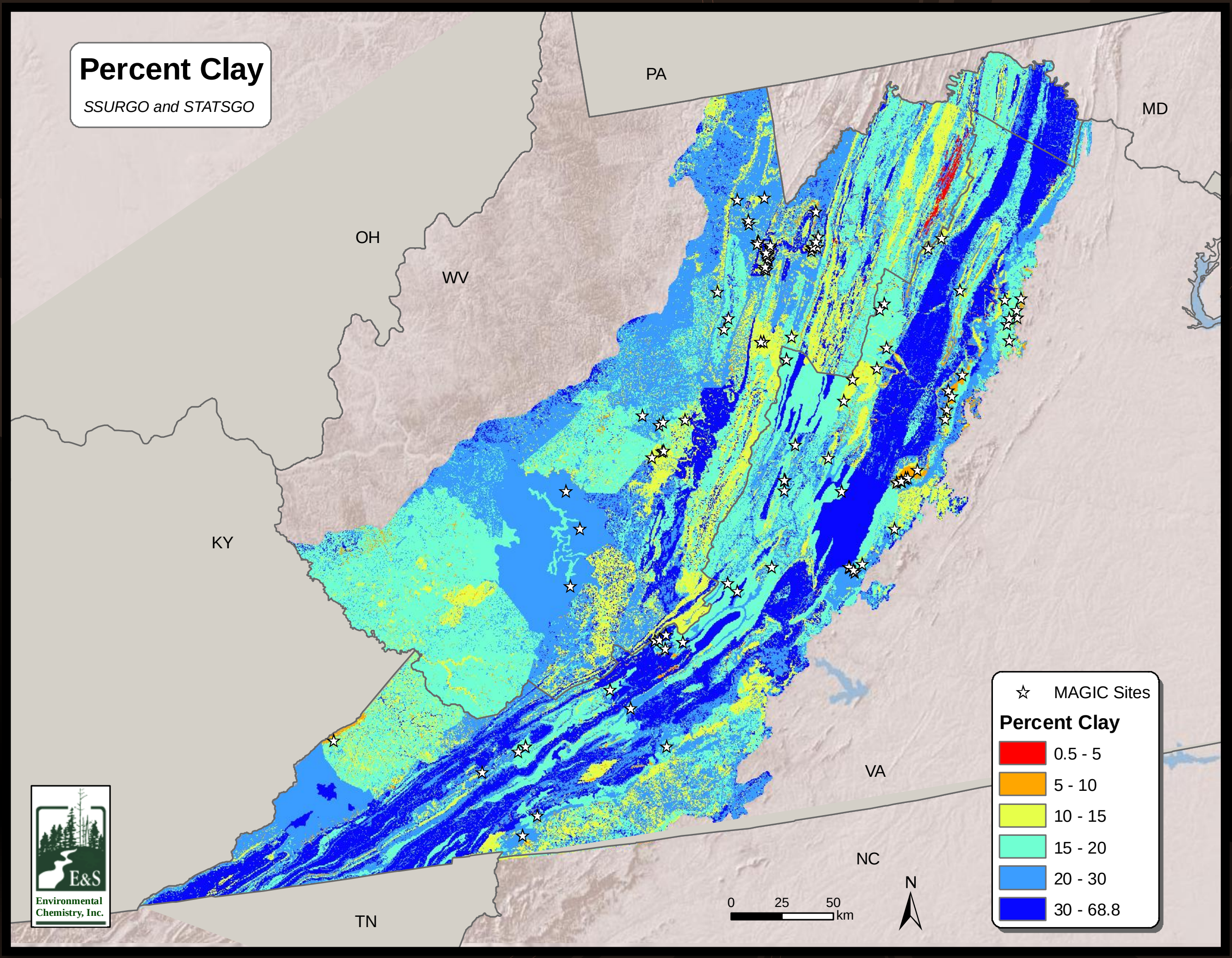
Spatial pattern in percent watershed slope across the study area. Also shown are MAGIC modeling sites.

Geologic Sensitivity Classes



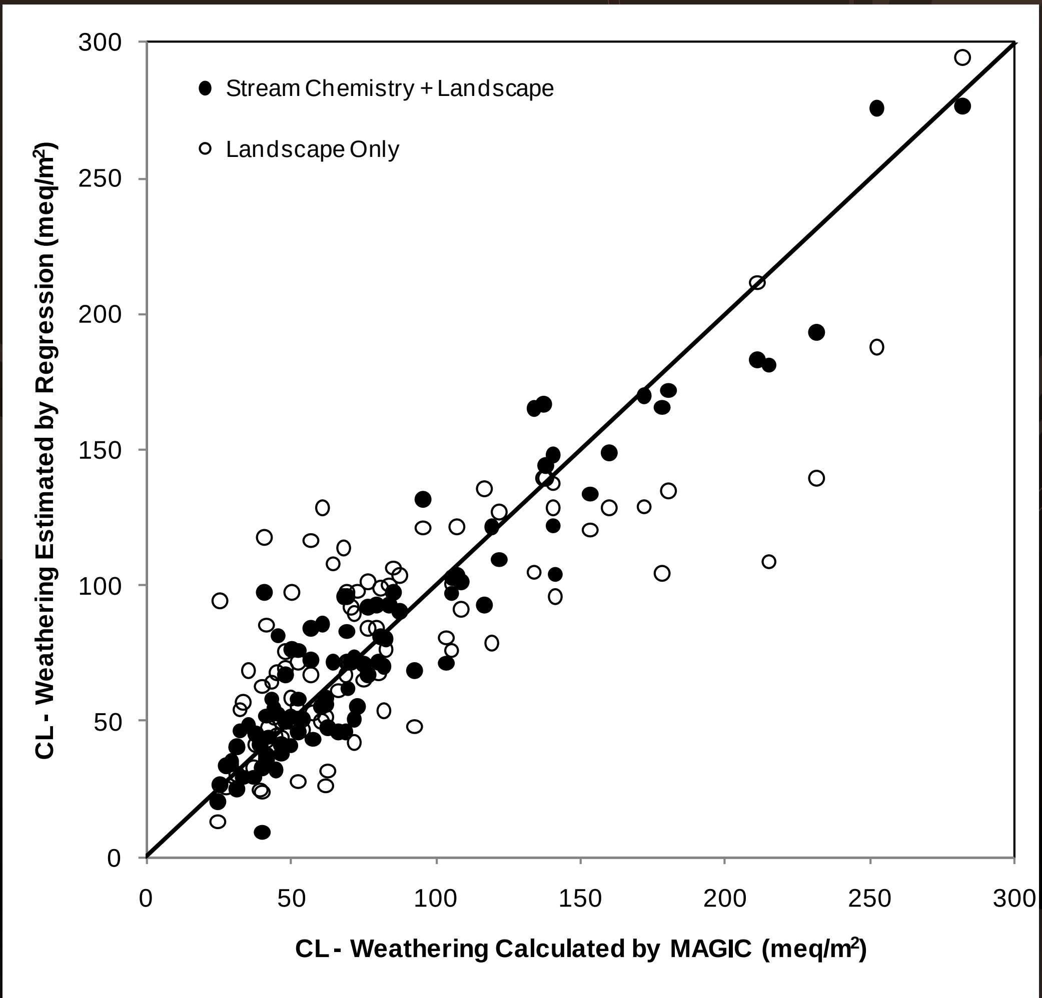
Geologic sensitivity classes, as determined by Sullivan et al. 2007 across the study area. Also shown are MAGIC model sampling sites.

Percent Clay



Percent clay in soils across the study area, based on SSURGO and STATSGO data. Also shown are MAGIC model sampling sites.

Weathering Calculations for 92 Sites



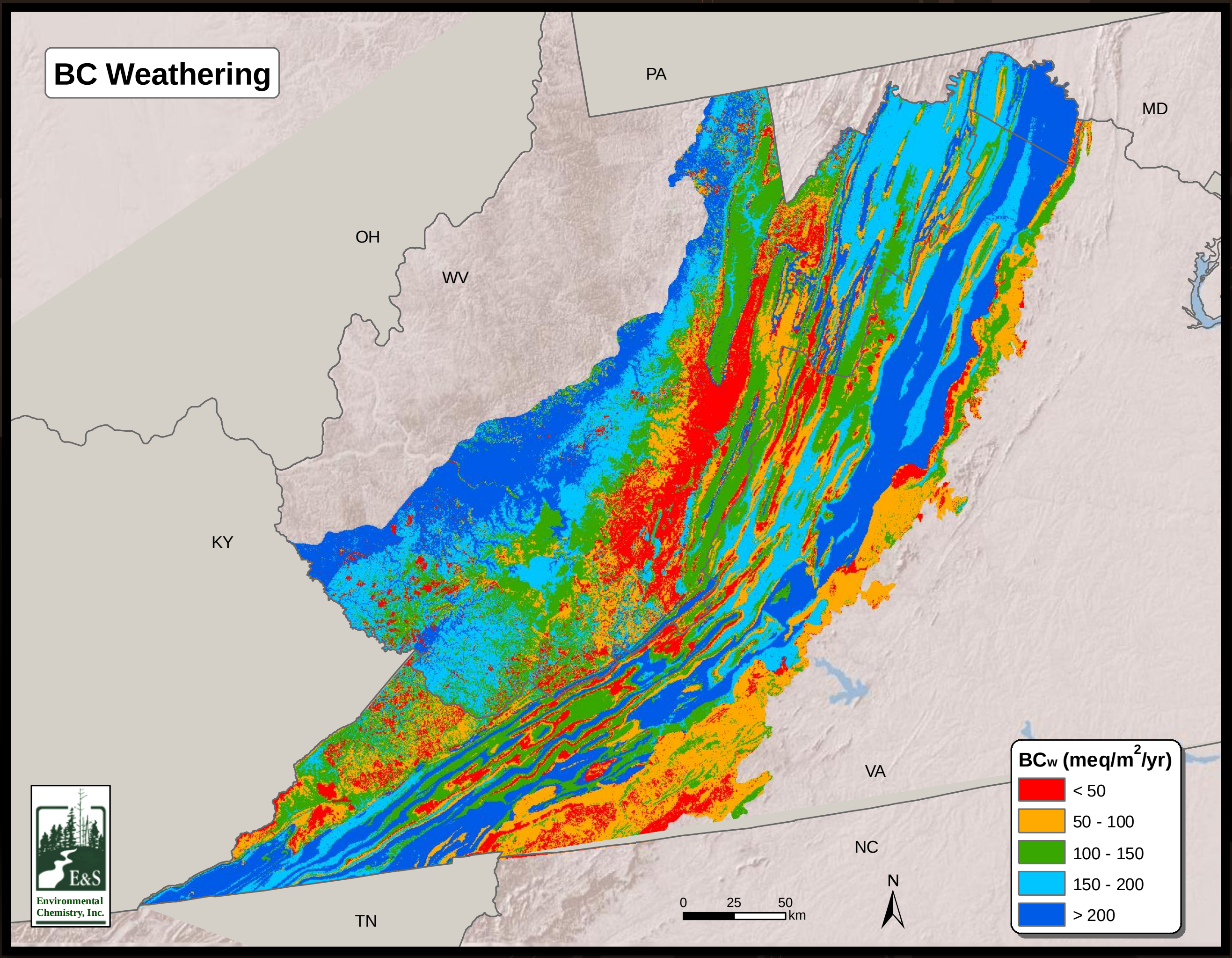
Critical load calculations for the 92 sites modeled with MAGIC. The CL calculations using SSWC, where weathering was calculated with MAGIC, are shown on the x-axis. SSWC CL calculations, where weathering was estimated using regression equations (water chemistry plus landscape data; or landscape data alone), are shown on the y-axis. One outlier was deleted; it was influenced by a small section of carbonate lithology at the stream outlet.

Multiple Regression Equations Stratified by Ecoregion

Multiple regression equations to estimate BC_w from either water chemistry and landscape variables or from landscape variables alone, stratified by ecoregion.

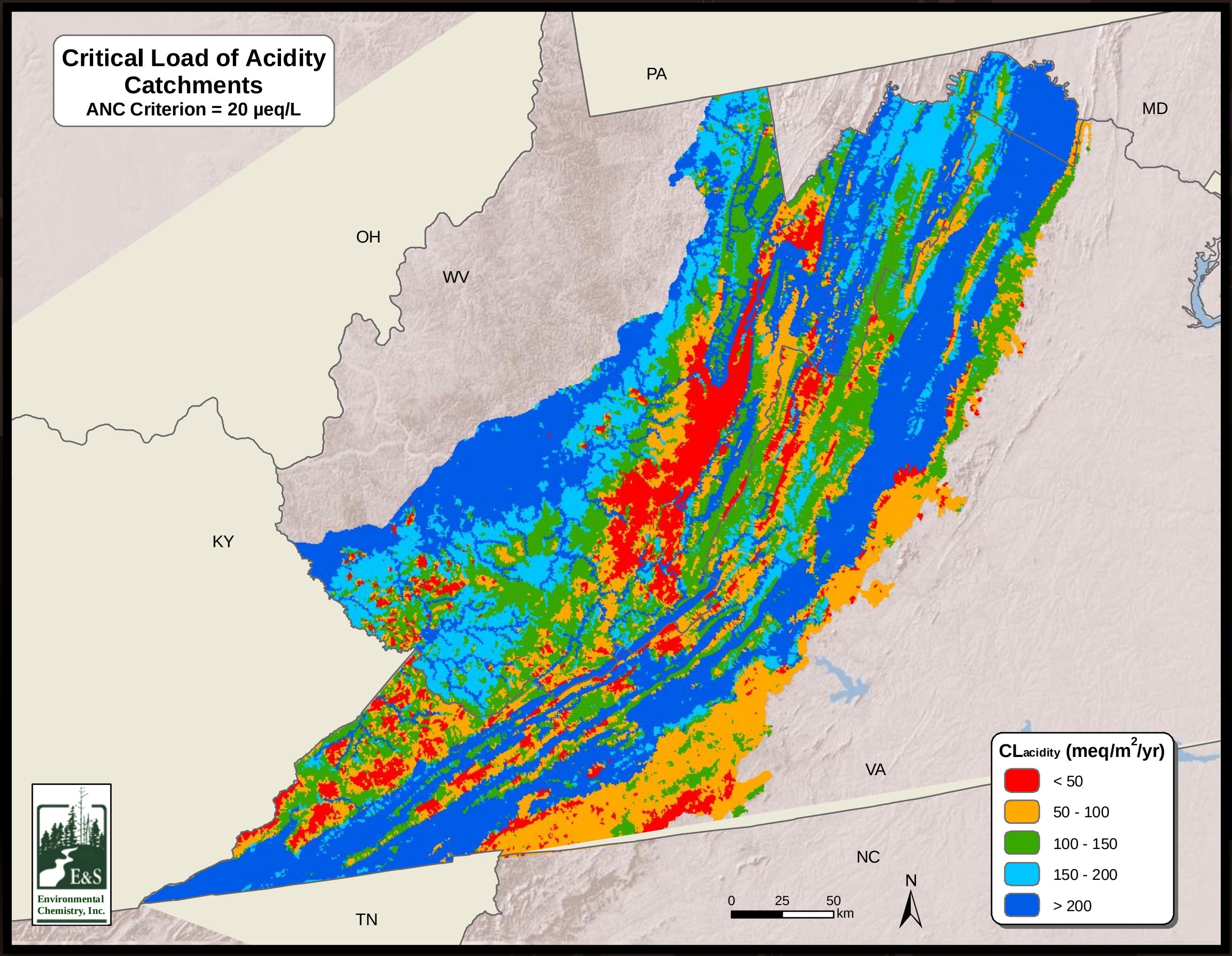
Ecoregion	n	Equation	r^2
<u>Water Chemistry and Landscape Variables</u>			
Central Appalachian	24	BC_w = -37.5 + 0.6 (SBC) + 0.9 (NO_3) + 0.006 (WS Area)	0.93
Ridge and Valley	42	BCw = 107.0 + 0.5 (SBC) - 0.06 (Elevation) - 3.2 (Slope)	0.86
Blue Ridge	26	BC_w = 27.1 + 0.6 (CALK) + 0.6 (NO_3)	0.90
<u>Landscape Variables Only</u>			
Central Appalachian	24	BC_w = 1186.2 + 0.01 (WS Area) – 0.3 (Elevation) – 179.3 (Soil pH)	0.66
Ridge and Valley	42	BC_w = 219.7 - 74.6 (% Siliciclastic) + 6632.4 (% Carbonate) – 0.1 (Elevation)	0.64
Blue Ridge	26	BC_w = 57.9 + 32.7 (% Felsic) + 69.6 (% Mafic) - 40.2 (Soil Depth) + 2.0 (% Soil Clay)	0.85

Calculated Values of BCw



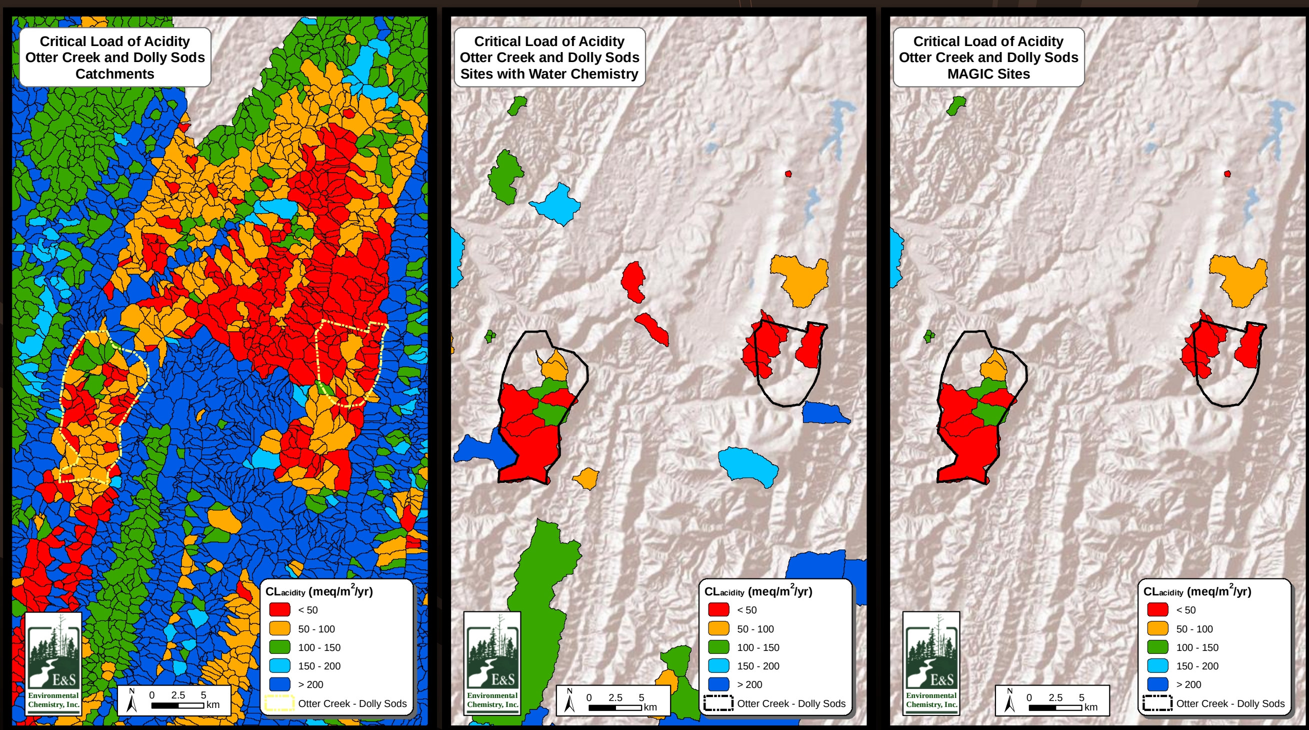
Calculated values of BCw for each 30 m grid cell in the study area, based on the regression relationships that were developed using landscape variables.

Critical Load of Acidity



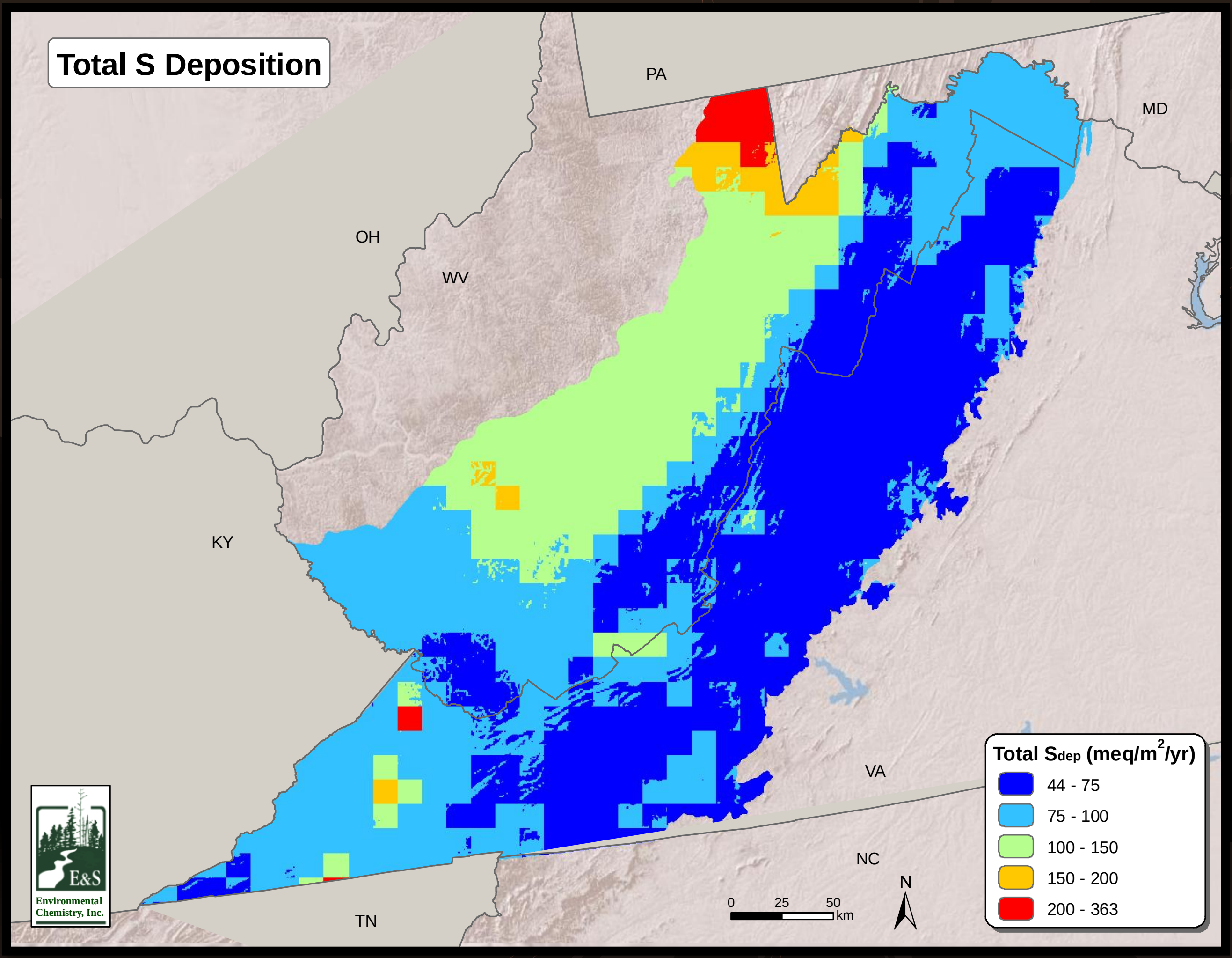
Final map of CL of acidity to protect stream ANC from falling below 20 µeq/L.

Critical Load of Acidity



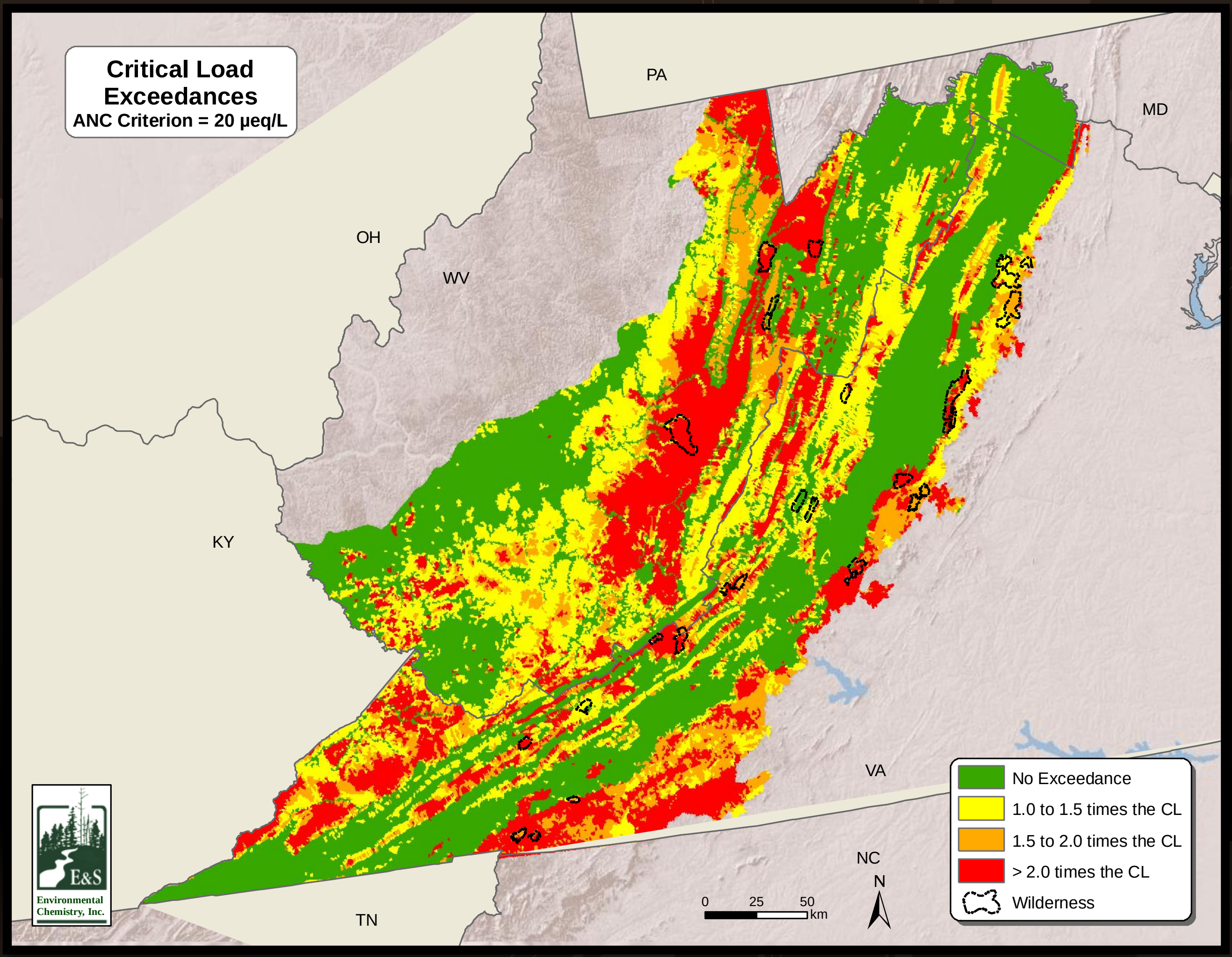
Comparisons among modeling approaches for calculating CL of acidity to prevent ANC from going below 20 μeq/L for watersheds in and around the Otter Creek/Dolly Sods wilderness areas. Spatial patterns in CL are similar using the three approaches.

Patterns in Total S Deposition



Regional patterns in total S deposition, based on interpolated NADP wet deposition averaged over a five year period centered on 2002 and CMAQ model estimates of dry deposition for 2002.

Critical Load Exceedances



Critical load exceedance map for the ANC criterion 20 µeq/L.