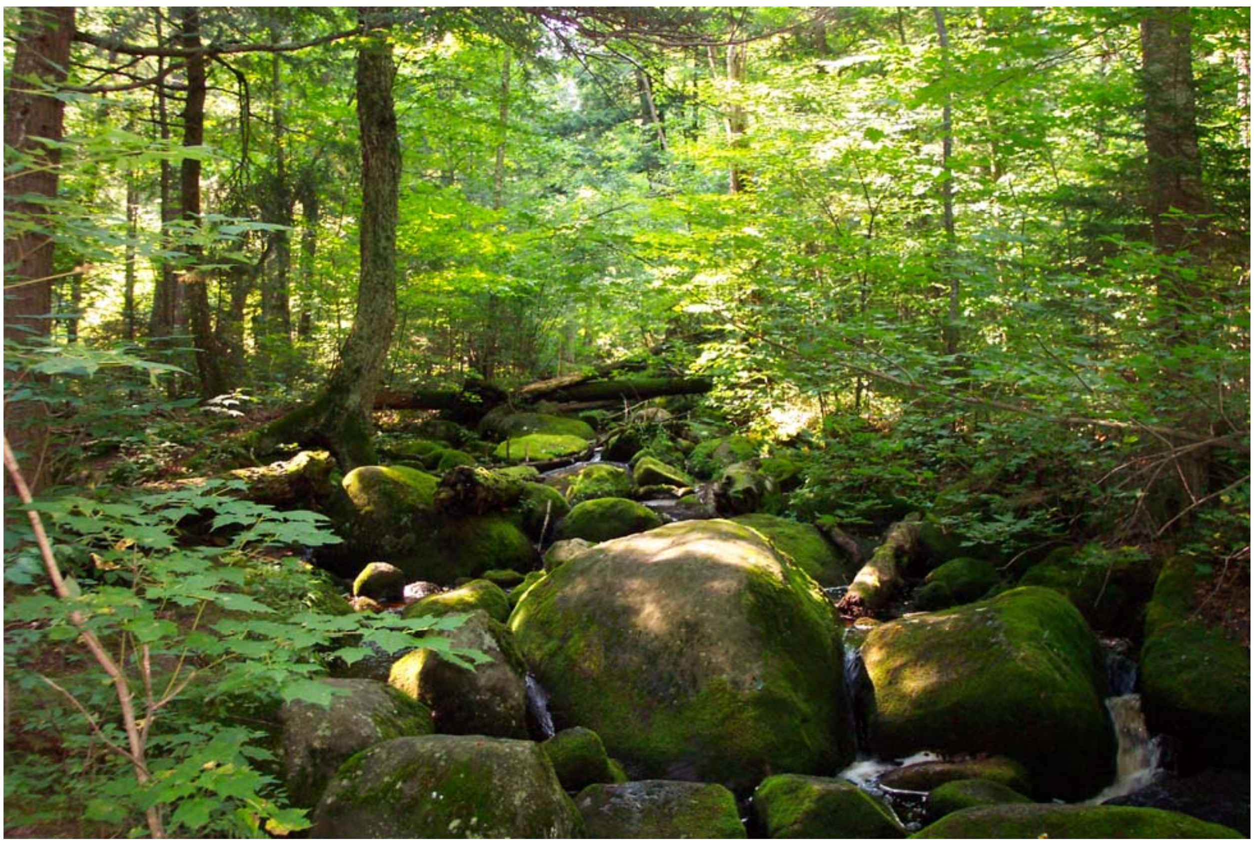
AQUATIC CRITICAL LOADS AND EXCEEDANCES IN ACID-SENSITIVE PORTIONS OF VIRGINIA AND WEST VIRGINIA

Results of Southeastern Multiagency Critical Loads Research Project



E&S Environmental Chemistry, Inc.

April, 2010

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Results of Southeastern Multiagency Critical Loads Research Project

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Executive Summary

<u>Background</u>

The critical load (CL) is the level of sustained atmospheric deposition of S, N, or acidity below which significant harm to sensitive ecosystems does not occur according to current scientific understanding. For the sensitive receptor stream water, the most commonly selected chemical indicator is acid neutralizing capacity (ANC). A number of critical criteria values of ANC have been used as the basis for CL calculations, the most common of which have been 0, 20, 50, and 100 µeq/L. Each is believed to be associated with biological responses. The steady state CL can be calculated using an empirical model. Results are reported here for a pilot project to explore approaches to CL calculation and mapping for the southeastern United States.

The most commonly used steady state CL model for aquatic resource protection is the Steady State Water Chemistry (SSWC) model (Henriksen and Posch 2001). In this approach, the CL is calculated as a simple balancing of watershed base cation (BC; e.g., Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) inputs and outputs with the atmospheric deposition of strong acids.

The watershed supply of BC due to weathering (BC_w) is the CL model parameter that generally has the most influence in the CL calculation. Regional approaches for estimating BC_w are uncertain, in that they are rooted in unsubstantiated assumptions and rely on data that may not be available at appropriate scales for sensitive watersheds. Because the CL is a theoretical construct, its estimation by any model cannot be directly confirmed or validated, at least in the short term.

<u>Estimation of Base Cation Weathering</u>

An important objective of the research reported here is to explore an alternative approach for estimating BC_w, arguably the key term for estimating CL using the SSWC model (or any other aquatic steady state CL model). The dynamic model MAGIC (Model of Acidification of Groundwater in Catchments; Cosby et al. 1985) was used to estimate watershed-specific values of effective BC_w. Based on empirical relationships between simulated BC_w and key stream chemistry variables and watershed characteristics, simulated BC_w and other spatial variables were extrapolated to the regional population of stream watersheds in acid-sensitive portions of Virginia and West Virginia, allowing regional calculation of CL and CL exceedance using SSWC.

Regression techniques were used to establish equations for BC_w prediction across the landscape within each of three study ecoregions (Blue Ridge, Ridge and Valley, and Central Appalachian). MAGIC model estimates of BC_w for the calibrated watersheds located throughout the study area were used as modeled weathering rates. Two predictor equations were established for each of the three ecoregions, one using both landscape characteristics and water chemistry parameters for use in the 522 watersheds for which stream chemistry data were available (estimated BC_w with water chemistry) and another using landscape characteristics only (estimated BC_w without water chemistry). Continuous upslope averages for each of the landscape predictor variables were calculated for each 30-m grid cell using hydrologically conditioned digital elevation model (DEM) data derivatives. This approach was used because stream chemistry integrates conditions throughout the drainage area.

A total of 92 stream sites were successfully calibrated using MAGIC. BC_w estimates for those watersheds were extracted from the model calibration files and used as inputs for SSWC calculations.

<u>Calculation of Critical Load</u>

The stream network generated from the DEM for the pilot project study region was based on a minimum contributing area of 0.5 km^2. In other words, the minimum drainage area that was designated as a stream watershed from the flow accumulation analysis was 0.5 km^2. The lower boundary of each watershed was determined on the basis of stream tributary junctions. This process resulted in generation of a topographically determined stream network that was intermediate in stream size and density between the 1:100,000 National Hydrography Dataset (NHD) moderate resolution stream network and the high resolution 1:24,000 NHD network. The typical topographically determined watersheds were on the order of 1 km^2 in area.

Values for each of the terms in the SSWC model were calculated for every 30-m grid cell in the study region. The SSWC equation was then solved to yield an estimate of CL for each 30-m grid cell. The representative watershed CL value was then calculated for each topographically determined watershed as an average of the CL values calculated at each stream cell (each grid cell intercepted by a topographically determined stream) within the watershed. A regional watershed CL map was prepared for each critical ANC indicator value.

Critical load results were also depicted for the network of streams that flow through these watersheds. Results of the CL calculations for the stream pixels (each 30-m grid cell that intersected a topographically determined stream) were averaged to reflect the CL of the stream reach that flows through that watershed based on the national stream network as represented in the high-resolution NHD database. This process was completed for all watersheds to yield a regional stream coverage that is coded with CL according to the value given to its associated watershed.

For the study area as a whole, about 30 to 40% of the stream length (depending on selection of threshold ANC value) was classified as having CL above 200 meq/m^2/yr. The remainder of the stream length had lower calculated CL values, with about one-fourth of the stream length having CL below 100 meq/m^2/yr. For most CL classes, there was not much difference in the extent of stream length within the class as influenced by the threshold ANC value selected. For the lowest CL class (less than 50 meq/m^2/yr), however, choice of threshold ANC value made a substantial difference to the stream length calculations. The length of stream estimated to have CL $\leq$ 50 meq/m^2/yr across the study area varied by about a factor of four depending on which threshold ANC value was selected.

Critical loads were generally much lower and more heavily influenced by selection of the threshold ANC value for Wilderness streams as compared with non-Wilderness streams. About 70% of the Wilderness stream length had CL less than 100 meq/m^2/yr to protect to stream ANC above 50 μeq/L. Nearly half of the Wilderness stream length had CL less than 100 meq/m^2/yr to protect to stream ANC above zero.

<u>Critical Load Exceedance</u>

Watershed averaged values of total ambient deposition of acidity were overlayed with the CL maps to generate regional estimates of CL exceedance, to identify areas where ambient deposition exceeds the CL. Broad areas of the study region were found to be in CL exceedance when compared to the 5-year average deposition centered on 2005. Such areas are disproportionately associated with Class I areas and other public lands.

Half of the stream length within the study region was calculated to receive current acidic deposition in exceedance of the CL to protect against stream ANC below zero. That percentage increased to 53% for the threshold ANC value of 20 μeq/L, to 57% for the threshold ANC value of 50 μeq/L, and 63% for the threshold ANC value of 100 μeq/L. Nearly one-fourth of the stream length in the study region was estimated to be receiving acidic deposition that is more than double the CL for protecting stream ANC from going below 50 μeq/L. Exceedance of the

CL was most prevalent in the Blue Ridge ecoregion, followed by the Central Appalachian ecoregion.

Temporal Patterns of Response

The CL and CL exceedance values calculated in this project pertain to long-term, steady-state water quality conditions. It may take a long time to reach the steady-state condition with respect to deposition acidity and stream chemistry at a constant loading rate. To address this concern, the dynamic model MAGIC was used to estimate the time to reach steady state at the CL deposition values calculated using the SSWC model. Results showed that:

- most of the modeled watersheds will not reach steady state for hundreds of years, and
- the time period is somewhat longer if the selected threshold ANC value is higher (more protective).

Summary

In summary, the SSWC steady state CL model was applied in a regional pilot study to estimate CLs and exceedances for aquatic resources in streams in the southeastern U.S. Terms in the SSWC model were derived on a regional landscape basis. Estimates of BC deposition and BC uptake by forests were available from national network databases. A computationally efficient and robust method for estimating weathering on a continuous basis across a regional landscape was developed for this project. It was based on weathering estimates extracted from a well-tested process-based watershed model of drainage water acid-base chemistry and also on features of the landscape that are available as regional spatial data coverages. This approach avoids many of the uncertainties associated with other common methods for estimating BC_w for input into SSWC and other steady state CL models.

Results indicate that more than half of the streams within the study region receive current acidic deposition that is higher than the steady state CLs. Furthermore, results indicate that most of the modeled watersheds will likely not reach the steady state condition for hundreds of years after continuous constant deposition at the CL levels are established.

It should be noted that CL and exceedance calculations and maps reported here represent examples of one approach to the CL process. No formal uncertainly analysis has been conducted. Therefore, the confidence level associated with these results is not known. Further research is needed to test, evaluate, and refine the approaches used to quantify weathering and CL.

1.0 INTRODUCTION

Atmospheric deposition of sulfur (S) and nitrogen (N), derived from utility, industrial, and nonpoint air pollution sources, has caused acidification of soils, soil water, and drainage water across broad areas of the eastern United States (Greaver et al. 2008). Such acidification has been associated with enhanced leaching of sulfate (SO_4^{2-}) and nitrate (NO_3^-) to drainage waters, depletion of calcium (Ca^{2+}) and other nutrient cations from soil, reduced pH and acid neutralizing capacity (ANC) of surface waters, and increased mobilization of potentially toxic inorganic aluminum (Al_i; Sullivan 2000). Resulting biological effects have included toxicity to fish and aquatic invertebrates and adverse impacts on forest vegetation, especially red spruce and sugar maple trees (U.S. EPA 2009). Aquatic effects have been better documented and appear to be more widespread than terrestrial effects, and have been especially pronounced in Monongahela National Forest in West Virginia (Sullivan and Cosby 2004), Shenandoah National Park in Virginia (Sullivan et al. 2003), and other forested mountainous areas of western Virginia (Cosby et al. 2001).

Resource managers are now confronted with the need for air pollution emissions reductions sufficient to allow damaged resources to recover. In order to inform public policy regarding air pollutant emissions controls, it is important to determine 1) the level of emissions, and associated atmospheric deposition, that are associated with varying degrees of chemical effects and 2) the associations between water and soil chemistry and consequent biological impacts. One of the most important tools available to natural resource managers in this context involves model calculation of critical loads (CLs).

The CL is the level of sustained atmospheric deposition of S, N, or acidity below which significant harm to sensitive ecosystems does not occur according to current scientific understanding (Nilsson and Grennfelt 1988). The CL process typically involves selection of one or more sensitive receptor(s), one or more chemical indicator(s) of biological response for the sensitive receptor(s) of concern, and one or more critical chemical indicator criteria (or threshold) values that have been shown to be associated with adverse biological impacts. For the sensitive receptor stream water, the most commonly selected chemical indicator is ANC. A number of critical criteria values of ANC have been used as the basis for CL calculations, the most common of which have been 0, 20, 50, and 100 μeq/L. The first two levels approximately correspond in the Appalachian Mountains region to chronic and episodic effects on brook trout, respectively (Bulger et al. 1999). An ANC threshold of 50 to 100 μeq/L is believed to be protective of general ecological health (cf., Cosby et al. 2006, U.S. EPA 2009).

The CL is generally calculated as a long-term steady state condition (Nilsson and Grennfelt 1988). It represents the amount of acidic deposition that is expected to result in achieving a particular stream ANC (or other designated receptor threshold value) over the long term. Under constant atmospheric deposition at the determined CL, however, it may take many decades or centuries for the sensitive chemical indicator (i.e., stream ANC) to reach the designated threshold ANC value.

The steady state CL for protection of either aquatic or terrestrial resources can be calculated using a simple mass balance, of which there are several alternative approaches. The most commonly used steady state CL modeling approach for aquatic resource protection is the Steady State Water Chemistry (SSWC) model (Henriksen and Posch 2001), which is calculated as a simple balancing of watershed base cation (BC; e.g., Ca^{2+}, Mg^{2+}, K^{+}) inputs and outputs.

$$CL(A) = BC_{dep} + BC_{w} - Bc_{up} - ANC_{limit} \quad (1)$$

The inputs to the subject watershed are base cation weathering (BC_w) and atmospheric deposition (BC_{dep}). The outputs include base cation nutrient (i.e., Ca^{2+}, Mg^{2+}, K^{+}) uptake by tree boles that are removed from the watershed through timber harvest (Bc_{up}). Vegetative uptake into plant material that is not harvested does not represent an output term in the model, as the BCs in non-harvested woody materials are largely recycled within the watershed rather than being transported out of the watershed.

Also included in the model with the BC output terms is a buffer, or allowance, for the BCs needed to support ecosystem health. In the SSWC and other aquatic CL approaches, this buffer is expressed as an ANC leaching flux (ANC_{limit}), which is calculated as the product of the selected threshold ANC value multiplied by water runoff. This BC buffer is needed to maintain surface water ANC at the designated level that is expected to support healthy fisheries and aquatic communities. The threshold ANC value is often set at 0, 20, 50, and/or 100 μeq/L. Data available within the pilot study area with which to evaluate aquatic biological response functions are summarized in Appendix A.

Critical load studies in North America have mainly been undertaken in Canada (cf., Henriksen and Dillon 2001, Ouimet et al. 2006), where the CLs have been used to design emissions reduction programs (Jeffries and Lam 1993, RMCC 1990). Much of this work was presented, along with steady state CL maps for eastern Canada, in the 2004 Canadian Acid Deposition Science Assessment (Jeffries et al. 2005). Dupont et al. (2005) estimated CLs and exceedances for lakes in eastern Canada and New England. Most other aquatic CLs studies in the U.S. have focused on smaller sub-regional areas or individual watersheds (cf., Sullivan et al. 2003, Sullivan and Cosby 2004).

While the concepts expressed in the definition of CLs are conceptually easy to understand, CL application requires careful consideration of a number of terms and procedures. It is apparent that there can be many different CL values for a given atmospheric pollutant depending on the receptor or sensitive element(s) being considered. Furthermore, the same atmospheric pollutant can produce a variety of different disturbances in a sensitive ecosystem that might occur at different pollutant loads. For example, N deposition produces both nutrient (eutrophication) and acidification effects, and the CL of N for each type of disturbance may be different.

The watershed supply of BC due to weathering is the CL model parameter that typically has the most influence in the CL calculation and has the largest uncertainty (Li and McNulty 2007, U.S. EPA 2009, McDonnell et al. in review). In essence, the maintenance of long-term aquatic ecosystem acid-base chemistry health depends on keeping the atmospheric acid load relatively low compared with the natural re-supply of BCs through weathering, Thus, CL is controlled largely by BC_w. If the estimate of BC_w is based on a faulty approach or insufficient data, and is therefore inaccurate, the resulting CL calculation may be of little value for its intended purpose: supporting resource management decision-making.

The most common methods for estimating BC_w for inclusion in the SSWC model involve either use of regional estimates of soil substrate and clay content or simple empirical calculations designed to estimate what the level of historical weathering would have to have been in order to support the observed current concentrations of BC in drainage water (Henriksen and Posch 2001). The former approach assumes that weathering varies with soil clay content and geologic substrate in ways that can be represented by available spatial soils and geologic data. Inputs to the soil clay/substrate approach to estimation of BC_w include mean annual air temperature, soil depth, % clay, and geologic type. The geologic types are acidic (e.g., granites, gneiss, sandstones, felsic rocks), intermediate (e.g., diorite, granodiorite, conglomerate, and most sedimentary rocks other than sandstone), and basic (e.g., mafic rocks, carbonates; Pardo and Duarte 2007). It is assumed that the lowest weathering rates will occur with cold temperatures, in shallow soils having low clay content, over acidic rock types (Sverdrup et al. 1990). The latter approach entails a number of assumptions about background pre-industrial water chemistry and the extent to which the base cation flux in drainage water has been changed in response to increased leaching of SO_4^{2-} and/or NO_3^- (the so-called F-factor approach; cf., Henriksen 1984, Henrikson and Posch 2001).

Both approaches discussed above are uncertain, in that they are rooted in unsubstantiated assumptions and rely on data that may not be available at appropriate scales for the sensitive watersheds within a given region of interest. Published studies based on the approach that assumes weathering varies with clay content and substrate use empirical regressions to quantify these relationships. The reported empirical regressions all use European soil and substrate data at high latitudes (cooler temperatures) and may not be expected to yield realistic values when applied outside of these conditions. There are no published accounts of empirical regression relationships developed for North America.

A primary objective of the research reported here is to explore an alternative approach for estimating BC_w, arguably the key term for estimating CL using the SSWC model (or any other aquatic steady state CL model). The dynamic model, MAGIC (Model of Acidification of Groundwater in Catchments; Cosby et al. 1985), was used to estimate watershed-specific values of effective BC_w for a suite of modeled streams. Based on empirical relationships between simulated BC_w and key stream chemistry variables and watershed characteristics, simulated BC_w and other spatial variables were extrapolated to the regional population of streams in acid-sensitive portions of Virginia and West Virginia, allowing regional calculation of CL and CL exceedance using SSWC. MAGIC is used here as a tool to estimate BC_w because 1) there are no rigorous estimates of BC_w for this region derived using other approaches, 2) MAGIC is a dynamic model that includes representation of major processes known to control acidification response, and 3) MAGIC has been well tested and confirmed in a number of studies (cf., Sullivan and Cosby 1995, Cosby et al. 1996, Sullivan et al. 1996).

Application of the SSWC model to the study region in Virginia and West Virginia allows estimation of potential risks and current extent of impact to streams across a large geographic area. This area shows spatial variation in both acidification sensitivity and air pollution exposure. It also shows spatial variability in land use, including substantial amounts of protected federal lands. Class I national park and designated Wilderness areas within the study region are afforded the highest level of protection against adverse impacts of air pollution by the Clean Air Act (cf., Sullivan et al. 2003).

The work reported here is one part of a pair of linked projects, broadly termed the "multiagency critical loads effort for the eastern United States". This project focuses on estimation of steady state aquatic CL values for streams in Virginia and West Virginia. Ecosystem Research Group, Ltd. is conducting the companion project, which is estimating steady state terrestrial and aquatic (lake) CL values in New England and New York, as a follow-up to earlier efforts performed on behalf of the Joint Conference of New England Governors and Eastern Canadian Premiers (Dupont et al. 2005). In addition, the Northeast States for Coordinated Air Use Management (NESCAUM) stakeholder group is coordinating outreach for the multiagency effort through state air quality agencies.

2.0 APPROACH

The major steps involved in developing CL and exceedance maps for the study region were as follows:

1. Assemble spatial data layers for each term in the CL equation
   - a.) create weathering overlay
   - b) create runoff overlay
   - c) generate regional estimates of wet and dry atmospheric deposition
   - d) generate forest uptake overlay
2. Estimate N uptake parameter values
3. Calculate regional CL values for the landscape
4. Transfer regional CL values from the landscape to the stream network
5. Calculate CL exceedances

2.1 Site Selection and Data Sources

The study area was defined as the portions of the Central Appalachian, Ridge and Valley, and Blue Ridge Omernik Level III Ecoregions that occur within the states of Virginia and West Virginia (Figure 1). Available water chemistry data were compiled for 522 streams from previous studies in acid-sensitive portions of VA and WV (cf., Sullivan et al. 2002, 2003; Sullivan and Cosby 2004). There are substantial numbers of known acidic (ANC ≤ 0 μeq/L) and low-ANC streams throughout the study region (Figure 2). Many of these acid sensitive streams occur on public lands, including national park, wilderness, and national forest lands (Figure 3).

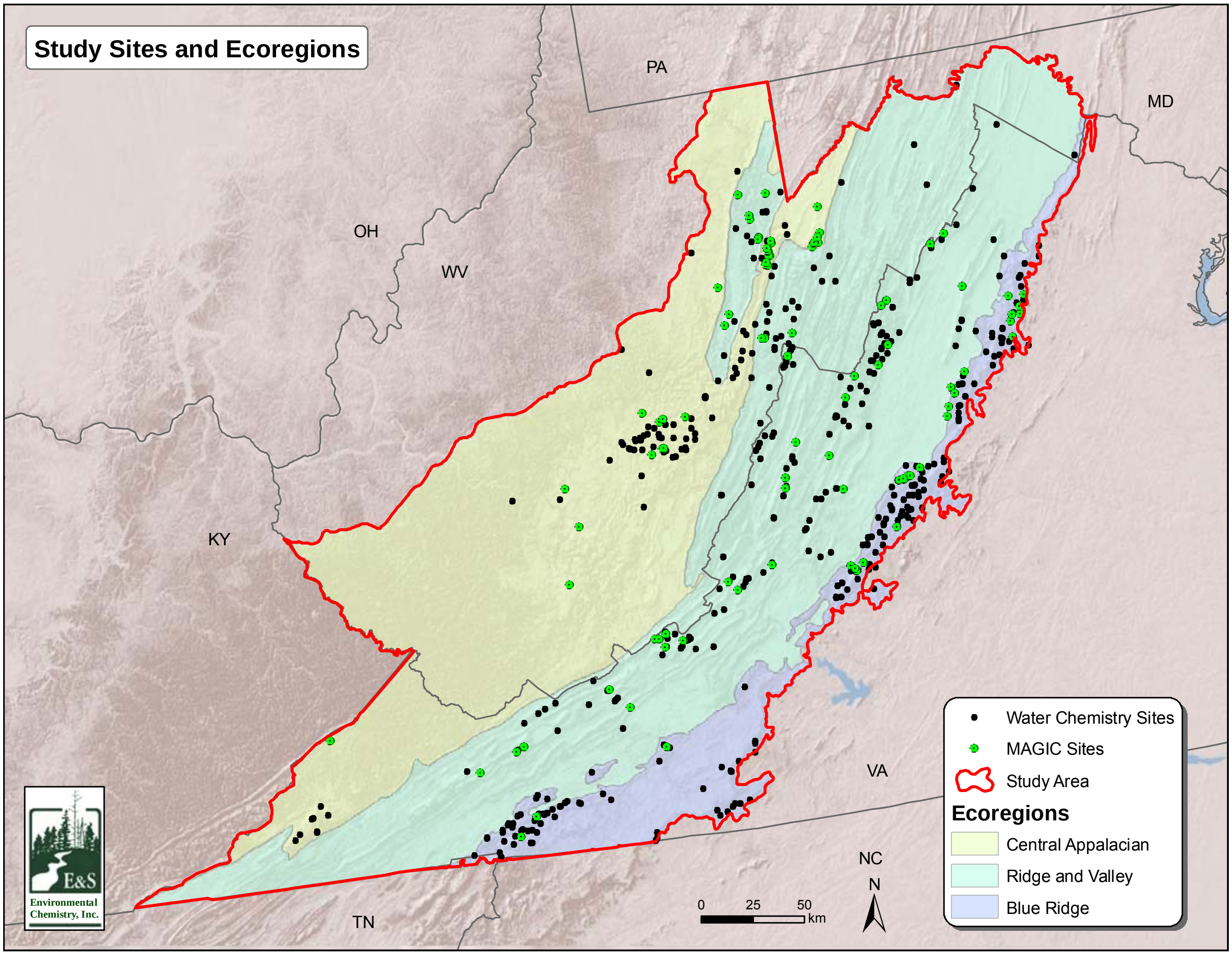

Figure 1. Study area selected for this research, showing the three ecoregions and locations of streams having water chemistry and those for which MAGIC model calibrations were available.

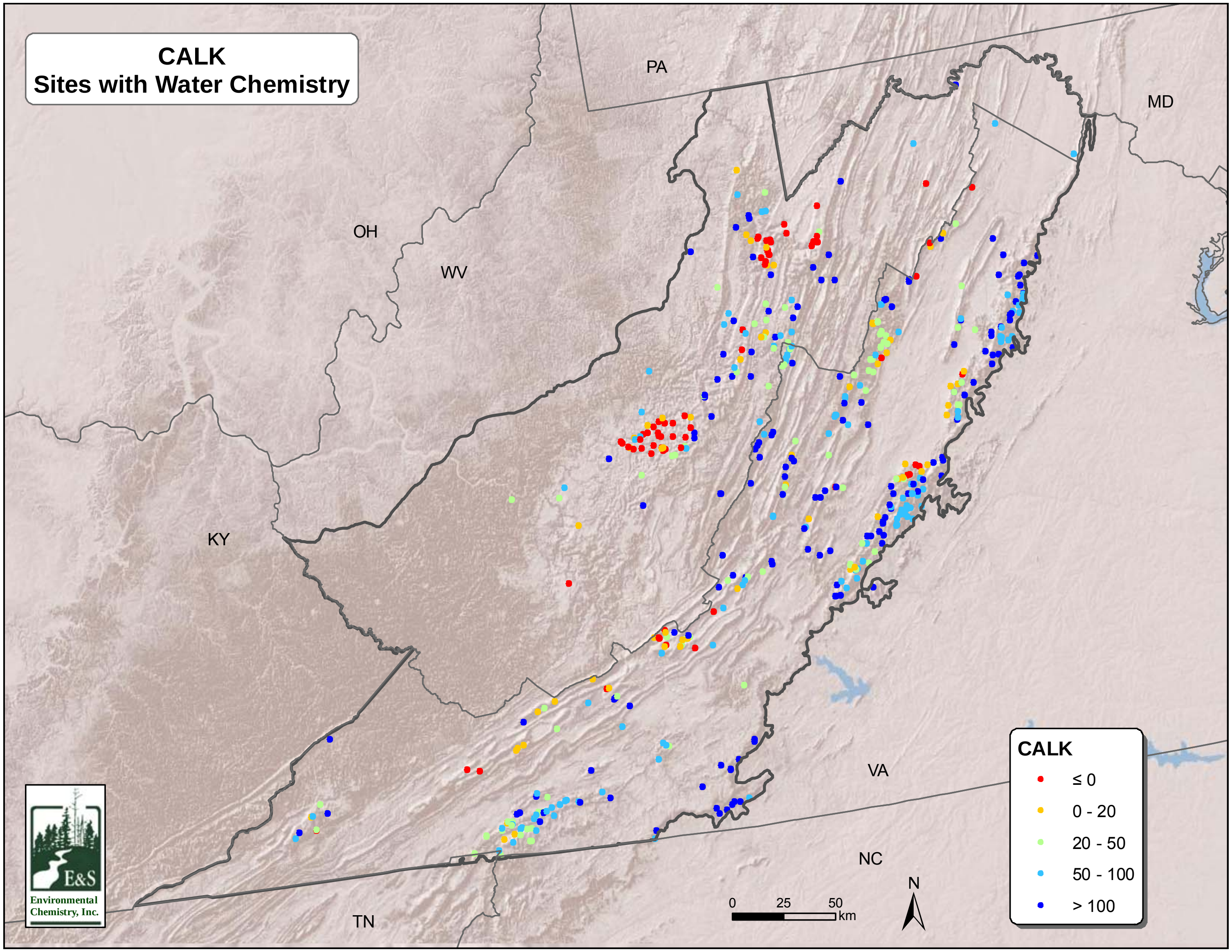

Figure 2. Calculated ANC (CALK) values of streams within the study region for which water chemistry data are available.

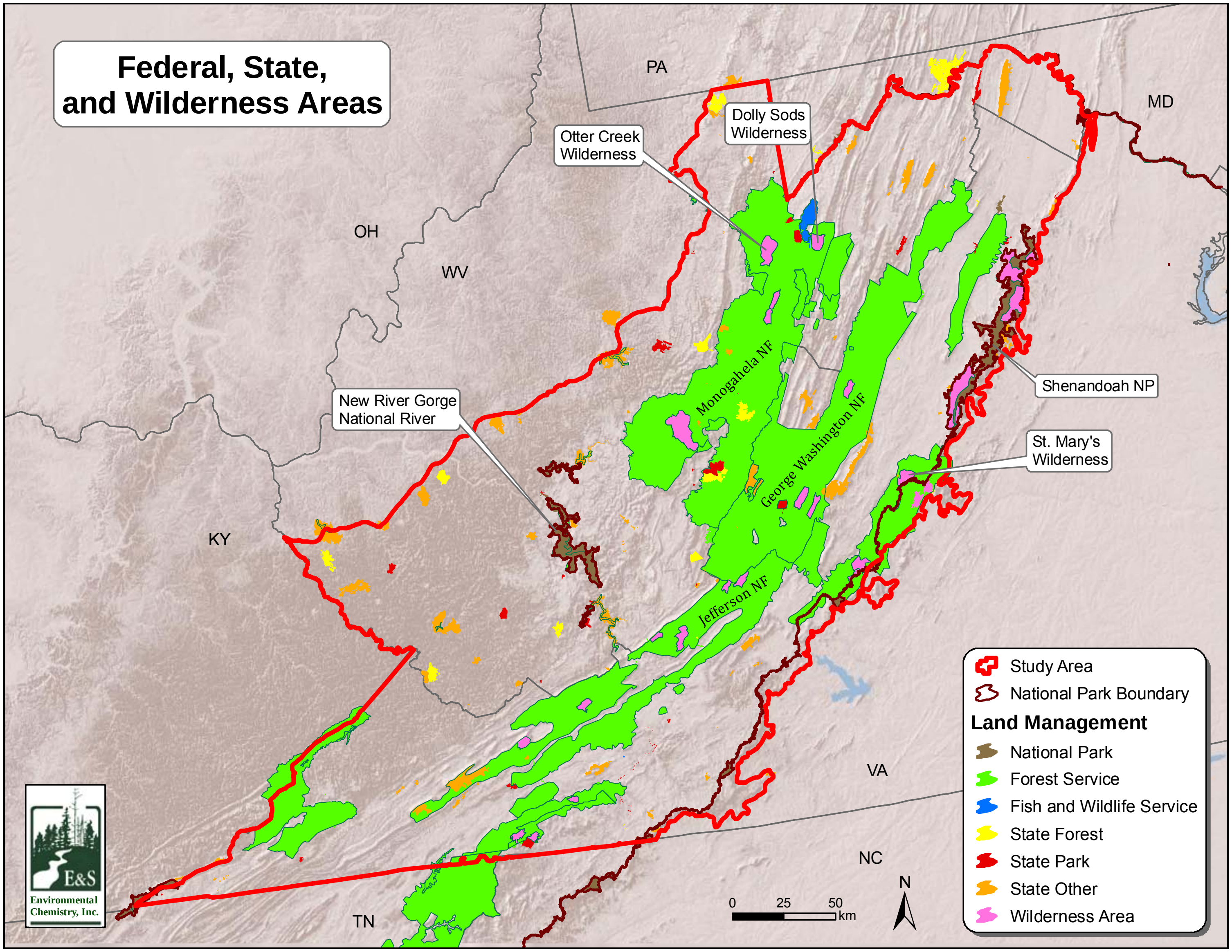

Figure 3. Map showing federal and state lands within the study area. Wilderness area boundaries are also shown.

A subset of these streams (n=100) was selected for dynamic modeling, including streams within the study region for which MAGIC model calibrations had previously been constructed. A geographic information system (GIS) data set was compiled for the study region that depicted regional spatial coverages of geologic sensitivity classes, soils characteristics, elevation, and watershed morphology (area, average slope).

2.2 Modeling

2.2.1 Steady State Water Chemistry Model

A modified version of the SSWC model (Sverdrup et al. 1990, Henriksen et al. 1992, Henriksen and Posch 2001) was used to calculate the steady state CL of acidity (CL(A)) for surface waters. It is based on the principle that acid loads should not exceed the balance of non-marine, non-anthropogenic base cation sources and sinks in a watershed, minus a buffer to protect selected aquatic biota from being damaged. This study employs the SSWC model as given in Equation 1 and also includes the necessary terms associated with biological N removal and immobilization. Nitrogen can be removed from the soil via uptake by tree boles that are harvested and removed from the watershed (N_{up}) and also through microbial denitrification (N_{de}) and long-term nitrogen immobilization (N_i) in forest soils. The CL of acidity is therefore calculated for this study as:

$$CL(A) = BC_{dep} + BC_w + N_{up} + N_{de} + N_i - Bc_{up} - ANC_{limit} \qquad (2)$$

where N_{de} is the removal of N from the site by denitrification, N_i is the immobilization of N by microbes, and N_{up} is the forest uptake of N. Note that the three N sink terms in this equation are included in addition to the CL equation parameters described by Henriksen and Posch (2001) for the SSWC. The addition of these terms renders Equation 2 similar in form to the First-order Mass Balance (FAB) model also used to calculate aquatic CL's (cf. Henriksen and Posch, 2001), the difference here being that the N terms in Equation 2 were estimated from regional empirical data rather than calculated based on landscape characteristics.

Because each of the variables given in Equation 1 can be estimated at broad spatial scales, it is possible to use the SSWC model to develop regional estimates of CL and CL exceedances. This model function allows assessment of regional patterns in acidification sensitivity and effects. It also allows for calculation of the total stream length and percent of stream length within the region of interest that fall within certain CL or exceedance classes.

All CL values calculated and presented in this report are based on the steady state approach given in Equation 2, and are expressed as CL(A), critical loads of acidity. These loads include both S and N sources of acidity.

2.2.2 MAGIC Model

MAGIC is a lumped-parameter model of intermediate complexity, developed to predict the long-term effects of acidic deposition on surface water chemistry (Cosby et al. 1985). The model simulates soil solution chemistry and surface water chemistry to predict the monthly and annual average concentrations of the major ions in these waters. MAGIC consists of: 1) a section in which the concentrations of major ions are assumed to be governed by simultaneous reactions involving SO_4^{2-} adsorption, cation exchange, dissolution-precipitation- speciation of Al and dissolution-speciation of inorganic C; and 2) a mass balance section in which the flux of major ions to and from the soil is assumed to be controlled by atmospheric inputs, chemical weathering, net uptake and loss in biomass and loss to runoff. At the heart of MAGIC is the size of the pool of exchangeable base cations in the soil. As the fluxes to and from this pool change over time owing to changes in atmospheric deposition, the chemical equilibria between soil and soil solution shift to give changes in surface water chemistry. The degree and rate of change of surface water acidity thus depend both on flux factors and the inherent characteristics of the affected soils.

Cation exchange is modeled using equilibrium (Gaines-Thomas) equations with selectivity coefficients for each base cation and Al. Sulfate adsorption is represented by a Langmuir isotherm. Aluminum dissolution and precipitation are assumed to be controlled by equilibrium with a solid phase of $Al(OH)_3$. Aluminum speciation is calculated by considering hydrolysis reactions as well as complexation with SO_4^{2-} and fluoride. Effects of carbon dioxide on pH and on the speciation of inorganic carbon are computed from equilibrium equations. Organic acids are represented in the model as tri-protic analogues. First-order rates are used for biological retention (uptake) of NO_3^- and ammonium in the soils and streams. Weathering of base cations is determined as part of the calibration process and is assumed to be constant. In the application here, nitrogen uptake dynamics do not vary in the long term. A set of mass balance equations for base cations and strong acid anions are included.

Given a description of the historical deposition at a site, the model equations are solved numerically to give long-term reconstructions of surface water chemistry (Cosby et al. 1989). MAGIC has been used to reconstruct the history of acidification and to simulate future trends on a regional basis and in a large number of individual catchments in both North America and Europe (e.g., Lepisto et al. 1988; Whitehead et al. 1988; Cosby et al. 1989, 1990, 1996; Hornberger et al. 1989; Jenkins et al. 1990a-c; Wright et al. 1990, 1994; Norton et al. 1992; Sullivan and Cosby 1998).

MAGIC Calibration Protocol

The aggregated nature of MAGIC requires that it be calibrated to observed data from a system before it can be used to examine potential system response. Calibration is achieved by setting the values of certain parameters within the model that can be directly measured or observed in the system of interest (called fixed parameters). The model is then run (using observed and/or assumed atmospheric and hydrologic inputs) and the outputs (streamwater and soil chemical variables - called criterion variables) are compared to observed values of these variables. If the observed and simulated values differ, the values of another set of parameters in the model (called optimized parameters) are adjusted to improve the fit. After a number of iterations adjusting the optimized parameters, the simulated-minus-observed values of the criterion variables usually converge to zero (within some specified tolerance). The model is then considered calibrated.

There are eight parameters to be optimized in this procedure (the weathering and the selectivity coefficient of each of the four base cations), and there are eight observations that are used to drive the estimate (current soil exchangeable pool size and current output flux of each of the four base cations). If new assumptions or new values for any of the fixed variables or inputs to the model are adopted, the model must be re-calibrated by re-adjusting the optimized parameters until the simulated-minus-observed values of the criterion variables again fall within the specified tolerance.

Estimates of the fixed parameters, deposition inputs, and the target variable values to which the model is calibrated all contain uncertainties. A "fuzzy optimization" procedure was utilized in this project to provide explicit estimates of the effects of these uncertainties. The procedure consists of multiple calibrations at each site using random values of the fixed parameters drawn from a *range* of fixed parameter values (representing uncertainty in knowledge of these parameters), and random values of Reference Year deposition drawn from a *range* of total deposition estimates (representing uncertainty in these inputs). The final convergence (completion) of the calibration is determined when the simulated values of the criterion variables are within a specified "acceptable window" around the nominal observed value. This "acceptable window" represents uncertainty in the target variable values being used to calibrate the site.

Each of the multiple calibrations at a site begins with (1) a random selection of values of fixed parameters and deposition, and (2) a random selection of the starting values of the adjustable parameters. The adjustable parameters are then optimized using an algorithm seeking to minimize errors between simulated and observed criterion variables. Calibration success is judged when all criterion values simultaneously are within their specified "acceptable windows", which may occur before the absolute possible minimum error is achieved. This procedure is repeated 10 times for each site.

For this project, the acceptable windows for base cation concentrations in streams were taken as +/- 2 µeq/L around the observed values (+/- 5 µeq/L for Ca^{2+}). Acceptable windows for soil exchangeable base cations were taken as +/- 0.2% around the observed values (+/- 0.5% for Ca^{2+}). Fixed parameter uncertainty in soil depth, bulk density, cation exchange capacity, stream discharge, and stream area were assumed to be +/- 10% of the estimated values. Uncertainty in total deposition was +/- 10% for all ions.

The final calibrated model at each site is represented by the ensemble of parameter values of all of the successful calibrations at the site. When performing simulations at a site, all of the calibrated parameter sets in the ensemble are run for a given historical or future scenario. The result is multiple simulated values of each variable in each year, all of which are acceptable in the sense of the calibration constraints applied in the fuzzy optimization procedure. The median of all the simulated values within a year is the "most likely" response for the site in that year. For this project, whenever single values for a site are presented or used in an analysis, these values are the median values derived from running all of the ensemble parameter sets for the site.

<u>MAGIC Weathering Estimates</u>

MAGIC is an aggregated catchment model. The base cation weathering terms in MAGIC are intended to represent the catchment-average weathering rates for the soil compartments. In a one soil-layer application of MAGIC (such as here) the weathering rates in MAGIC thus reflect the catchment-average net supply of base cations to the surface waters draining the catchment.

The sum of the MAGIC weathering rates for the individual base cations is therefore identical in concept to the base cation weathering term, BC_w, in the SSWC CL model. Base cation weathering rates from MAGIC should be directly applicable in the SSWC model.

Base cation weathering rates in MAGIC are calibrated parameters. The calibration procedure uses observed deposition of base cations, observed (or estimated) base cation uptake in soils, observed stream water base cation concentrations, and runoff. These observed input and output data provide upper and lower limits for internal sources of base cations in the catchment soils. The two most important internal sources of base cations in catchment soils are modeled explicitly by MAGIC: primary mineral weathering and soil cation exchange. During the calibration process, observed soil base saturation for each base cation and observed soil chemical characteristics are combined with the observed input and output data to partition the inferred net internal sources of base cations between weathering and base cation exchange.

Weathering is assumed constant in MAGIC, but base cation exchange varies through time as anion fluxes change and as the soil base saturation increases or decreases. Therefore, the calibration simulations are performed over an historical period of approximately 150 years. Weathering and cation exchange selectivity coefficients are selected during calibration such that the model starts with "reasonable" soil and stream conditions, responds to the 150 year period of deposition changes at the site, and ends with simulated values of stream and soil base cations that are consistent with the currently observed stream export at the site and the current observed soil base saturation at the site. The partitioning of observed base cation export into weathering and cation exchange by MAGIC is thus heavily constrained by observed deposition, soil and stream water data. The better the data quality, the more extensive the soils measurements, the longer the observed record, the more robust and reliable the weathering estimates are likely to be.

The catchment-average estimates of weathering rates derived from MAGIC calibrations provide data-constrained, site-specific, conceptually appropriate values for inclusion in the SSWC model for that site. The calibrated MAGIC weathering estimates at multiple sites in a region can be used as the basis for development of empirical regression models to spatially extrapolate the site-specific weathering rates to the regional landscape.

<u>Calibration of MAGIC to Study Sites</u>

For each of the 100 selected study sites, the MAGIC model calibrations conducted as part of the previously completed Southern Appalachian Mountain Initiative (SAMI) modeling project

(Sullivan et al. 2002), Shenandoah Park Assessment (Sullivan et al. 2003), and Monongahela National Forest modeling effort (Sullivan and Cosby 2004) were retrieved. These already developed model calibrations provided the starting point for the MAGIC re-calibrations in this project. Details of the original input databases, data aggregation procedures, and protocols for assigning wet and dry deposition, soils and streamwater inputs for MAGIC at each site are given by Sullivan et al. (2002, 2004).

Some changes in the original SAMI model calibration protocols were required for this project because the base cation weathering values derived from the MAGIC calibrations were passed directly to the SSWC model for individual site estimations of CLs (or extrapolated to a GIS layer for later spatial estimation of SSWC CLs). It was therefore important that all assumptions or inputs being used for the SSWC model also be included in the MAGIC calibrations. To bring the original SAMI calibrations of MAGIC in line with the assumptions being used to implement the SSWC CLs model for this project, three components employed in the calibration approach used for the SAMI aquatic assessment (Sullivan et al. 2002) were changed. With the exception of these three components (described below), all other inputs to MAGIC were identical to those used in the original SAMI project.

First, the dry deposition of base cations and chloride (Cl^-) were modified slightly from the original SAMI values. This was necessary to make the total deposition of base cations and Cl^- used for MAGIC calibrations equal to the total deposition of those ions to be used in the SSWC model calculations.

Second, during the original SAMI calibrations, an examination of the empirical input-output mass balances of SO_4^{2-} and Cl^- for each of the sites revealed slight discrepancies at some of the sites. For those sites, the estimated stream outputs of these ions were higher than the estimates of deposition inputs. As a result, small catchment sources of SO_4^{2-} and Cl^- were assumed during the MAGIC calibrations for SAMI. The values of those catchment sources were re-derived for this project to bring the mass balances into alignment with the more recent deposition data to be used in the SSWC model. Of the sites included in this study, 16 were simulated as having small sources of SO_4^{2-} and Cl^- in their catchments.

Third, assumptions regarding internal soil sources and sinks were modified from the original SAMI protocol. In the SAMI study, the base cation uptake from soils by forest growth and harvesting was not included in the MAGIC calibrations. Because the SSWC explicitly includes these terms, it was necessary to include them as soil sinks of base cations in the re-calibrations of MAGIC for this project.

Following the three adjustments to the input data described above, the 100 sites were re-calibrated using the "fuzzy" optimization procedure. For 92 of the sites, the optimization procedure produced 3 or more successful calibrations out of the 10 attempted for the site (85 of the sites had 7 or more successful calibrations). The median simulated values (of the ensemble of successful calibrations) at each of the 92 sites agree well with the observed data during the calibration year (Figure 4). The median weathering estimates extracted from the MAGIC calibrations for these 92 sites were used in the next phase of this study.

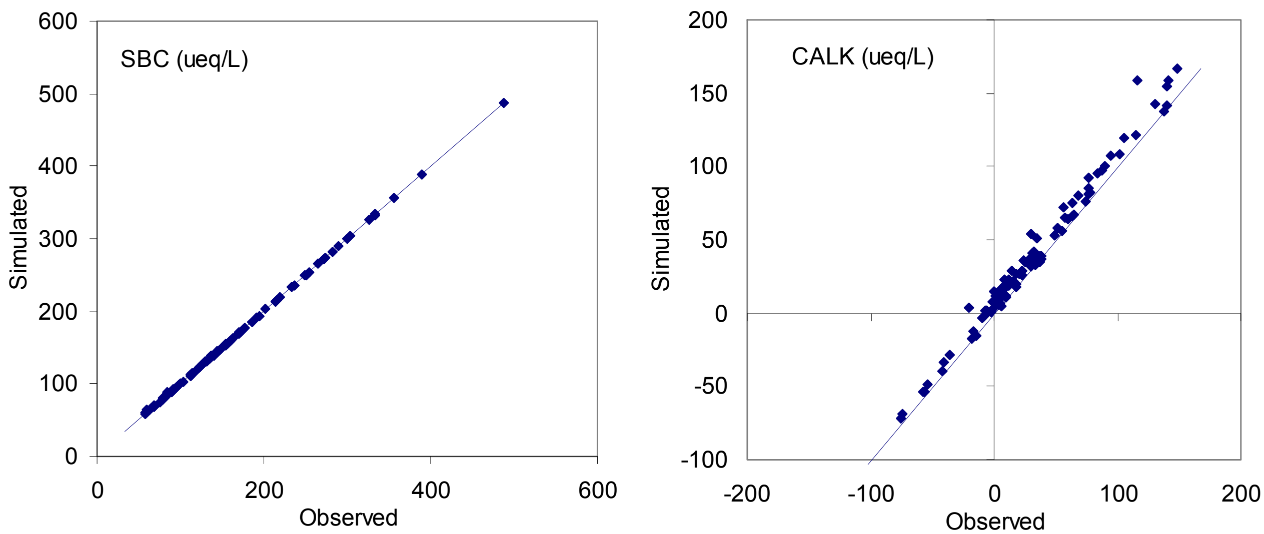

Figure 4. Simulated vs observed values of sum of base cations and calculated ANC (CALK) for the calibration period at each of the study sites modeled using MAGIC (n = 92).

2.3 Regional Extrapolation of Base Cation Weathering for Input to SSWC

Calibrated MAGIC estimates of effective base cation weathering (BC_w) at individual modeling sites were extrapolated to the study region using a combination of water chemistry and/or landscape variables thought or known to be associated with weathering rates and watershed acid sensitivity. The candidate independent variables are described below. The major steps employed in developing regional estimates of BC_w were as follows:

1. Identify candidate stream sites for dynamic modeling.

2. Refine MAGIC model calibrations and extract effective watershed-specific BC_w estimates for the dynamic modeling sites.
3. Compile regional data on stream chemistry and candidate explanatory landscape variables for extrapolation of the weathering estimates derived for the dynamic modeling sites to the regional landscape.
4. Develop an approach for watershed delineation in the regional landscape.
5. Develop empirical relationships with which to extrapolate BC_w to the study region, using regional stream chemistry and/or landscape characteristics.
6. Process predictor variable data using grid cell flow direction derived from the digital elevation model (DEM) and a continuous upslope averaging model.
7. Calculate BC_w for each 30-m pixel within the study area using the empirical relationships that were established in Step 5 and the upslope continuously averaged predictor variable datasets calculated in Step 6.

2.3.1 Input Data for BC_w Regression Equations

Stream Chemistry

The acid-base chemistry of streams is reflected in the stream water by ANC and the concentrations of strong mineral acid anions and base cations in solution. Thus, candidate water chemistry independent variables selected for this analysis included the variables given in Table 1. MAGIC calculates ANC as the difference between the sum of the base cations (SBC) and the sum of the mineral acid anions (SAA). The calculated ANC is termed CALK.

Elevation and Slope

Elevation data at a resolution of one arc-second (approximately 30 m) were extracted from the U.S. Geological Survey (USGS) National Elevation Dataset. Average elevation and percent slope for each watershed modeled with MAGIC were calculated from the elevation data.

Geologic Sensitivity

Data representing regional geologic sensitivity were mapped at coarse resolution (1:250,000 scale) based on USGS lithology data (Sullivan et al. 2007). The geologic sensitivity classes represented by the data included siliciclastic, argillaceous, felsic, mafic, and carbonate.

Table 1. Candidate variables for predicting BC_w.

Landscape Characteristics	Water Chemistry
• Watershed area	• Sum of base cations
• Elevation	• Sum of base cations – chloride
• Slope	• Calculated ANC
• % siliciclastic	• Sulfate
• % argillaceous	• Nitrate
• % felsic	
• % mafic	
• % carbonate	
• % clay in soil	
• Soil pH	
• Soil depth to restricting layer	

The polygon data were converted to five grids, each representing an individual sensitivity class. Grid cells were assigned a value of 1 to indicate presence of the respective sensitivity class and 0 representing its absence. A weighted-average kernel smoother was used to generate a transition zone of approximately 800 m between adjacent geologic sensitivity classes to reflect the coarse scale and spatial uncertainty in the lithology data.

Soils

Soils data from the Soil Survey Geographic (SSURGO) database were available for the majority of the study area (http://soils.usda.gov/survey/geography/ssurgo/). Where SSURGO data were not available, the coarser-scaled State Soil Geographic (STATSGO2; U.S. General Soils Map, http://soils.usda.gov/survey/geography/statsgo/) data were substituted. Soil parameters that were extracted from these databases for this study included depth to restricting layer, percent clay, and pH. SSURGO and STATSGO2 are spatially represented using “map units”. Each map unit is typically comprised of multiple “components”. The soils parameters were tabulated and coded to each soil map unit based on a component weighted average. The resulting tabular data were joined with the spatial polygon data and converted to a 30-m grid using the maximum area cell assignment option in ArcGIS.

Depth to restricting layer was defined as the depth to the first layer that prevents root penetration and water movement as represented in the soil databases. These depths were calculated for each component and then weighted and summed to generate a representative depth to restricting layer for each map unit. STATSGO2 data were used where SSURGO data contained no data or a value of 0. A limited portion of the study area was classified as open water, and was represented in SSURGO as having no soils data. The no-data cells (corresponding with open water) were filled with an average of the nearby data cells (30 x 30 cell window) using the focal statistics function in ArcGIS. This step was required in order to maintain continuity during application of the continuous upslope averaging function.

Soil components in SSURGO and STATSGO2 are attributed with percent clay at multiple soil horizons. Therefore, percent clay was calculated as a soil horizon thickness weighted average for each component. The representative percent clay for each map unit was then calculated as a component weighted average. STATSGO2 data were used where SSURGO data contained no-data or a value of 0. The open water cells were treated as for soil depth calculations. The same methods as described for percent clay were followed for generating a representative pH value for each map unit.

2.3.2 Establishing BC_w Predictor Equations

Regression input data were developed at different scales, ranging from 30-m DEM grid data to lithologic polygon data developed at a scale of 1:250,000 in West Virginia and 1:500,000 in Virginia (Table 2). In order to use a regression approach to estimate BC_w from calibrated MAGIC BC_w, it was necessary to express all candidate predictor variables on a grid basis at the same scale. This was accomplished at the 30-m grid scale, which provided sufficient resolution to conduct flowpath analyses that could be used to develop topographically determined streams. Polygon data were resampled to 30-m grid cells, preserving the data developed at the original

Table 2. Source and scale of input data for spatial extrapolation.

Dataset	Source	Scale or Resolution
Elevation	National Elevation Dataset (NED)	1 arc-second (30m)*
Slope	Derived from NED data	1 arc-second (30m)*
Geology	USGS Statewide Geology	1:250,000 (WV), 1:500,000 (VA)
Soils	SSURGO STATSGO	1:24,000 1:250,000
Watershed Area	Derived from NED data	1 arc-second (30m)*

* approximately equivalent to 1:24,000

input database scale. The only scale adjustment that was made involved generating a transition zone between adjacent geologic sensitivity classes to smooth out the uncertainty in the geologic sensitivity class boundary locations.

Regression techniques were used to establish equations to be used for BC_w prediction within each of the three study ecoregions. MAGIC model estimates of BC_w for the 92 calibrated watersheds located throughout the study area were used as observed weathering rates. Both landscape and water chemistry variables were used as predictor variables in the regression analyses (Table 1).

Each of the calibrated MAGIC study watersheds was placed in an ecoregion category based on which ecoregion contained the maximum watershed area. Two predictor equations were established for each of the three ecoregions, one using both landscape characteristics and water chemistry parameters (for use in watersheds for which stream chemistry data are available) and another using landscape characteristics only. Watershed averages were used to represent the spatial variability within each watershed for the landscape characteristics, except for watershed area.

Regression models were established using stepwise linear regression in Statistix 8.0. Best subset regression was used for model selection in the Blue Ridge ecoregion using landscape variables only, in order to reduce the number of independent predictor variables. Regional distributions of the candidate predictor variables are described for each study ecoregion in Appendix B.

2.3.3 BC_w Estimates for Sites with Water Chemistry, Based on Water Chemistry plus Landscape Variables

Water quality predictor data had been collected during several regional surveys, as compiled by Sullivan et al. (2002) and Sullivan and Cosby (2004). One water quality sample, generally collected during the spring between 1985 and 2001, was used to characterize each watershed. Water quality data were derived from several regional surveys, including the National Stream Survey (NSS), Environmental Monitoring and Assessment Program (EMAP), Virginia Trout Stream Sensitivity Study (VTSSS), and stream surveys conducted in Monongahela National Forest (cf., Sullivan and Cosby 2004). Watershed averages of the landscape predictor variables were calculated using the zonal statistics function in ArcGIS. Estimates of BC_w were made using the appropriate regression equation as established through the methods described below. Coefficients and their standard errors are given in Appendix C.

2.3.4 BC_w Estimates for Entire Study Area, Based on Landscape Variables Only

Continuous upslope averages for each of the landscape predictor variables were calculated for each 30-m grid cell using hydrologically conditioned DEM data derivatives (NHDPlus). The continuous upslope averaging function begins with using a continuous spatial dataset (such as soil pH) as a weighting factor in a DEM-based flow accumulation algorithm within ArcGIS (Jenson and Domingue 1988, Verdin and Worstell 2008). This function sums all of the data values that occur within cells upslope from the target cell. This accumulated data layer is then added to the raw input data layer in order to account for the value that occurs at the target cell itself. A value of one is added to the flow accumulation grid, which results in a count of all upstream contributing cells including the target cell. These two values are then divided to generate an average of all data values that occur upslope from the target cell. This process is described by the equation:

$$P_{avg} = (P + P_{fac})/(fac + 1) \tag{3}$$

where P_{avg} = upslope averaged parameter value
P = a continuous input parameter
P_{fac} = a flow accumulated input parameter
fac = flow accumulation grid

Each of the input landscape datasets was processed in this manner, except for watershed area. Watershed area was obtained by summing the new contributing area gained while moving down gradient (i.e., setting the denominator in the above equation equal to 1).

Stream chemistry input data for the regression models were the same as the stream data used to calibrate MAGIC. However, none of the landscape variables listed in Table 1 were used in calibrating MAGIC. Thus, the extrapolations based only on landscape variables, which were used for the regional CL evaluation, were independent of any calculations done with MAGIC.

2.4 Calculation of Critical Loads and Exceedances

2.4.1 Inputs for SSWC Critical Load Calculations

BC Weathering

Base cation weathering values for the SSWC were derived from regional extrapolations of weathering estimates extracted from the MAGIC model calibrated to 92 sites in the study region (see section 2.3). Two extrapolation methods were employed which allowed estimation of BC_w at any location in the study region using either landscape characteristics and observed stream water chemistry, or landscape characteristics alone.

BC Deposition

Wet deposition estimates were obtained from interpolated National Acid Deposition Program (NADP) data at 375 m resolution. A five-year average centered on 2002 was used as model input. Literature values of dry:wet deposition ratios for the Southern Blue Ridge Mountains were used to estimate dry deposition of base cations from the NADP interpolations (Baker et al. 1991). BC_{dep} was corrected for sea-salt influence by subtracting the Cl^- deposition rate. Total deposition may be underestimated at the highest elevation areas, where unmeasured cloud deposition might be quantitatively important. BC_{dep} was calculated as a continuous upslope average, using the procedures developed for calculation of BC_w.

Nitrogen Immobilization and Denitrification

Denitrification rates in boreal and temperate ecosystems can be variable. Denitrification was set to 7.14 meq/m^2/yr (1 kg N/ha/yr) as an approximate average representative value for the study area (cf., Ashby et al. 1998). Long-term net nitrogen immobilization (N_i) was set to 4.3 meq/m^2/yr (McNulty et al. 2007).

ANC Limit

The ANC_{limit} was calculated for the various CL applications as the product of estimated runoff and the designated critical ANC criteria values (0, 20, 50, 100 µeq/L). These ANC thresholds for biological response should be interpreted within the context of known or suspected dose-response functions, summarized for Shenandoah National Park in Appendix A. They should also be interpreted within the context of model hindcast estimates of pre-industrial stream chemistry, which are given for the 92 MAGIC sites in Appendix D.

While the ANC criteria values did not vary across the study region, the runoff used to calculate the ANC_{limit} was assumed to vary spatially. An algorithm was developed using USGS runoff estimates at gaging stations within the study region, combined with elevation and orographically-correlated precipitation amounts from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) , to estimate fine-scale variation in runoff across the study domain (Figure 5). The ANC limit was not calculated as an upslope average using the watershed pixels because the runoff term used to calculate the ANC_{limit} already reflects an upslope averaged condition.

<u>Forest Uptake</u>

Forest uptake fluxes of the three nutrient base cations (Ca^{2+}, Mg^{2+}, K^{+}; Bc_{up}) and nitrogen (N_{up}) were estimated from literature values summarized from the U.S Forest Service, Forest Inventory Analysis (FIA) project by McNulty et al. (2007). It was assumed that 65% of the estimated average forest volume increment is removed from the watershed annually through

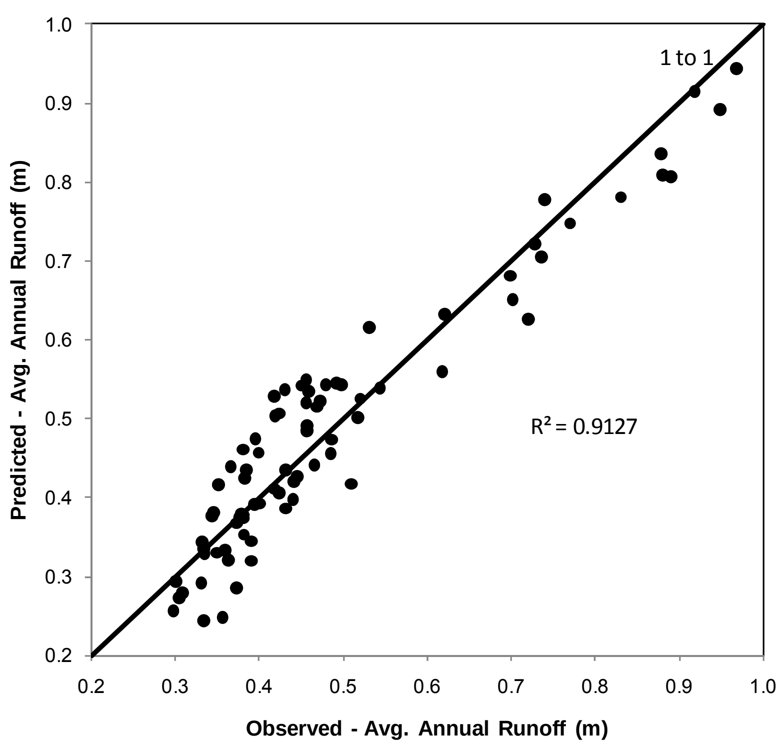

Figure 5. Predicted (from PRISM precipitation model and elevation) versus observed (at USGS gages) runoff in Virginia and West Virginia. The predictive equation was used to predict runoff for the study region. Predictions beyond the range of observed values were truncated at the levels of the extreme values.

harvesting. These uptake terms reflect uptake into woody materials that are removed from the watershed through forestry practices. Uptake into vegetation that subsequently dies on site represents within-watershed recycling; this is not a watershed output and is not included in the SSWC model calculations. Lands identified as national park, designated Wilderness, and other protected areas were classified as “no harvest”; Bc_{up} and N_{up} were set to zero in such areas. These areas included the Protected Areas database constructed by the Commission for Environmental Cooperation, corresponding to GAP codes 1 and 2 (Scott et al. 1993). It must be recognized that other forest lands, for example in the national forests, may also be considered “no harvest” under current, or future, management plans. The possible existence of such management policies is not accounted for in the modeling reported here. Bc_{up} and N_{up} were calculated as continuous upslope averages, using the procedures developed for calculation of BC_w.

2.5 Critical Load and Exceedance Calculation Methods

Each of the terms in the SSWC model was calculated for every 30-m grid cell in the study region and then combined to yield an estimate of CL for each grid cell. Each of the variables in the SSWC formulation (Equation 2) was represented as a spatial coverage across the study region based on the topographically determined watershed polygons. The CL values for each threshold ANC value were calculated and mapped. Watershed CL values were then extracted with the topographically derived stream network to include only those 30 m pixels that occurred along the stream grid cells. Results of the CL calculations for those pixels that occurred along topographically derived streams were averaged to yield the CL of the stream reach that flowed through each watershed. These watershed CL estimates were intersected with the high-resolution NHD dataset to yield a regional coverage of stream reaches, coded by CL class.

Critical load and ambient deposition acidity data were overlayed to determine the exceedance, or the amount by which ambient deposition exceeds the estimated CL. Exceedance maps were developed for the various threshold ANC values.

Atmospheric deposition of acidity, CL(A), and exceedances at the various ANC threshold values are all reported and mapped in equivalents per unit watershed area, rather than for example in kilograms per hectare or some other mass unit basis. This is necessary in order to combine S acidity and N acidity to evaluate total deposition acidity. For a given amount of deposition acidity, there exists an infinite number of possible combinations of S and N inputs that could achieve that acidity. However, in most watersheds within the study region, mineral acid anion leaching is comprised primarily by SO_4^{2-}; in general, most atmospheric N is retained in watershed soils and vegetation, with limited NO_3^- leaching (Sullivan et al. 2002). Therefore, equivalent units of deposition can be approximately converted to mass units if one makes assumptions about the contribution of N to the acidity of deposition. For example, if all of the acidity is derived from S, and none is derived from N, then CL(A) in units of meq/m^2/yr times 0.16 is equal to CL of S deposition in units of kg S/ha/yr.

3.0 RESULTS

3.1 MAGIC Simulations and Development of Equations to Predict BC_w

A total of 92 stream sites were successfully calibrated using MAGIC. BC_w estimates for those watersheds were extracted from the calibration files. Of those sites, 26 were in the Blue Ridge, 42 in the Ridge and Valley, and 24 in the Central Appalachian ecoregion. Ecoregion-specific regression equations were developed with which to predict the MAGIC estimates of BC_w at the 92 sites. Two sets of predictive equations were developed, using either stream chemistry and watershed features (for 522 sites for which water chemistry data had been compiled) or using watershed features alone (for all watersheds within the study area). The predictor water chemistry variables included calculated ANC, sum of base cations, and NO_3^- concentration. Significant predictor landscape variables included aspects of lithology (% siliciclastic, felsic, mafic, or carbonate geological types), soils characteristics (pH, depth to confining layer, % clay), and watershed physical condition (area, elevation, average slope; Table 3). For the predictive equations that included water chemistry, neither the soils variables nor the geologic variables were included in the final regression equations. In contrast, for the predictive equations that did not include water chemistry, one or more soil variables were included, and for two of the three ecoregions, one or more geologic variables were included in the final regression equations. This result is likely because stream chemistry integrates soil and geologic condition within the watershed, and may be a better predictor of catchment weathering than available aggregated and mapped soil and geologic information. Thus, geologic and edaphic variables do not provide much additional explanatory power if water chemistry data are already included in the regression relationship.

Table 3. 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[1]	r^2
Water Chemistry and Landscape Variables			
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
Landscape Variables Only			
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

[1] SBC is sum of base cations; CALK is calculated ANC.

Watershed boundaries and stream sampling locations for the MAGIC sites are shown in Figure 6. Most modeled watersheds are small and located at moderate to high elevation (Figure 7). Few sites were below 500 m elevation. Percent watershed slope was variable, with most sites having slope greater than about 10% (Figure 8). Much of the geology in the study area is expected to exhibit relatively low weathering rates, based on the preponderance of siliciclastic and argillaceous lithologies (Figure 9; cf., Sullivan et al. 2007). Soil % clay is relatively high (greater than about 15%) throughout much of the study area (Figure 10), with nearly all areas having % clay above 10%. Soil pH typically varied between about 4.5 and 5.5 (Figure 11). Soils are generally shallow (less than about 1 m to a confining layer in large portions of the study areas), but deeper soils are also common (Figure 12).

Equations for the three ecoregions with which to predict BC_w, using a combination of stream chemistry and watershed features, yielded good agreement with MAGIC simulations of catchment weathering (Figure 13; Table 3). For the Blue Ridge ecoregion, the predictive equation based on landscape data alone (% felsic and mafic lithologies, soil % clay, soil depth) explained nearly as much of the variation in MAGIC weathering (85%) as the equation based on water chemistry (calculated ANC and stream NO_3^- concentration); none of the landscape variables entered into that equation (Table 3). For the Ridge and Valley and the Central Appalachian ecoregions, the equations to predict BC_w based on landscape variables alone

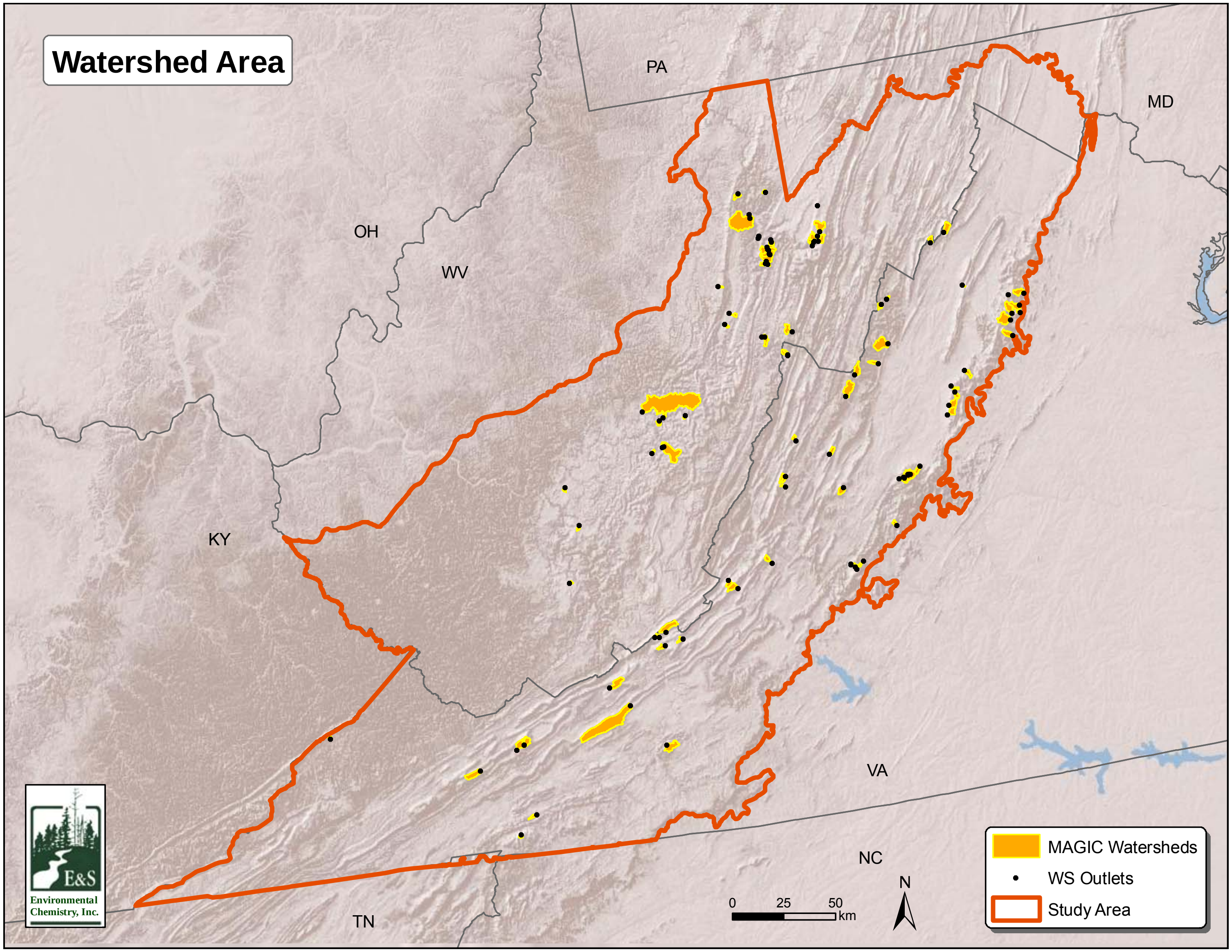

Figure 6. Stream sampling locations and associated watersheds for sites modeled with MAGIC.

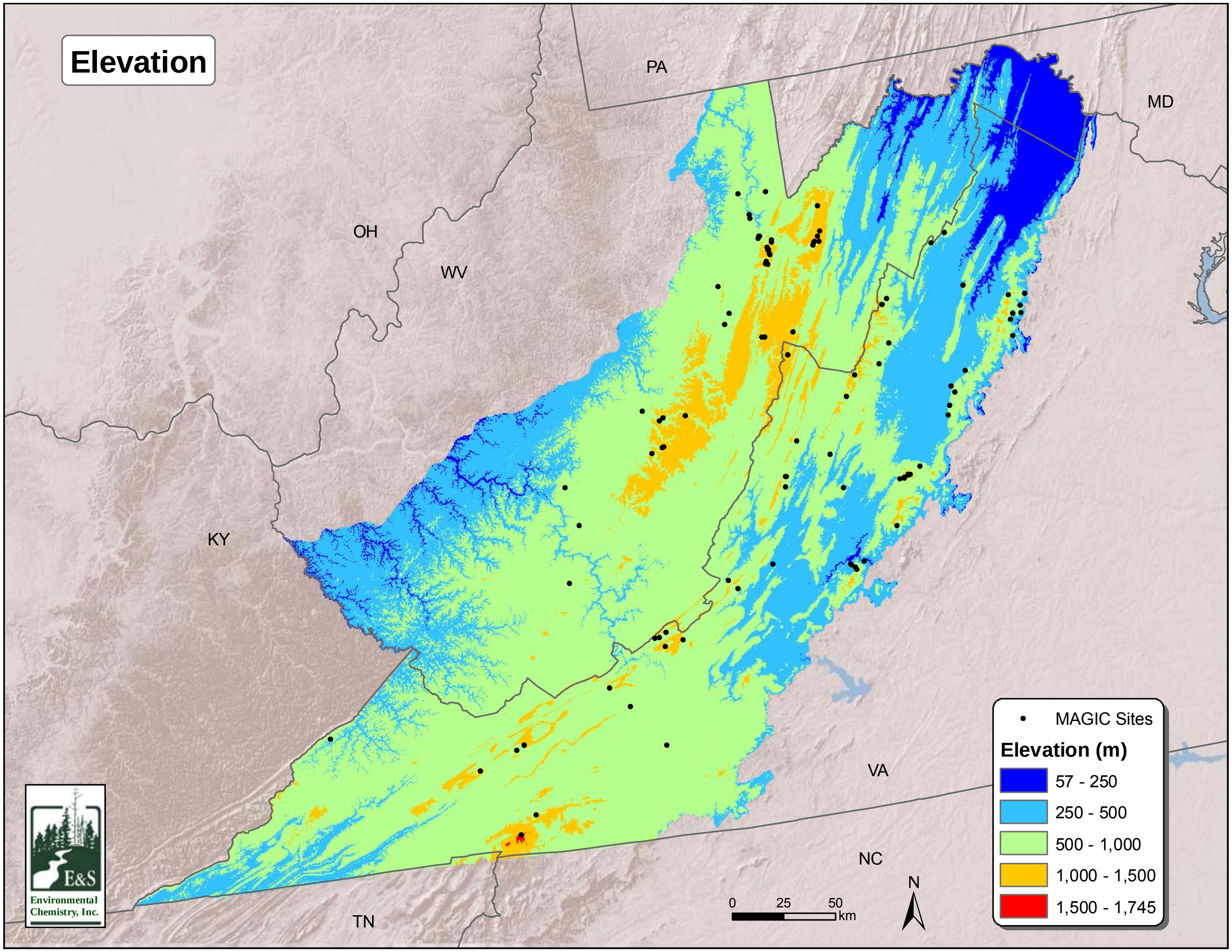

Figure 7. Elevation pattern across the study area. Also shown are MAGIC model sampling sites.

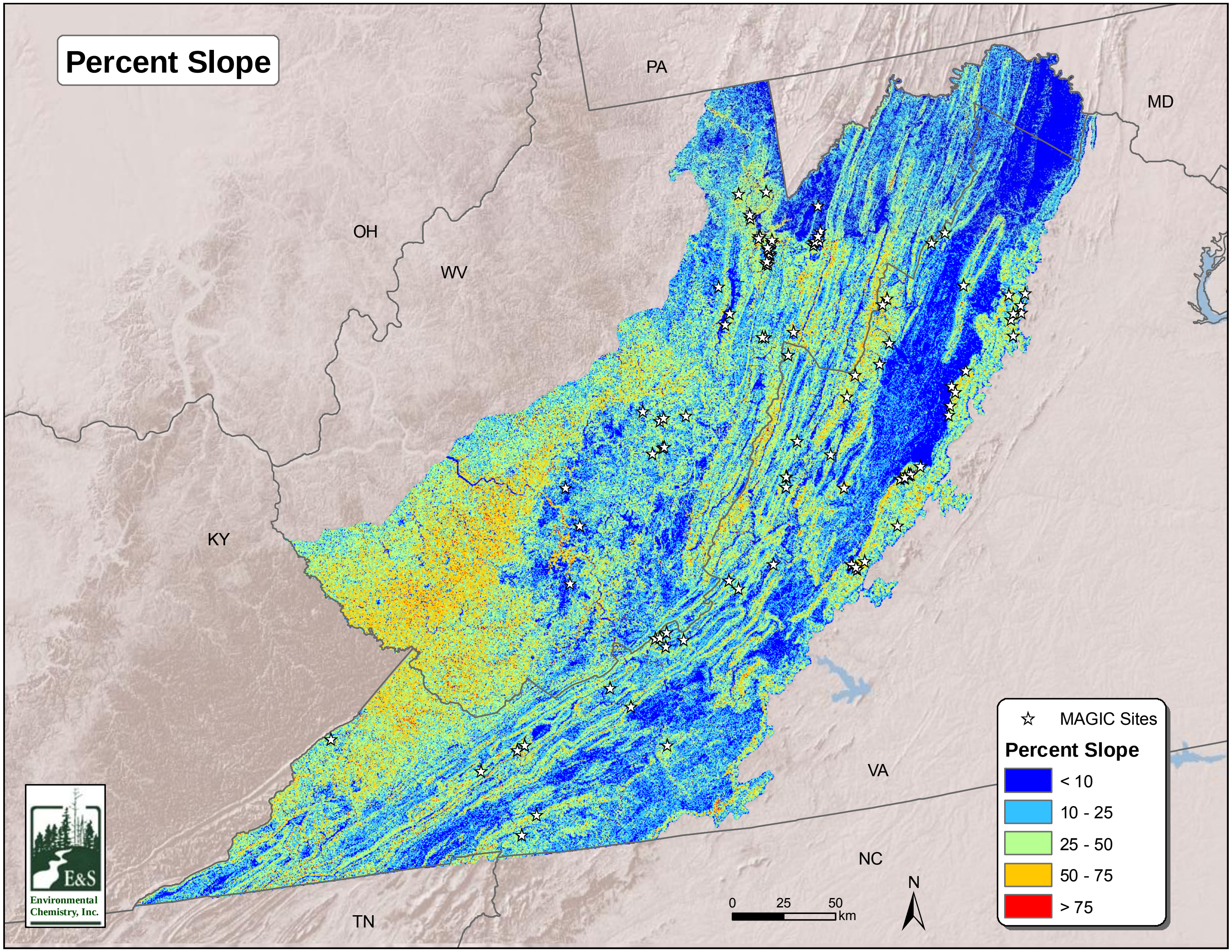

Figure 8. Spatial pattern in percent watershed slope across the study area. Also shown are MAGIC modeling sites.

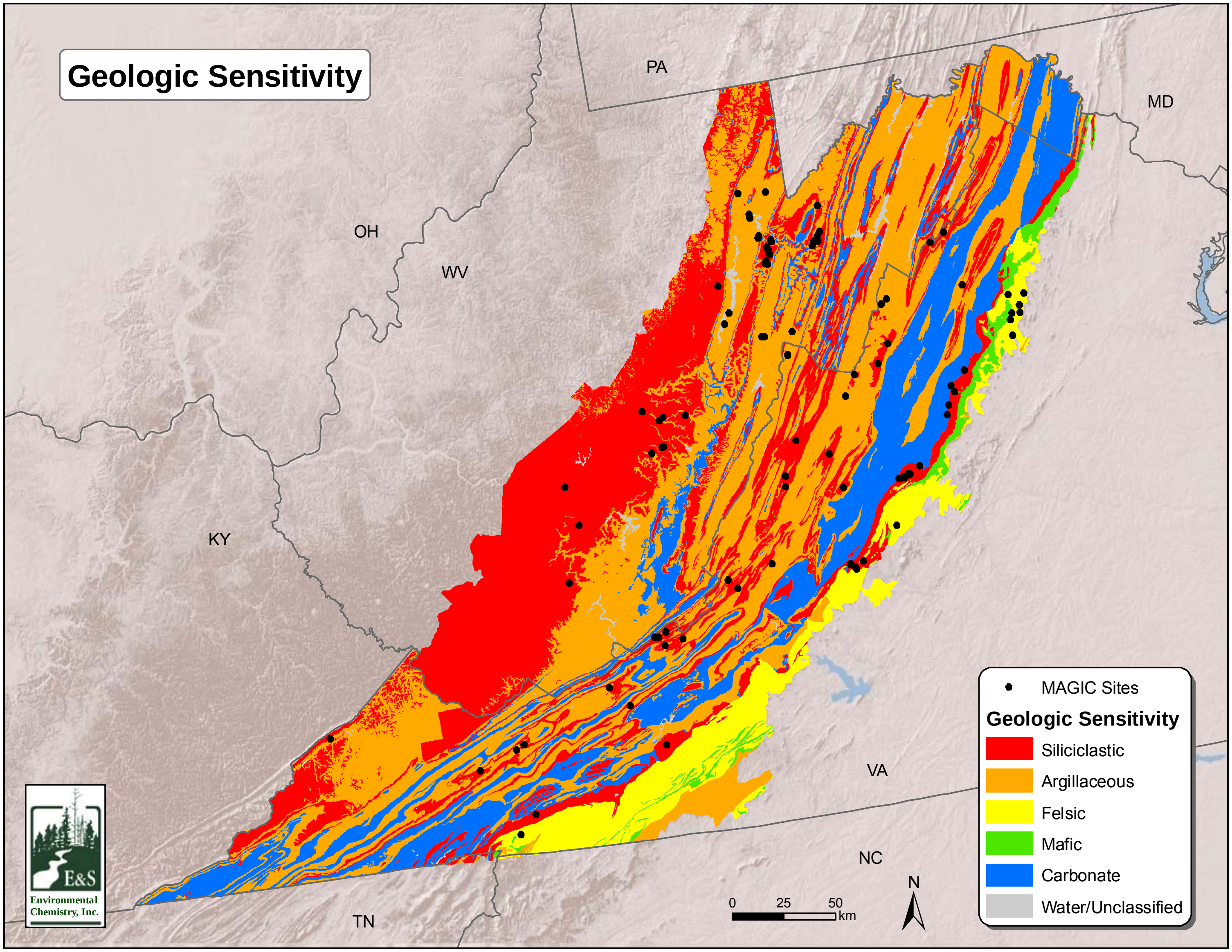

Figure 9. Geologic sensitivity classes, as determined by Sullivan et al. (2007) across the study area. Also shown are MAGIC model sampling sites.

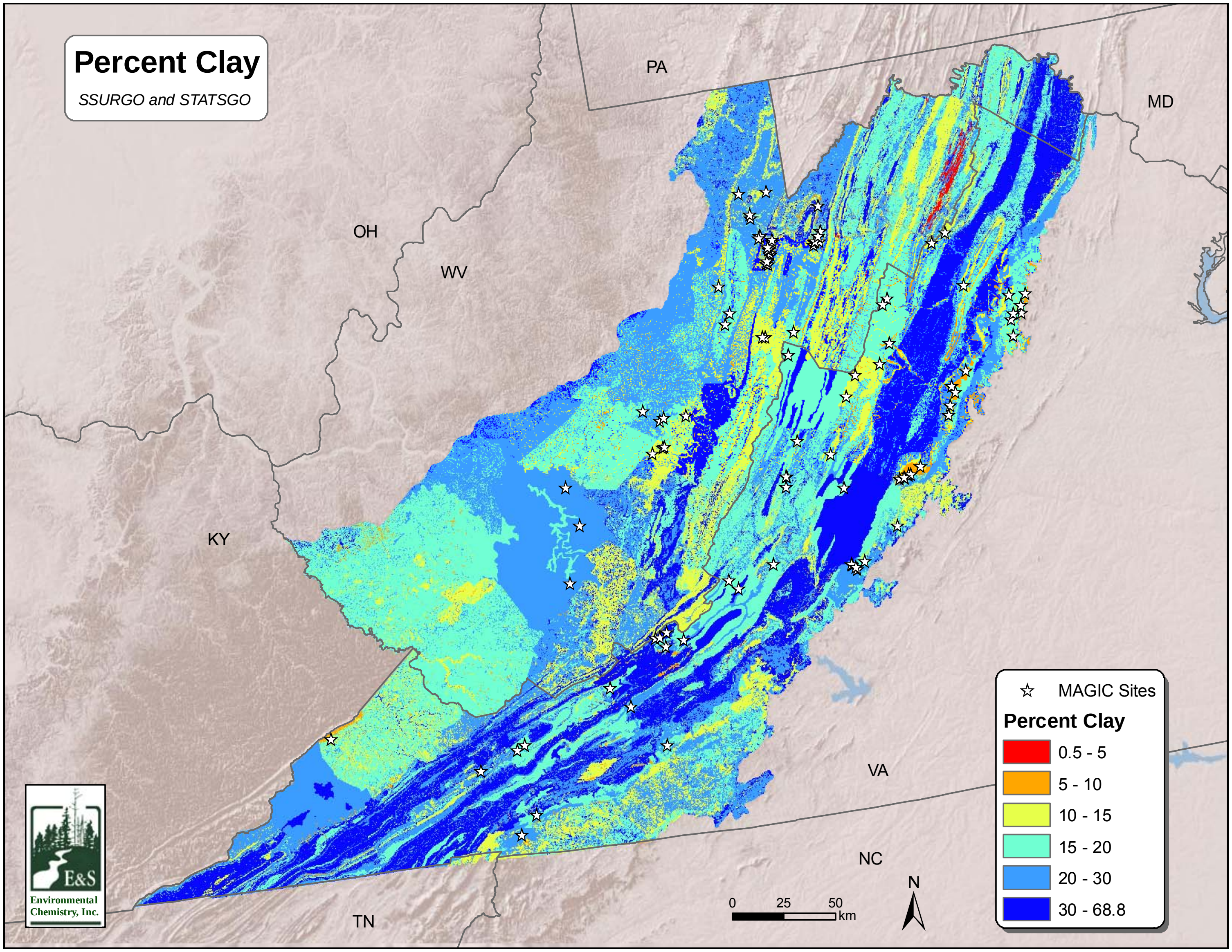

Figure 10. Percent clay in soils across the study area, based on SSURGO and STATSGO data. Also shown are MAGIC model sampling sites.

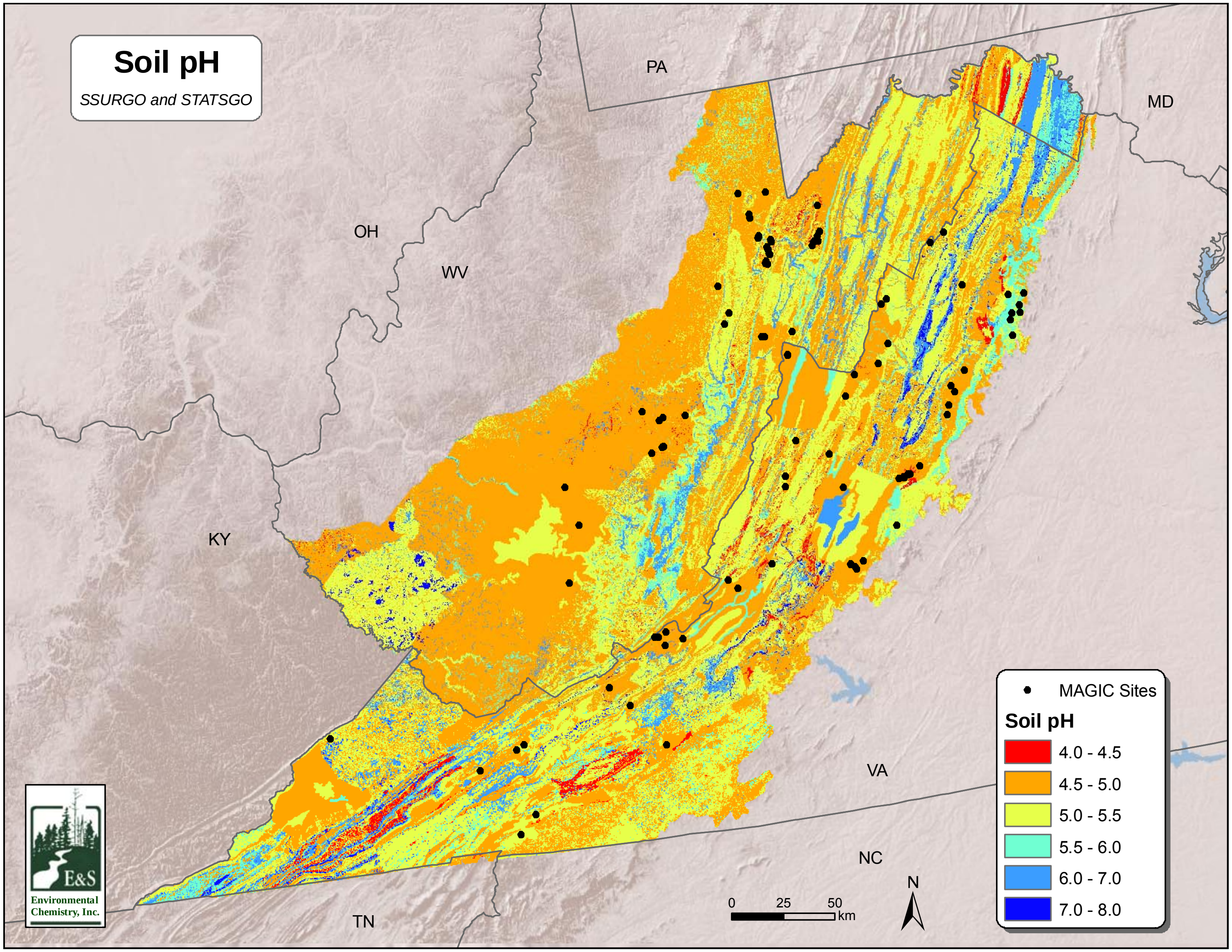

Figure 11. Soil pH across the study area, based on SSURGO and STATSGO data. Also shown are MAGIC model sampling sites.

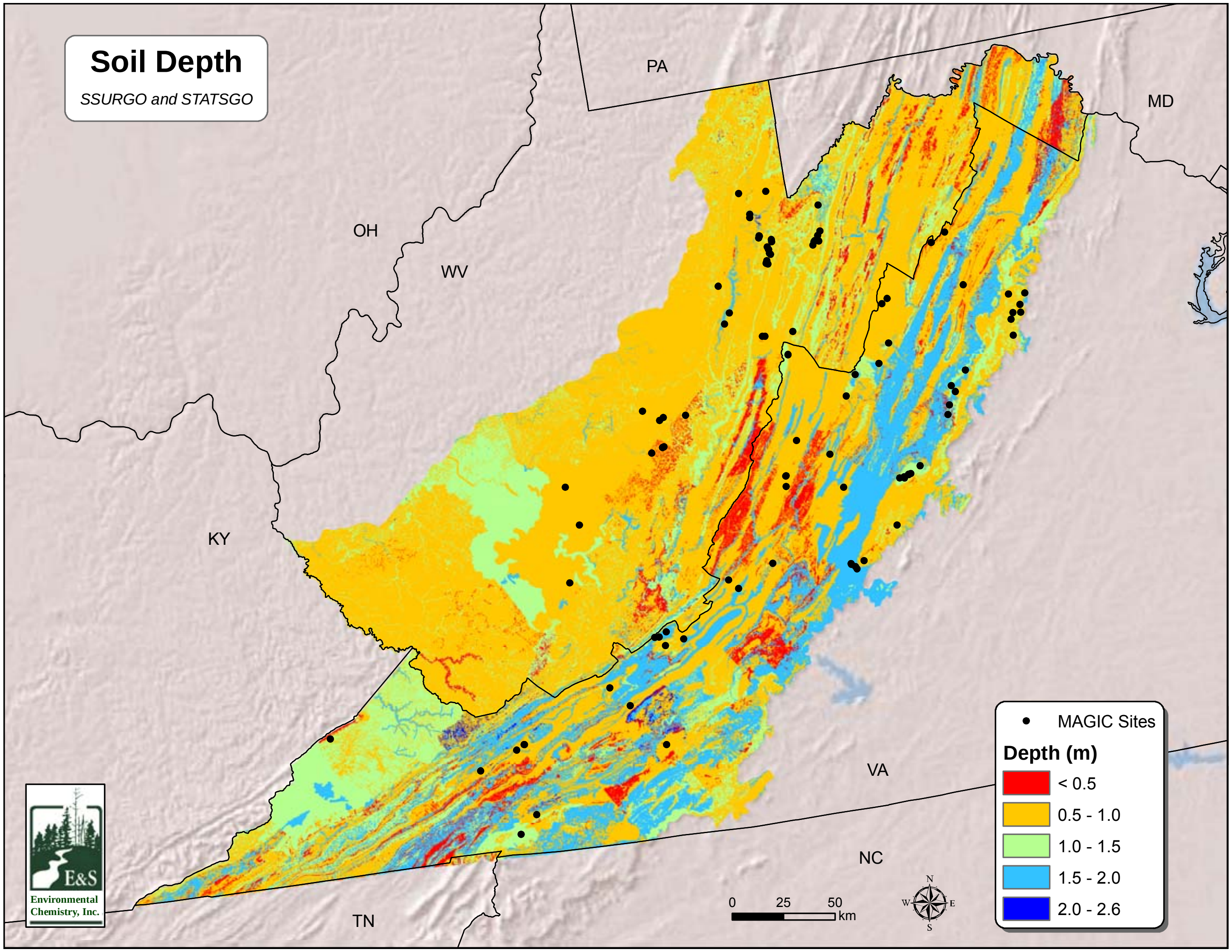

Figure 12. Soil depth to first restricting layer across the study area, based on SSURGO and STATSGO data. Also shown are MAGIC model sampling sites.

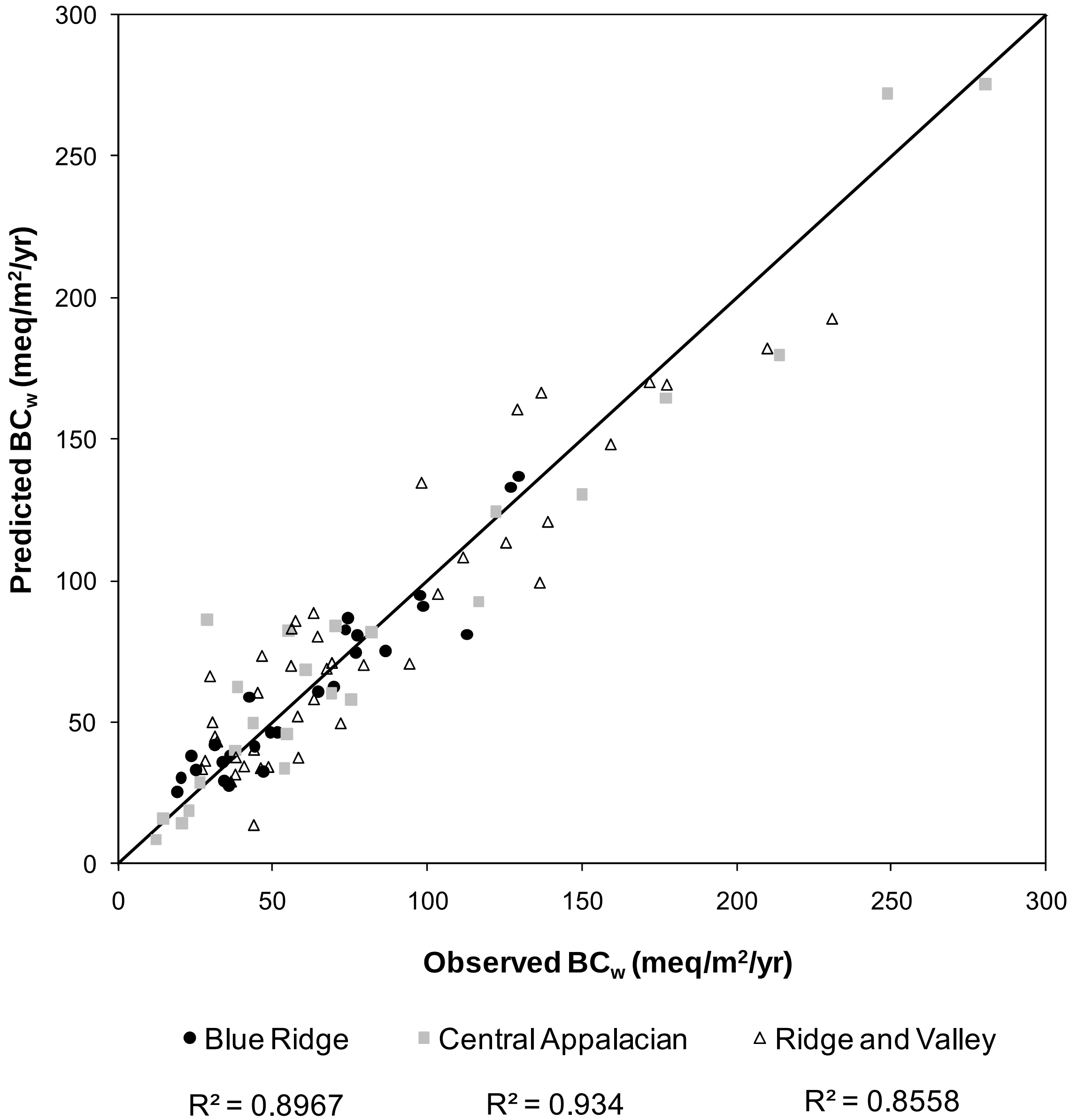

Figure 13. Predicted versus observed weathering rate, where predicted values are based on regressions using both stream chemistry and landscape variables. Observed weathering is taken from MAGIC calibrations. Sites are coded by ecoregion.

explained about two-thirds of the variation in MAGIC weathering (Figure 14), whereas the percent explained by the equations that included water chemistry were higher (85 and 93%, Table 3).

3.2 Landscape BC_w Extrapolation

The first step in extrapolating BC_w estimates to the region was to divide the study area into topographically determined watersheds. Because drainage water acidification is primarily a headwater phenomenon, these topographically determined watersheds must be small. For generating the stream network from the DEM, we specified a minimum contributing area of 0.5 km^2. In other words, the minimum drainage area that was designated as a stream watershed from the flow accumulation analysis was 0.5 km^2. The upper and lower boundaries of each down-gradient watershed was determined on the basis of tributary junctions. This process resulted in generation of a synthetic stream network that was intermediate in stream size and density between the 1:100,000 NHD stream network and the high resolution 1:24,000 NHD network (Figure 15). The typical topographically determined watersheds were on the order of 1 km^2 in area.

At each 30 x 30 m pixel, BC_w was estimated for regional CL extrapolation using the regression equations that were based on landscape variables alone. Each regression model input parameter was calculated as an upslope averaging of all cells that flowed into a given cell (except watershed area, which was calculated as the total contributing area to a given cell). A schematic example of the averaging process is given in Figure 16 for the predictor variable soil pH. The upslope average soil pH was calculated for each cell as the average of all cells that flow into that cell. This same process was repeated across the study region for the other regression input variables. An example watershed is shown in Figure 17, where soil % clay data from SSURGO (shown in Figure 17A) are averaged in an upslope fashion to yield continuous average soil % clay for each pixel in the Meadow Run watershed in Shenandoah National Park (Figure 17B). The boundary of the Meadow Run watershed is determined by the sampling location at the base of the watershed. The sampled watershed contains three topographically determined watersheds within it, each created based on the flow accumulation method, using a minimum topographically determined watershed area of 0.5 km^2 and downslope end determined on the basis of topographically determined stream junctions. Thus, the Meadow Run watershed contains three topographically determined subwatersheds, which differ in their clay content as represented

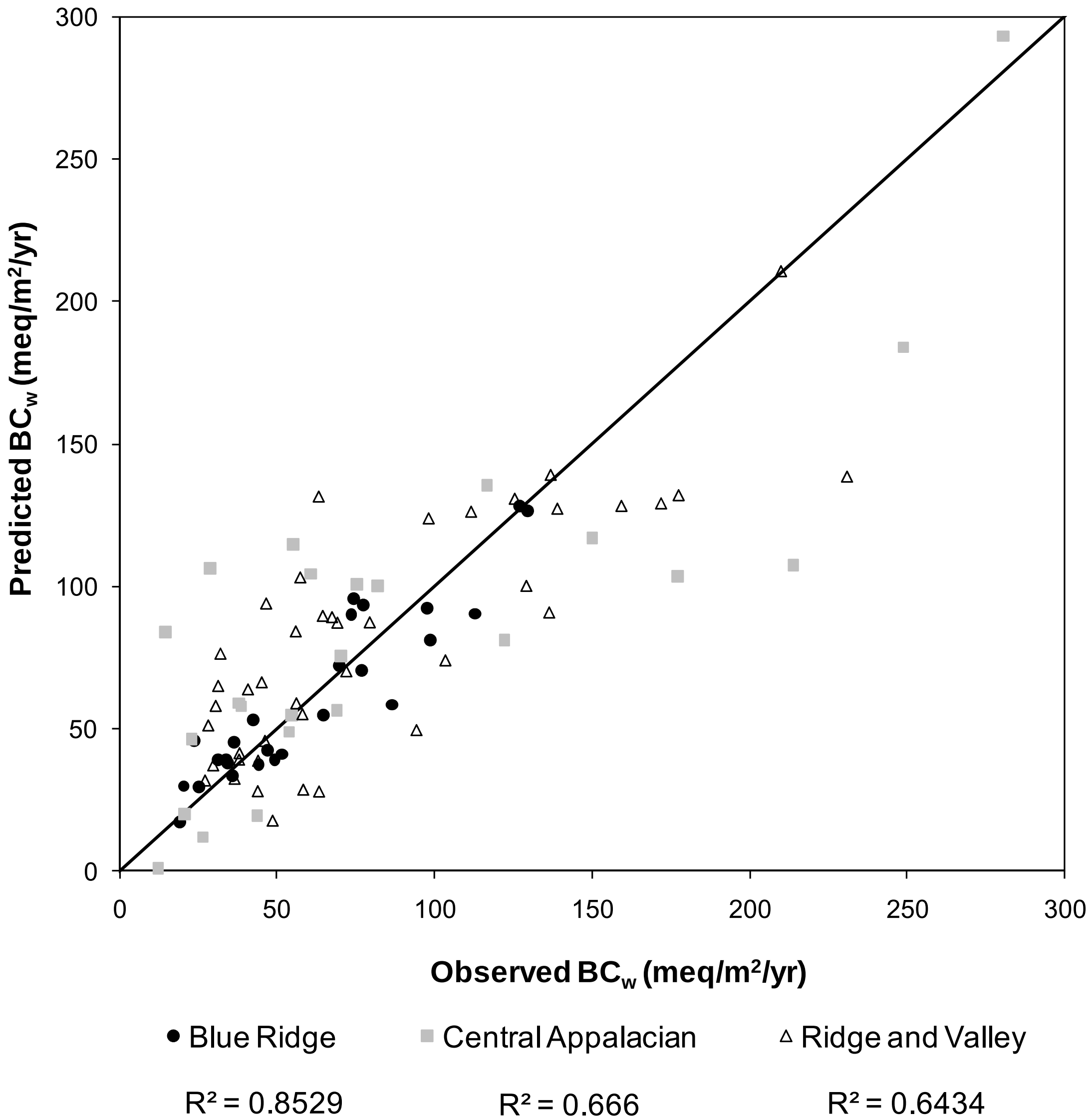

Figure 14. Predicted versus observed weathering rate, where predicted values are based on regressions using only landscape variables. Observed weathering is taken from MAGIC calibrations. Sites are coded by ecoregion.

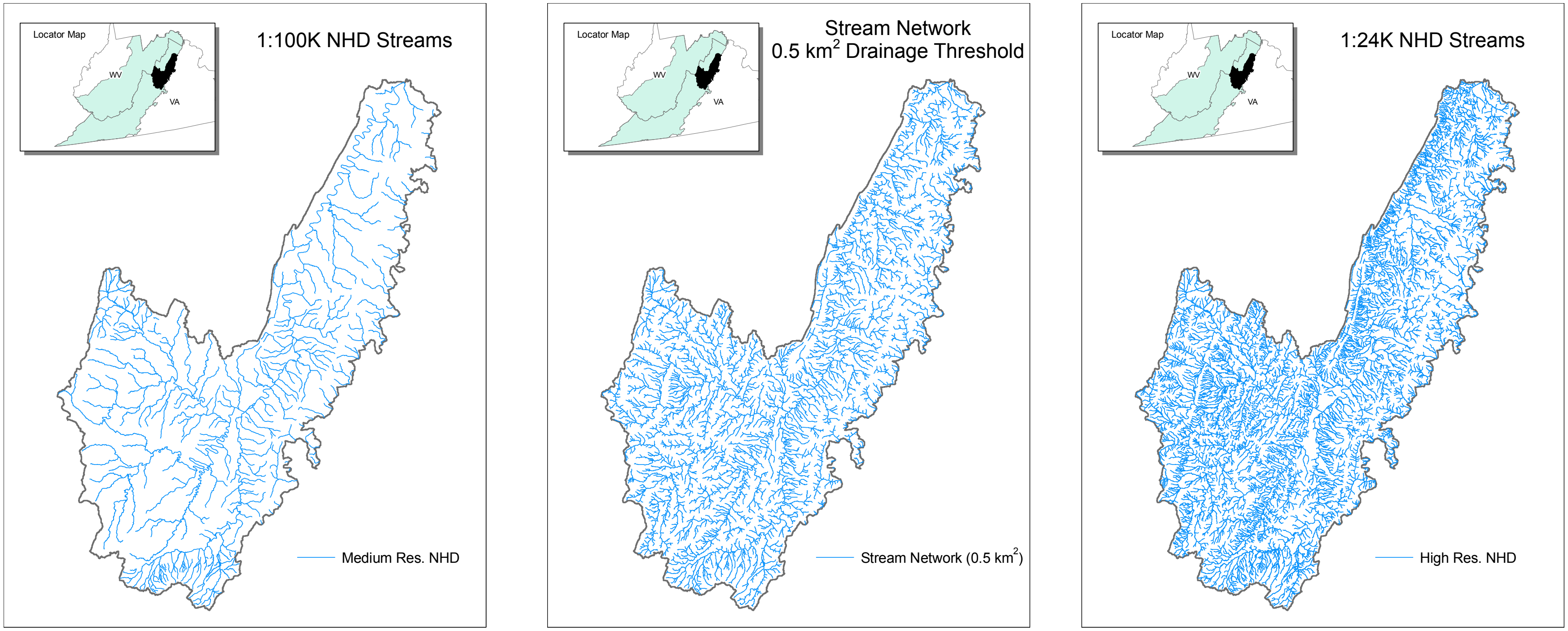

Figure 15. Stream network generated using a 0.5 km^2 contributing area minimum threshold and stream junction locations to define watersheds. This topographically determined stream network (center) has resolution that is generally between the moderate resolution (left) and high resolution (right) NHD datasets.

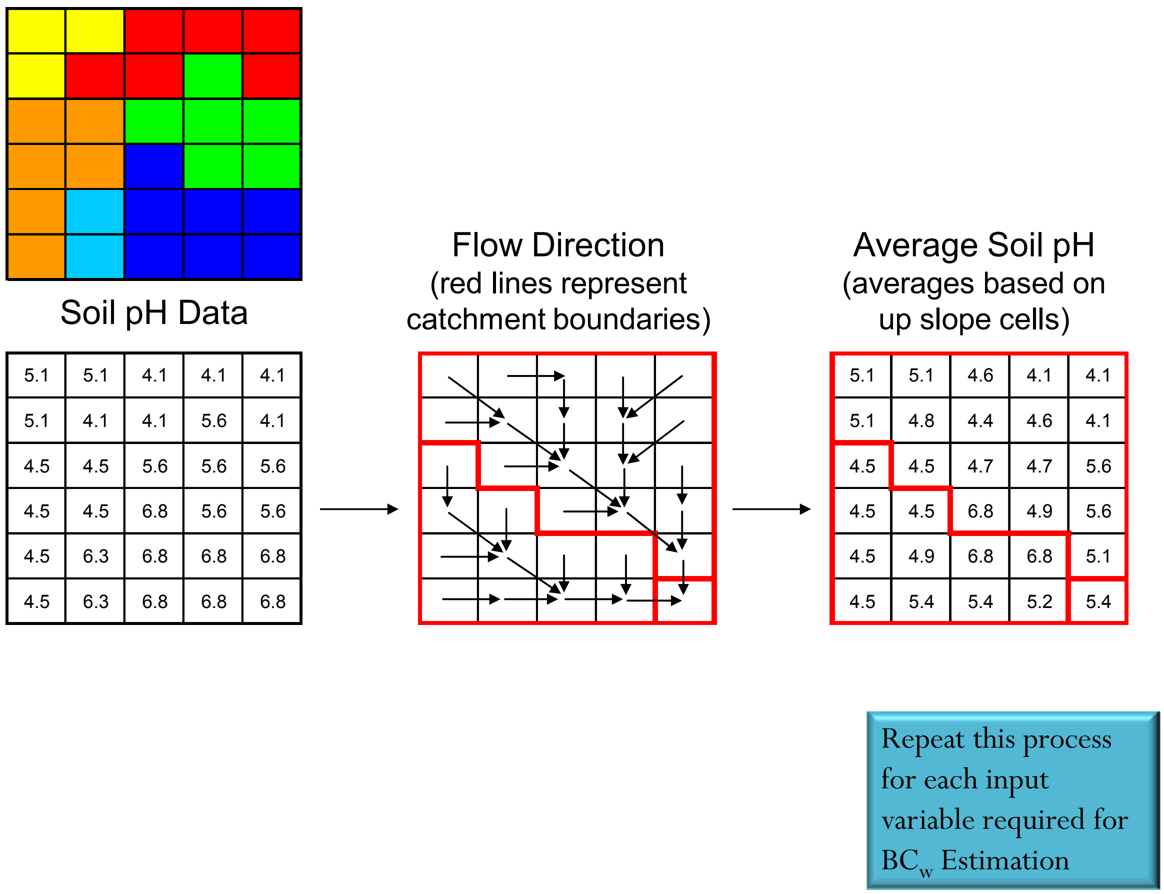

Figure 16. Example illustration of combining soil pH data (grids from SSURGO) with NHD-Plus data derived from the DEM to estimate the soil pH value in each grid cell based on an average of all upslope cells that flow into a given cell.

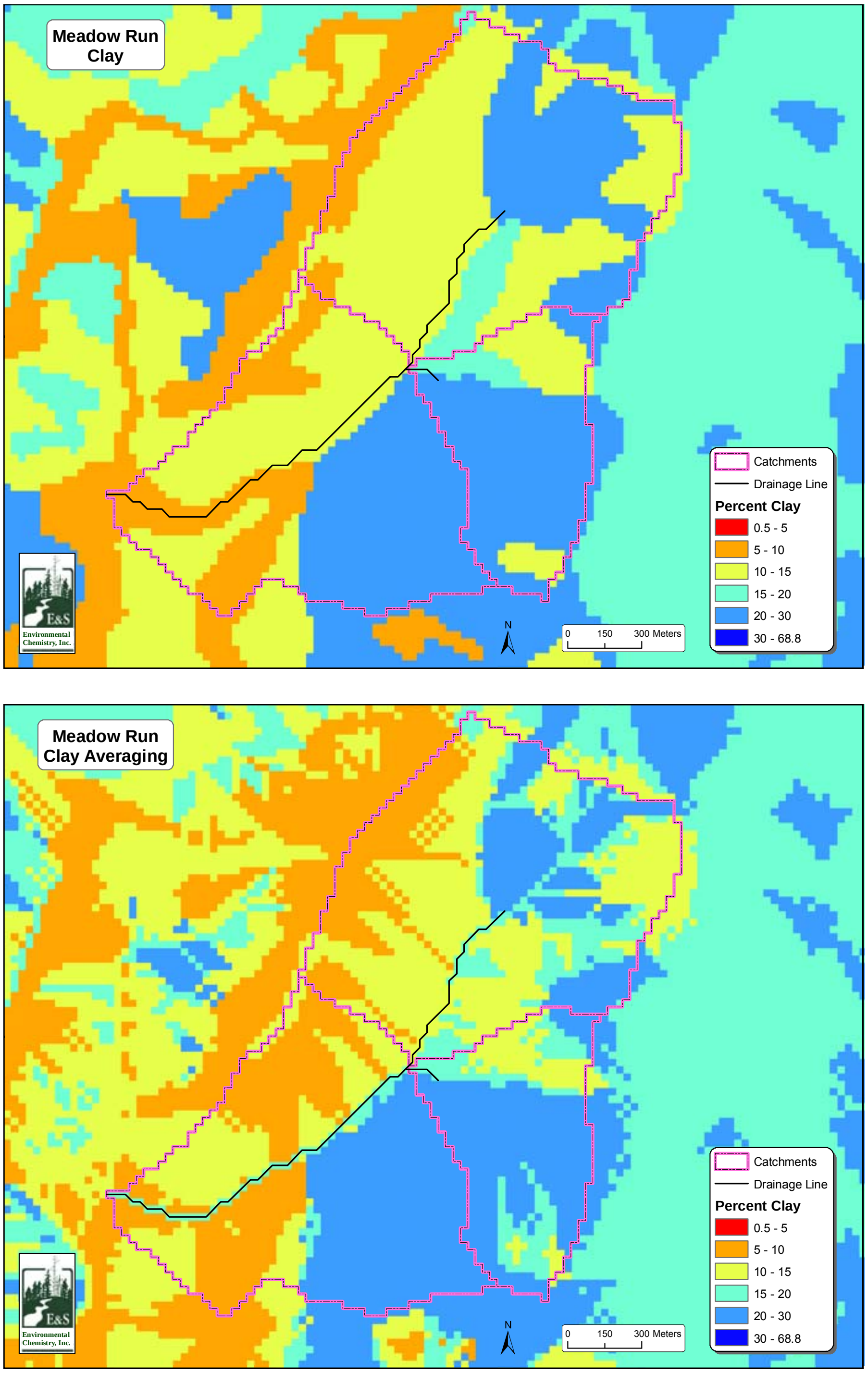

Figure 17. Example of continuous upslope averaging of clay data to derive for each 30-m grid cell an average value of all upslope cells that flow into a given cell. A) Data directly from SSURGO, B) continuous flow-averaged data. Note that grid cells towards the upper left tend to have relatively low percent clay, whereas cells towards the lower right have relatively high percent clay. Grid cells along the stream itself (Meadow Run in Shenandoah National Park) have intermediate values, reflecting the averaging of all upslope cells that contribute drainage to the stream cells.

in SSURGO. The continuous averaging process (Figure 17B) shows upslope average values in some cases tracing the flow pattern of the topographically determined stream as the % clay changes along the drainage path across the landscape.

Based on calculations for each pixel, using the ecoregion-specific regression equations given in Table 3, BC_w was calculated across the study area (Figure 18). Results of that calculation for the Meadow Run watershed are given in Figure 19. Meadow Run has the lowest ANC among the sites in Shenandoah National Park that are routinely monitored for stream chemistry (Sullivan et al. 2003). Consequently, large portions of the watershed showed low estimates of weathering (less than 50 meq/m^2/yr). Nevertheless, some portions of the Meadow Run watershed show somewhat higher weathering (between 50 and 100 meq/m^2/yr). Despite the contribution of drainage from the areas that are characterized by higher weathering, the pixels along the topographically determined stream are entirely in the lowest weathering class. This is because the BC_w in each pixel reflects an average of all upslope contributing pixels at each point along the stream, rather than just the adjacent pixels. This illustrates the value of using an upslope averaging approach to integrate features of the landscape throughout the entire drainage area that contributes runoff to a given stream location.

3.3 Calculations of Critical Load of Acidity

The CL equation (Equation 1) has four terms. The BC_w term is generally quantitatively highest and most uncertain. Results applied to the calculation of BC_w were provided in the section above. Results for BC_{dep}, Bc_{up}, and ANC_{limit} are presented below. Regional BC_{dep} is shown in Figure 20. It ranges from low values in the range of 6 to 10 meq/m^2/yr in northern Virginia to the range of 15 to 20 meq/m^2/yr in West Virginia and smaller portions of Virginia. Base cation uptake was set to zero in protected areas such as Shenandoah National Park and the various Wilderness areas, but increased to over 20 meq/m^2/yr in loblolly-shortleaf pine, oak-pine, and oak hickory forests in unprotected areas (Figure 21).

Runoff from the USGS grid, based on 1 km grid cells, was too coarse for this study (Figure 22A). Our regional estimates of runoff, calculated using PRISM model estimates of precipitation and elevation, yielded much finer resolution (Figure 22B) that more closely corresponded with terrain differences. The combination of runoff and the selected critical ANC values to protect aquatic biota yielded spatially variable ANC_{limit} values that varied several fold.

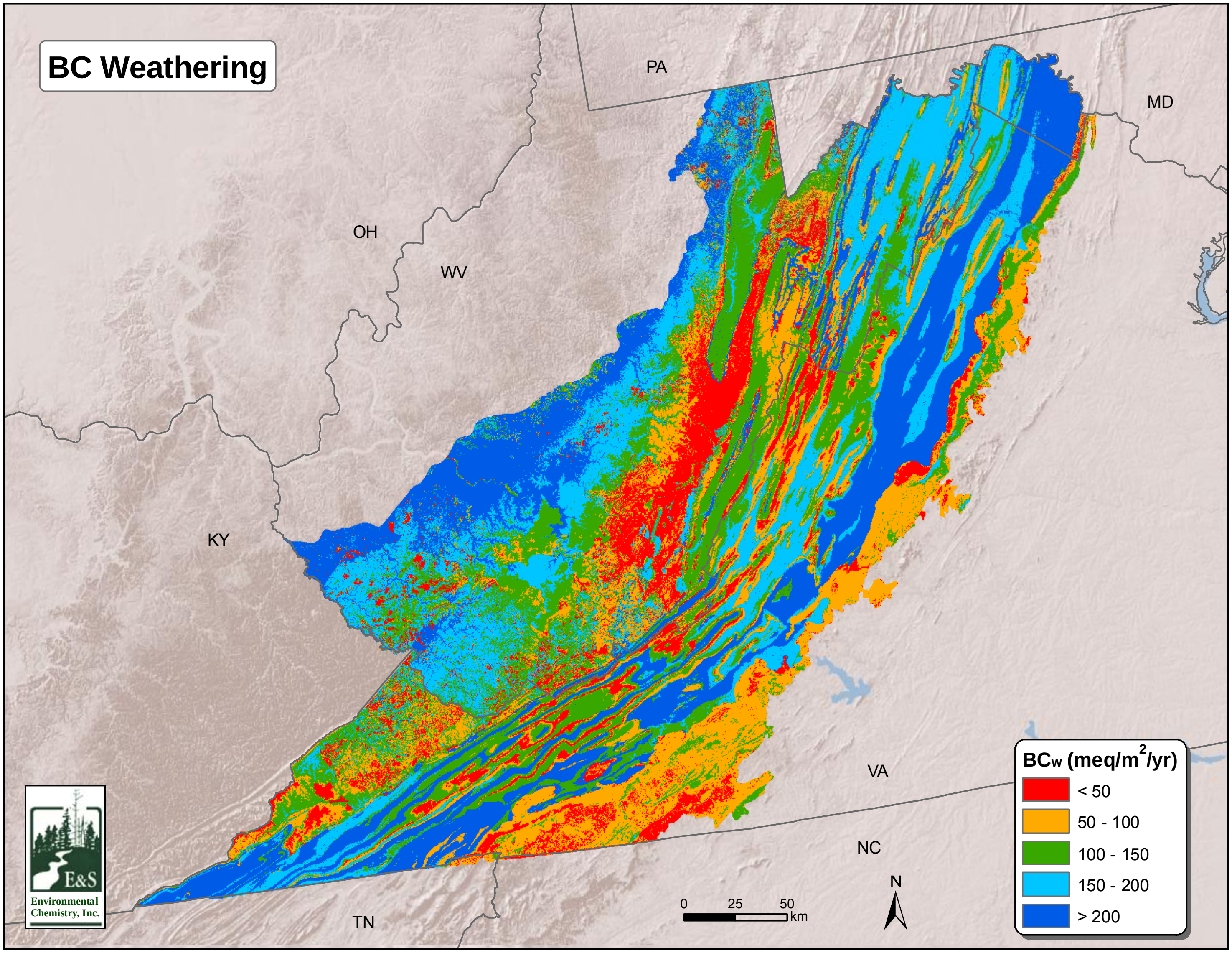

Figure 18. Calculated values of BC_w for each 30-m grid cell in the study area, based on the regression relationships that were developed using landscape variables.

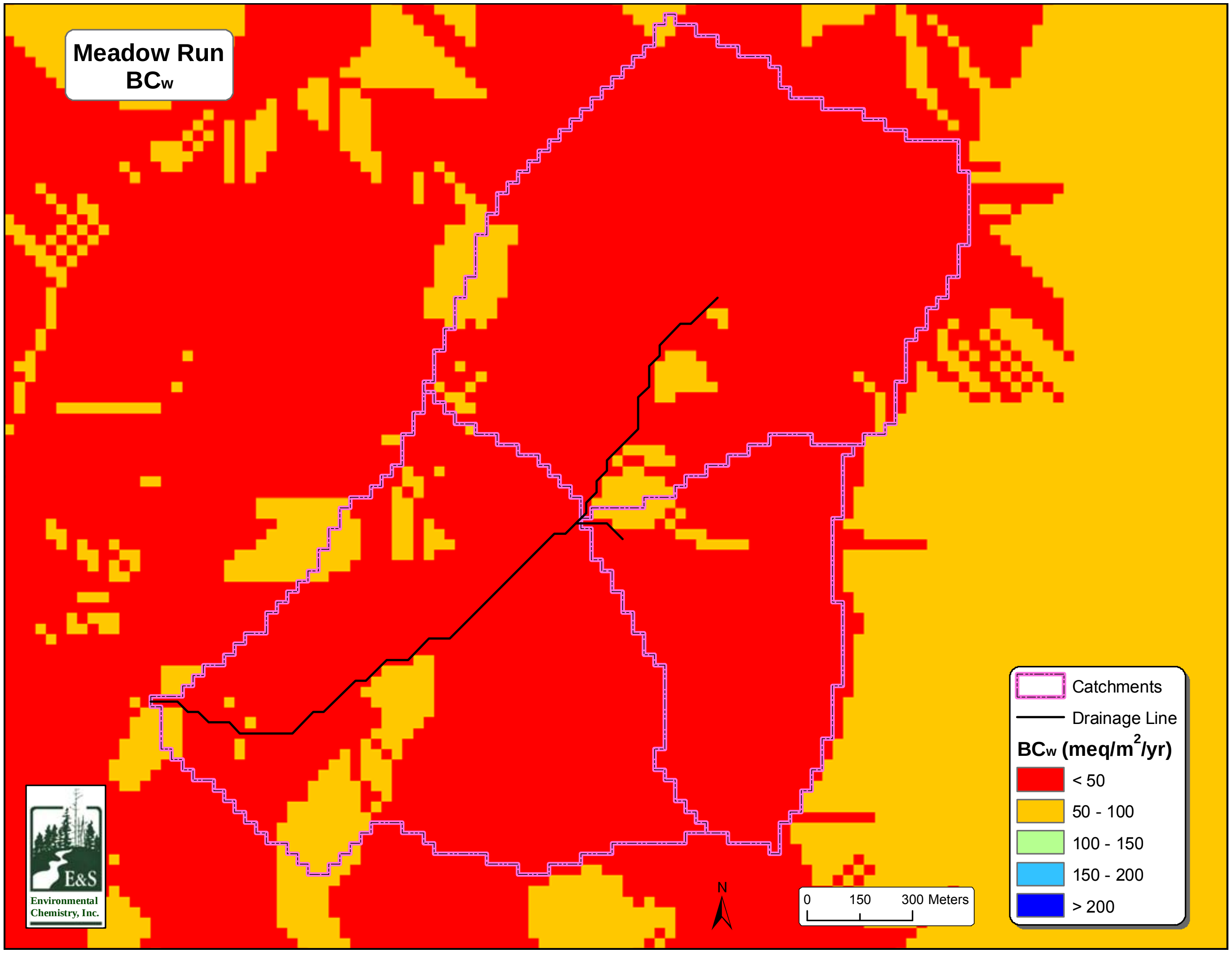

Figure 19. BC_w estimates for each 30-m pixel in the Meadow Run watershed in Shenandoah National Park, developed based on continuous downslope averaging of each variable used to calculate BC_w within the Blue Ridge ecoregion (% siliciclastic lithology, % clay in soil, and soil depth). These estimates of BC_w within each grid cell were combined with estimates for each grid cell of the other terms in the SSWC model (BC_{dep}, Bc_{up}, and ANC_{limit}) to calculate CL.

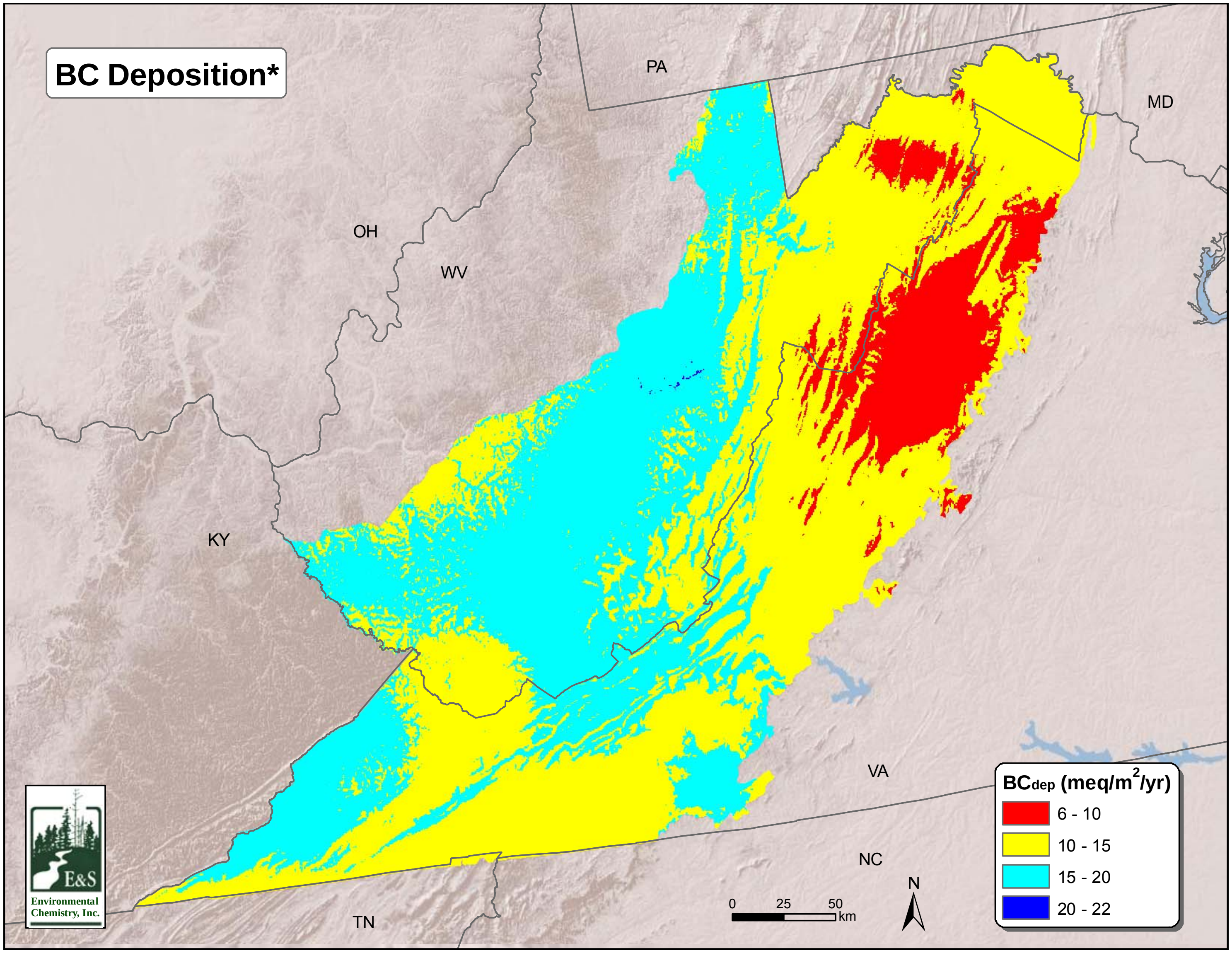

Figure 20. Base cation deposition (BC_{dep}) across the study region, Cl^- corrected, calculated as the sum of wet deposition (five-year average centered on 2002 of interpolated NADP wet deposition measurements using the Grimm and Lynch [1997] approach) and dry deposition (literature values of dry as percentage of wet; Baker et al. 1991).

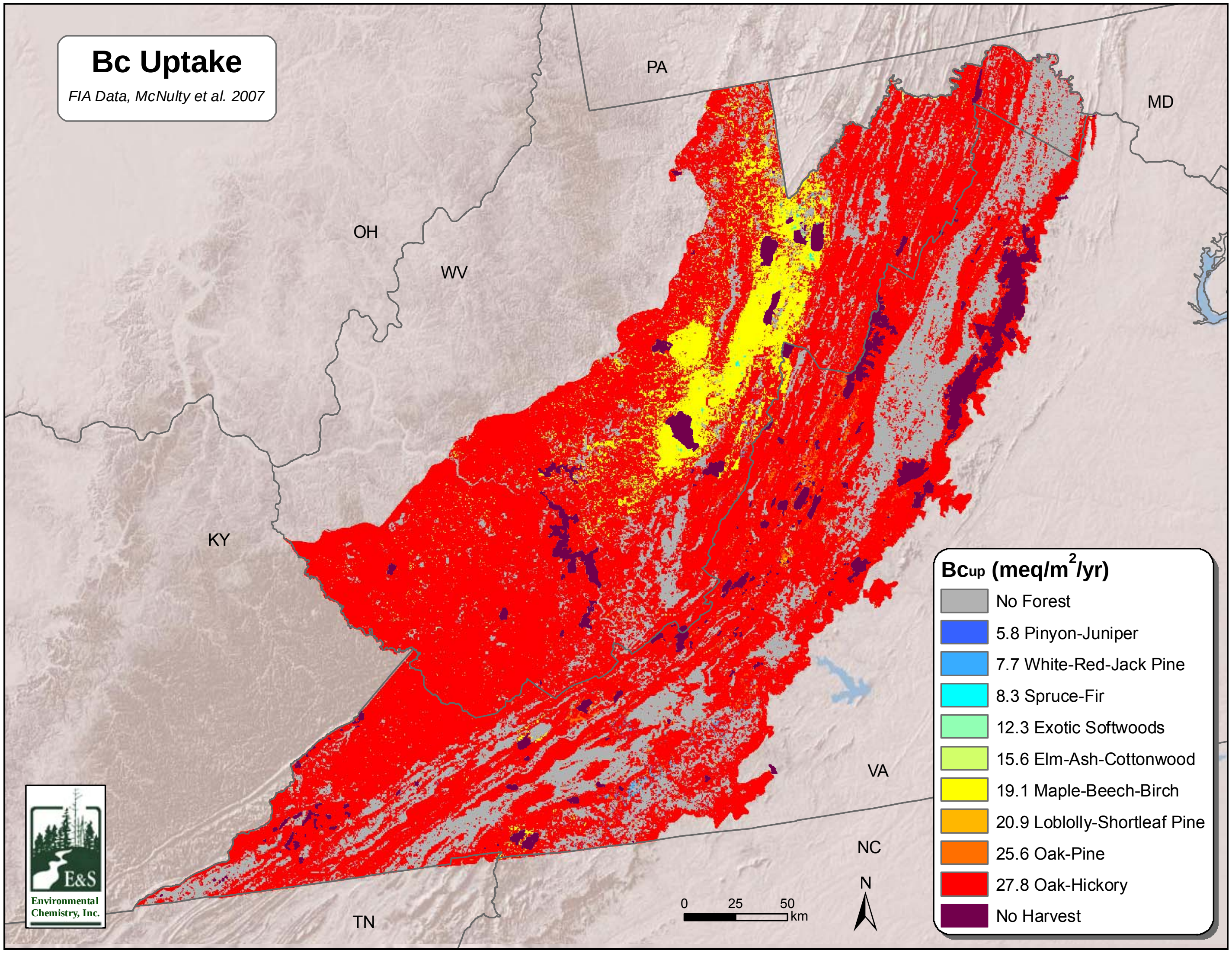

Figure 21. Base cation uptake (Bc_{up}) across the study region, based on uptake estimates for nine Forest Inventory Analyses (FIA) forest types (McNulty et al. 2007) assuming an annual harvest rate of 65% of the annual volume increment. Harvest is assumed to be zero in protected areas such as national parks, Wilderness areas, and other preserves.

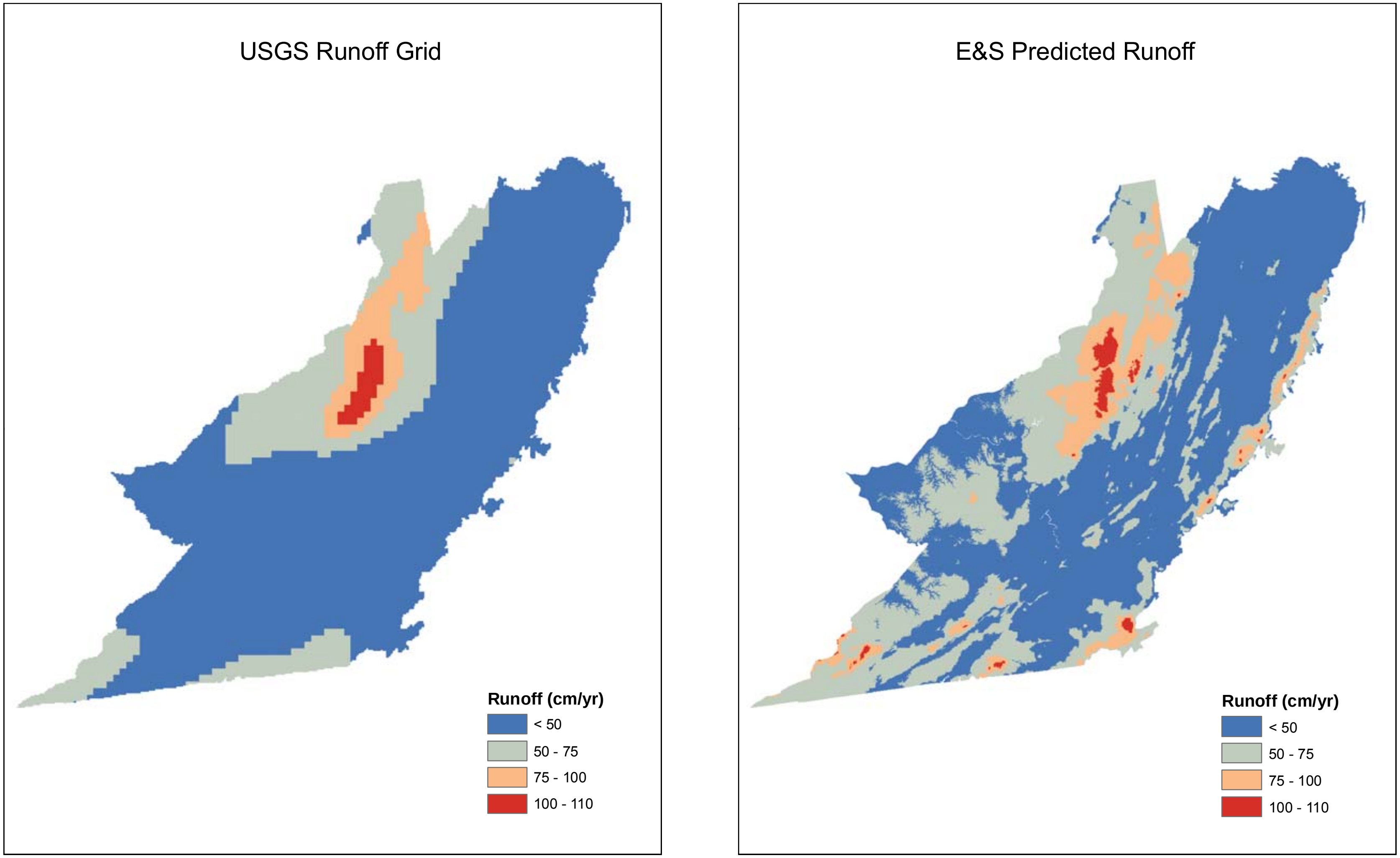

Figure 22. Runoff estimates across the study areas. A) USGS coarse runoff grid, B) E&S estimated runoff, based on measured discharge within the study area and a regression equation to predict runoff from precipitation (PRISM model) and elevation (r^2=0.91). The upper and lower bounds of the predicted runoff distribution were truncated so as not to extend beyond the range of values determined buy USGS. Note the finer resolution of the E&S approach.

An example of the resulting calculation using the ANC value 20 μeq/L is shown in Figure 23. Patterns for other ANC threshold values were the same as is shown in Figure 23 for the threshold of 20 μeq/L.

Mapped results of CL calculations are provided in the body of this report for ANC threshold values of 20, 50, and 100 μeq/L. Mapped results for the threshold of 0 μeq/L ANC, which are not considered to be protective of the environment, are given in Appendix E. It should be noted that 100 μeq/L may not be an appropriate threshold for evaluation of CL in this study area. Of the 92 MAGIC modeling sites, 55 had model hindcast estimates of pre-industrial (1860) ANC below 100 μeq/L (Appendix D). Thus, it would not be reasonable to expect to recover ANC in a given stream to a value that is higher than the pre-industrial value. In contrast, only 11 of the 92 MAGIC modeled streams had estimated pre-industrial ANC below 50 μeq/L and all except 2 of those had estimated pre-industrial ANC between 40 and 50 μeq/L.

Values of each of the CL equation input terms for each of the 522 watersheds having stream chemistry are given in Appendix F. The three different methods of calculating BC_w (Table 4), when combined with all other terms in Equation 2, yield somewhat different estimates of CL for the sites for which CL was calculated using more than one approach. These site-specific CL results are given in Table F-4 of Appendix F.

Table 4. Outline of different approaches for estimating BC_w.

Approach	n	Description
Primary site-specific	92	Weathering extracted from MAGIC calibrations at sites modeled using MAGIC
Secondary site-specific	522	Weathering estimated using an ecoregion-specific regression model based on predictor variables that included site-specific stream chemistry and landscape features
Mapped regional	Entire study area	Weathering estimated using an ecoregion-specific regression model based on predictor variables that included landscape features only.

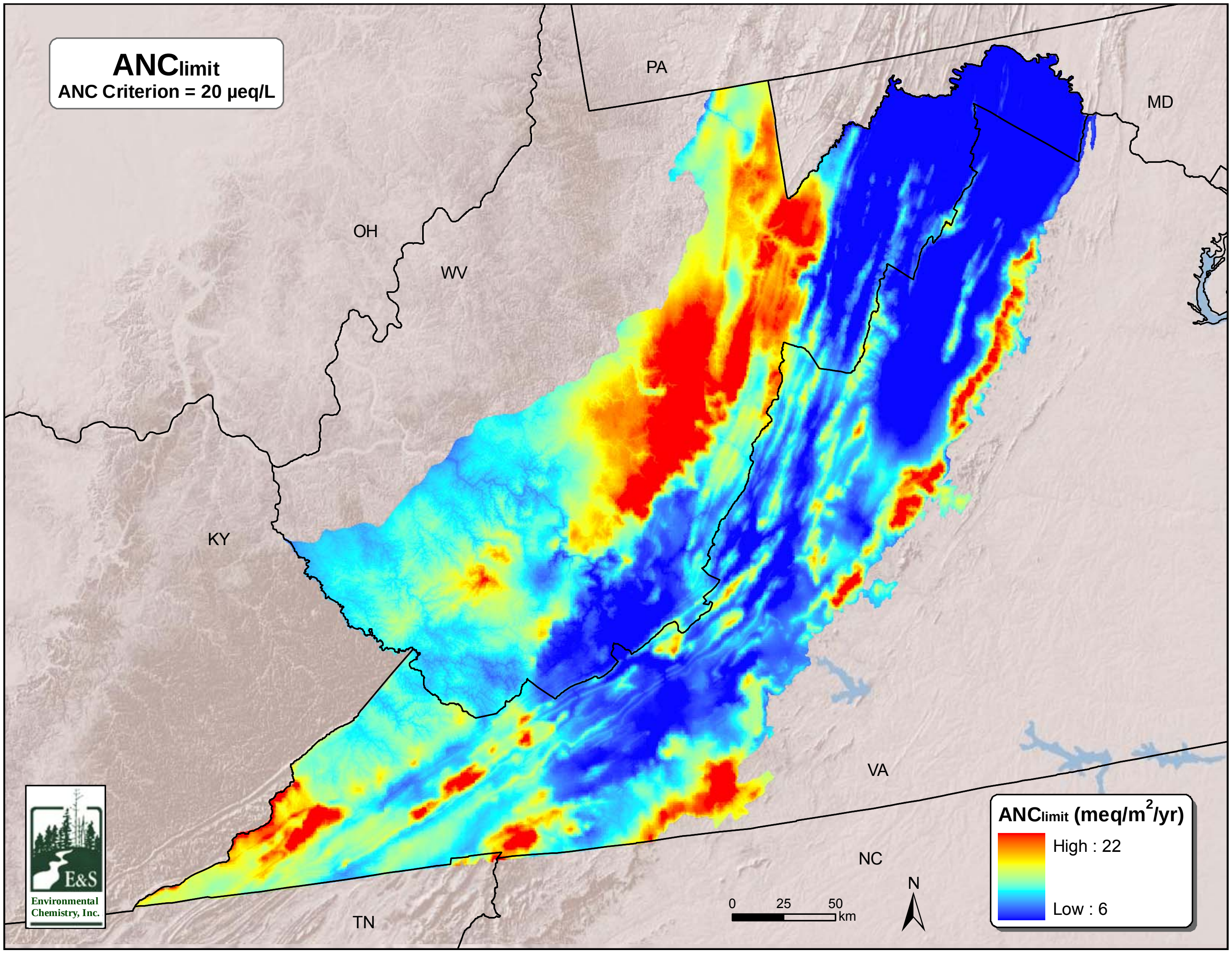

Figure 23. Distribution of calculated ANC_{limit} for the critical ANC level equal to 20 µeq/L, calculated as the product of annual runoff and the assumed critical ANC level.

3.4 Transfer of the CL Estimate from Watershed to Stream

The previous section presented our regional depiction of CL, calculated and mapped as values for small watersheds. Also of interest is a presentation of CL results for the network of streams that flow through these watersheds. Streams considered thus far in this analysis have been topographically determined streams, generated from the DEM and flow trajectory analysis. These topographically determined streams are expected to correspond approximately, but not exactly, with streams represented in the national stream network as depicted in the high-resolution NHD. It was therefore desirable to transfer our CL calculations from topographically determined watersheds to NHD streams. That step is described here.

Meadow Run is again illustrated as an example of the model input terms in Figure 24, and the resulting CL that is calculated from these terms is given in Figure 25. The representative watershed CL value is determined from the CL values calculated at each stream pixel within the watershed because the focus of this effort is on aquatic CLs. A regional watershed CL map was prepared for each critical ANC indicator value (Figures 26 through 28).

Calculated CL values for the Meadow Run watershed, as an example, were clipped to include only those pixels that lie along the topographically determined stream (Figure 29), coded for this figure to reveal the spatial variation in CL. All stream pixel values exhibited BC_w estimates that were below 50 meq/m^2/yr but, nevertheless, did reveal some spatial variation. Results of the CL calculation for these stream pixels were averaged to reflect the CL of the stream reach that flows through that watershed based on the national stream network as represented in the high-resolution NHD database. This process was completed for all watersheds and NHD stream reaches to yield a regional stream coverage that is coded by CL according to the value given to its associated watershed. An example for the southern portion of Shenandoah National Park is shown in Figure 30.

3.5 Differences Among Extrapolation Approaches

Calculated CL for the 522 stream watersheds having water chemistry data (secondary site-specific results) are shown in Figure 31. Despite the seemingly large number of sites included in the analysis, the spatial coverage is sparse. The modeled watersheds tend to be relatively small, reflecting known spatial patterns in acid sensitivity. Where larger watersheds are represented by the available stream chemistry data, their calculated CL tends to be at least moderately high (greater than 100 meq/m^2/yr).

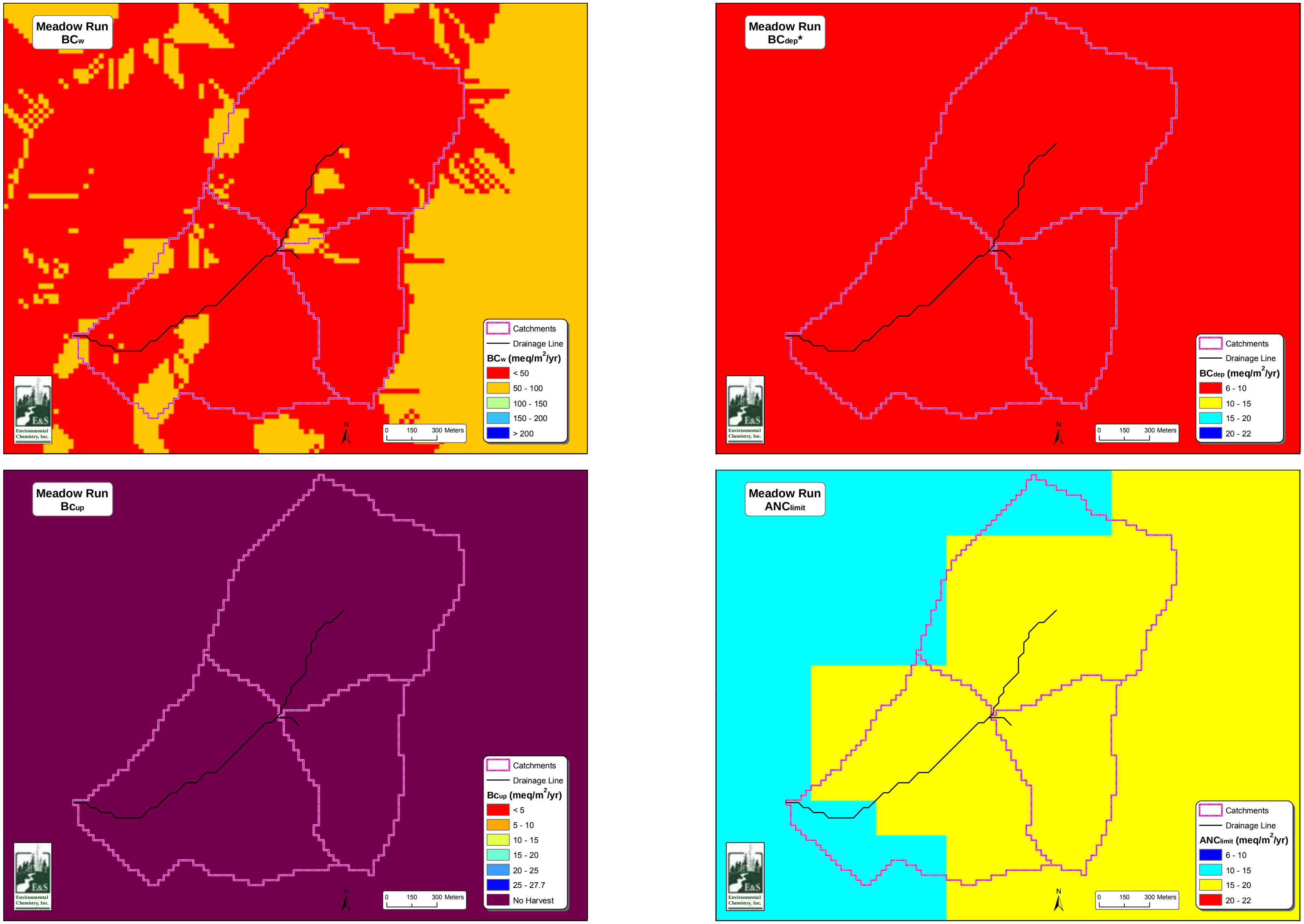

Figure 24. Example for the Meadow Run watershed in Shenandoah National Park showing the spatial coverages of each of the four terms used in the SSWC model to calculate the CL. Based on these coverages, CL was calculated for each 30-m pixel.

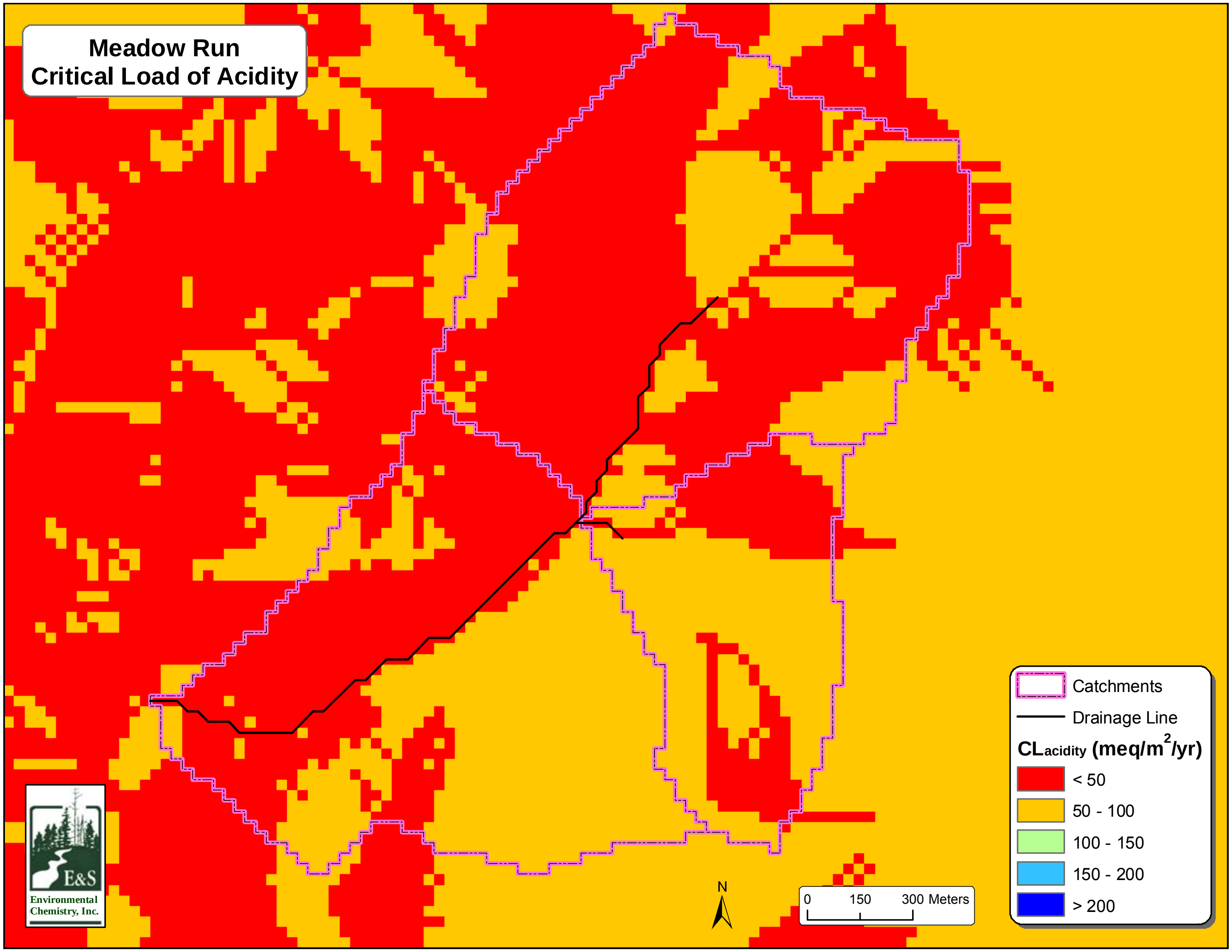

Figure 25. Calculated CL of acidity for the Meadow Run watershed in Shenandoah National Park to protect against ANC below 20 μeq/L.

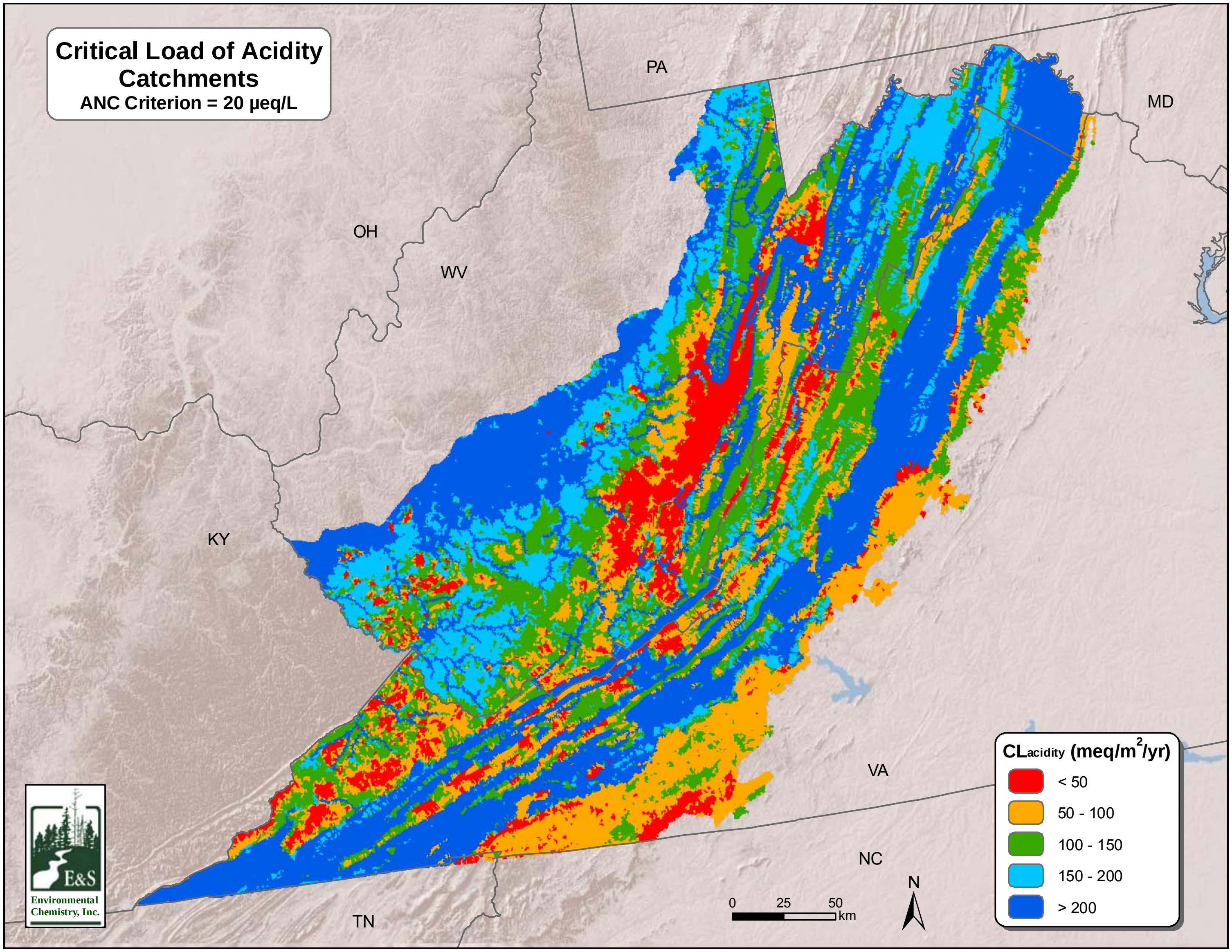

Figure 26. Final map of CL of acidity to protect stream ANC from falling below 20 µeq/L.

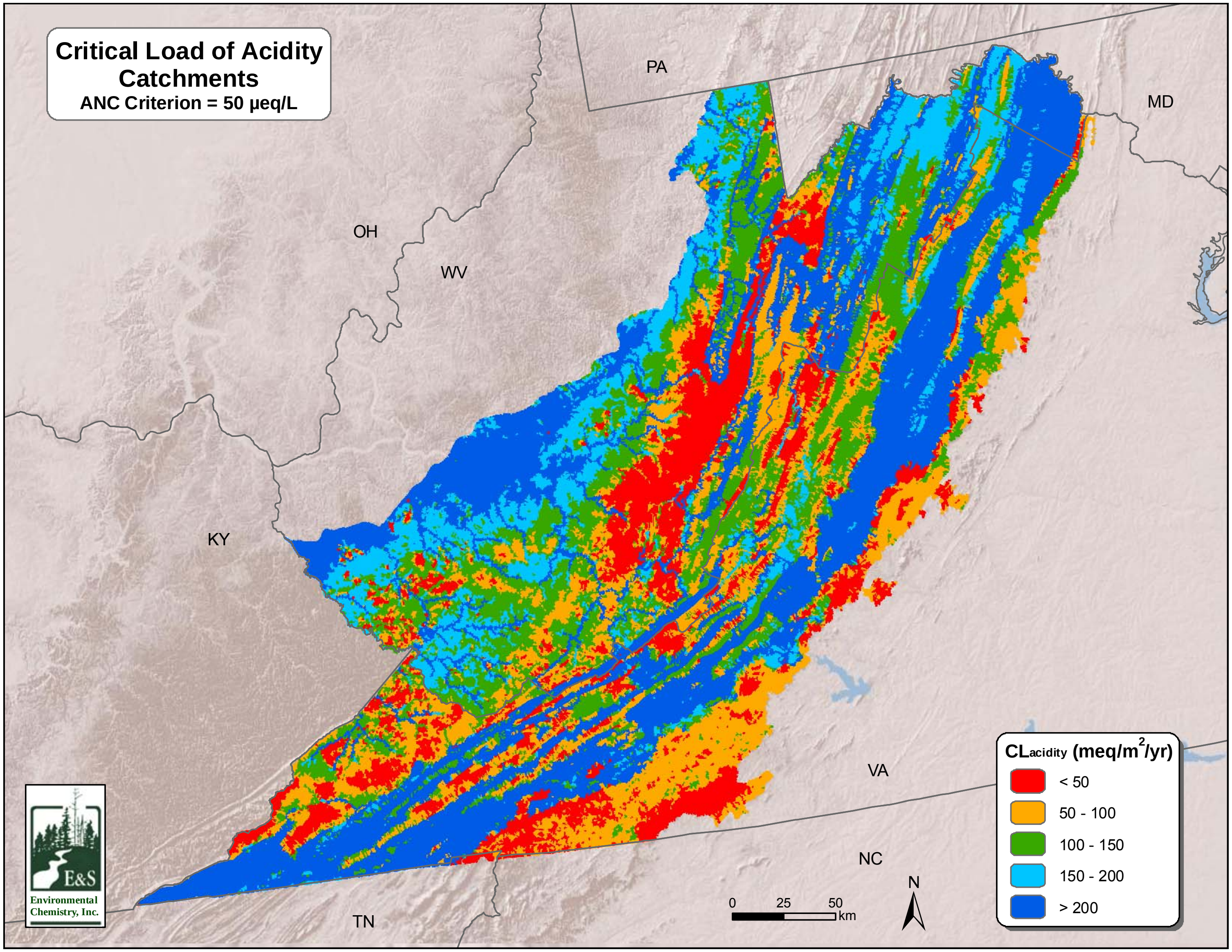

Figure 27. Final map of CL of acidity to protect stream ANC from falling below 50 µeq/L.

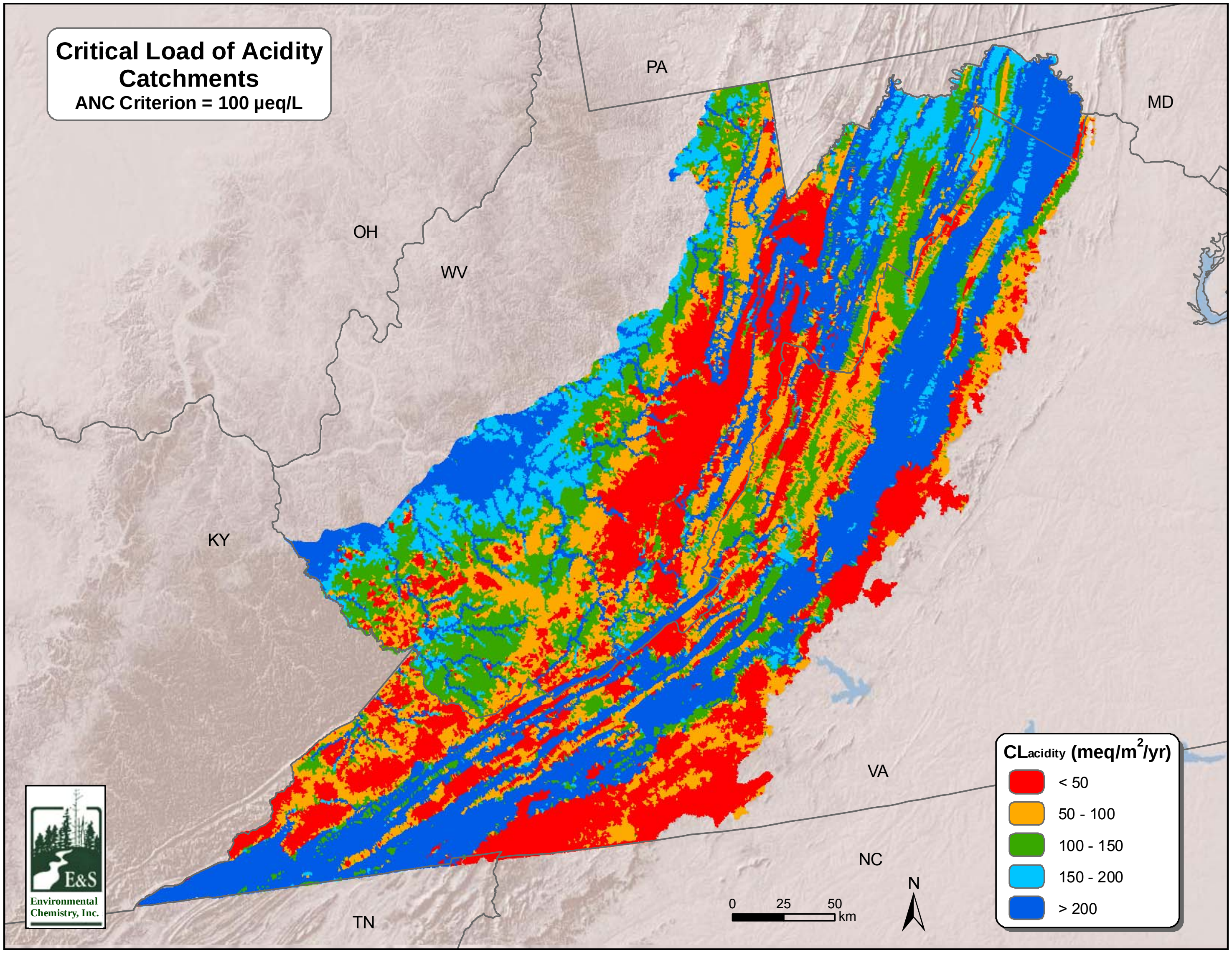

Figure 28. Final map of CL of acidity to protect stream ANC from falling below 100 µeq/L, based on an average of CL values calculated for each of the 30 m stream cells within each watershed.

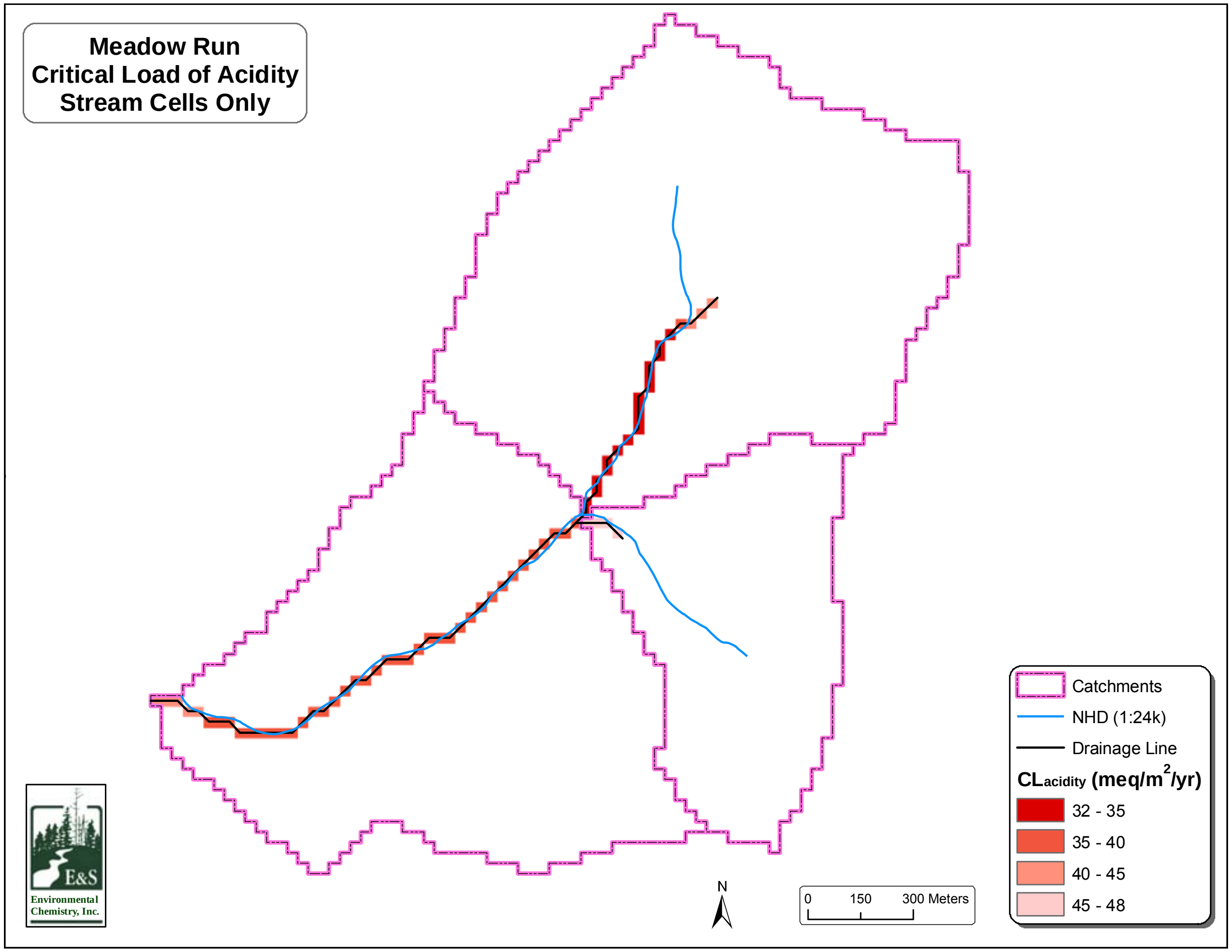

Figure 29. Extraction of CL for stream cells only from among all 30-m cells within the Meadow Run watershed in Shenandoah National Park. Stream cell locations were determined by assumed water flow paths from cell to cell according to topography generated from the DEM. This step is necessary in order to transfer results of CL calculation for the watershed to the stream locations determined in the NHD. The average calculated CL from among the stream cells depicted here was assigned to NHD streams that occur within this watershed, which are indicated here with a blue line. Synthetic streams, determined from the apparent drainage pattern, closely approximated NHD stream locations.

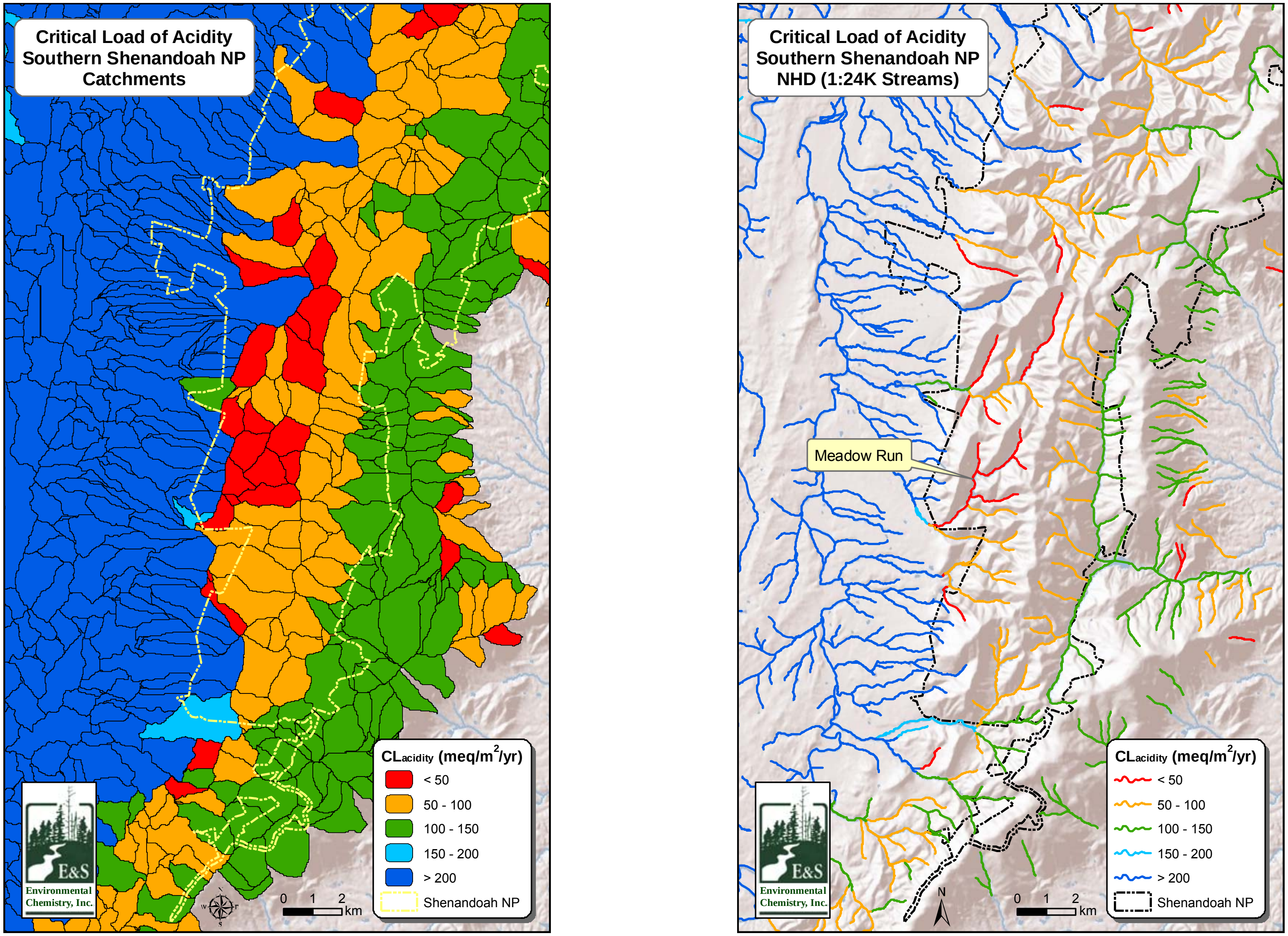

Figure 30. Calculated CL of acidity to protect against ANC below 20 μeq/L for watersheds in and around the southern portion of Shenandoah National Park, based on watersheds (left column) and stream reaches (right column).

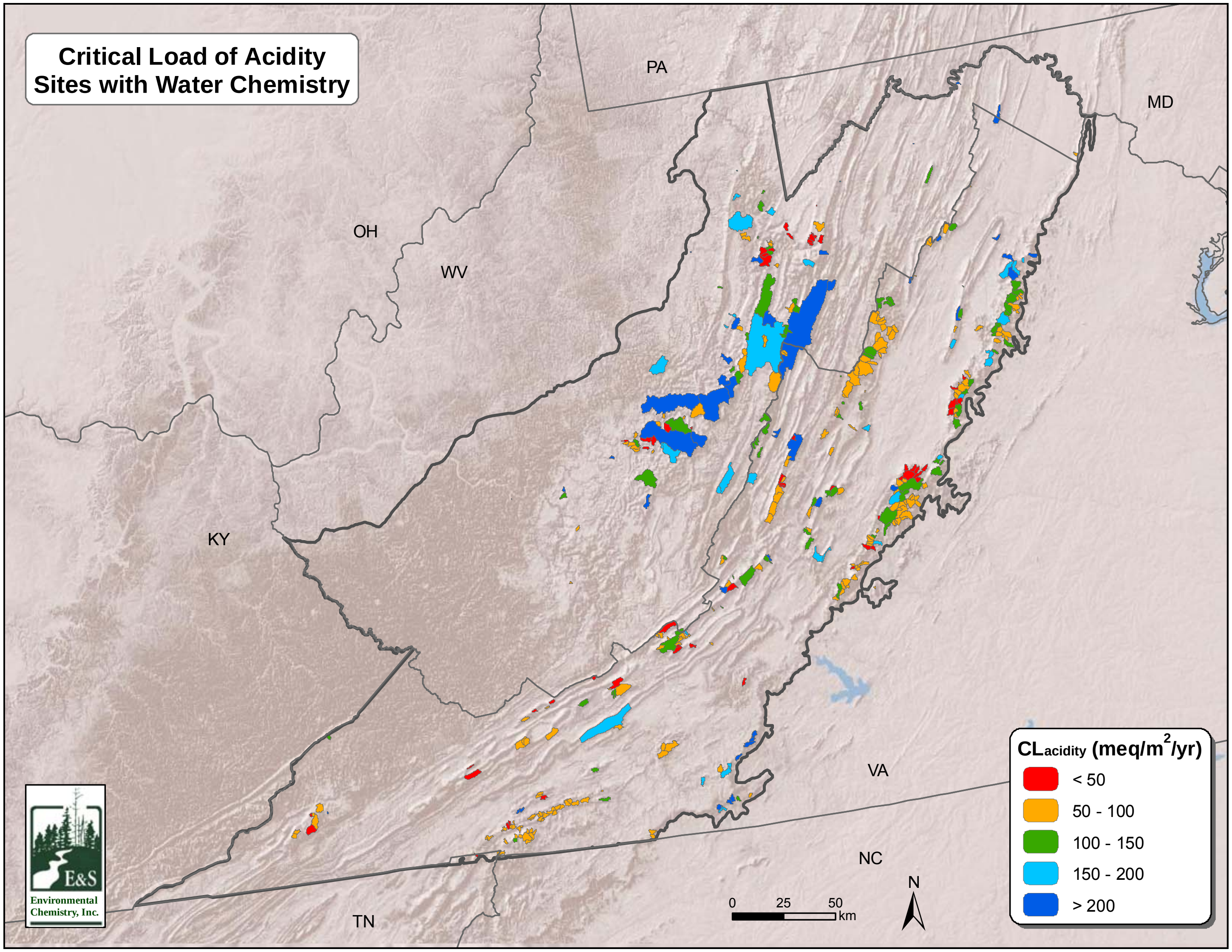

Figure 31. Results of calculations for CL of acidity to prevent ANC from going below 20 μeq/L for all watersheds (n=522) having stream chemistry, using algorithms for calculating BC_w that were based on relationships with water chemistry plus landscape characteristics.

Examples are shown in Figures 32 and 33 for southern Shenandoah National Park in Virginia and the area around Otter Creek and Dolly Sods Wilderness areas in West Virginia, illustrating different CL results based on varying levels of data specificity. The right panel in each of these figures shows the primary site-specific CL results calculated using BC_w estimates taken directly from MAGIC. For the respective middle panels, BC_w was calculated using stream chemistry plus mappable watershed attributes (the secondary site-specific results). Note that the watershed sizes shown in the right and middle panels were determined by the locations of the stream samples. The left panels reflect results for the topographically determined watersheds that were calculated based on topography (mapped regional results). These tend to be smaller than the watersheds defined by the stream sampling locations. Thus, the topographically determined watersheds provide a higher resolution depiction of CL than do the sampled watersheds. Results of the CL calculations for the mapped regional approach are more uncertain because they are based on regression equations that included only landscape variables. Nevertheless, the patterns in the calculated CL are similar, regardless of approach.

Overall, CL calculations using SSWC were similar across the three methods of estimating BC_w. Critical load calculations using the regression equations to predict BC_w, based on the secondary site-specific results and based on mapped regional results, yielded reasonable agreement with primary site-specific CL calculations using MAGIC estimates of BC_w (Figure 34). Nevertheless, results of regression estimates more closely matched MAGIC estimates in the Blue Ridge ecoregion than in the other two ecoregions investigated.

3.6 Length of Stream in Various Critical Load Classes

Results of CL calculations were expressed across the entire stream network within the study area. This allowed data to be reported statistically and to be mapped as a continuous function, rather than discrete points along the stream. Thus, results are expressed on the basis of stream length.

For the study area as a whole, about 32 to 38% of the stream length (depending on selection of threshold ANC value) was classified as having CL above 200 meq/m^2/yr (Figure 35; Table 5). The remainder of the stream length had lower calculated CL values, with 22% to 43% of the stream length having CL below 100 meq/m^2/yr. For most CL classes, there was not much difference in the extent of stream length within the class as influenced by the threshold ANC value selected. For the lowest CL class, however (less than 50 meq/m^2/yr), choice of threshold ANC value made a substantial difference to the stream length calculations. The length of stream estimated to have

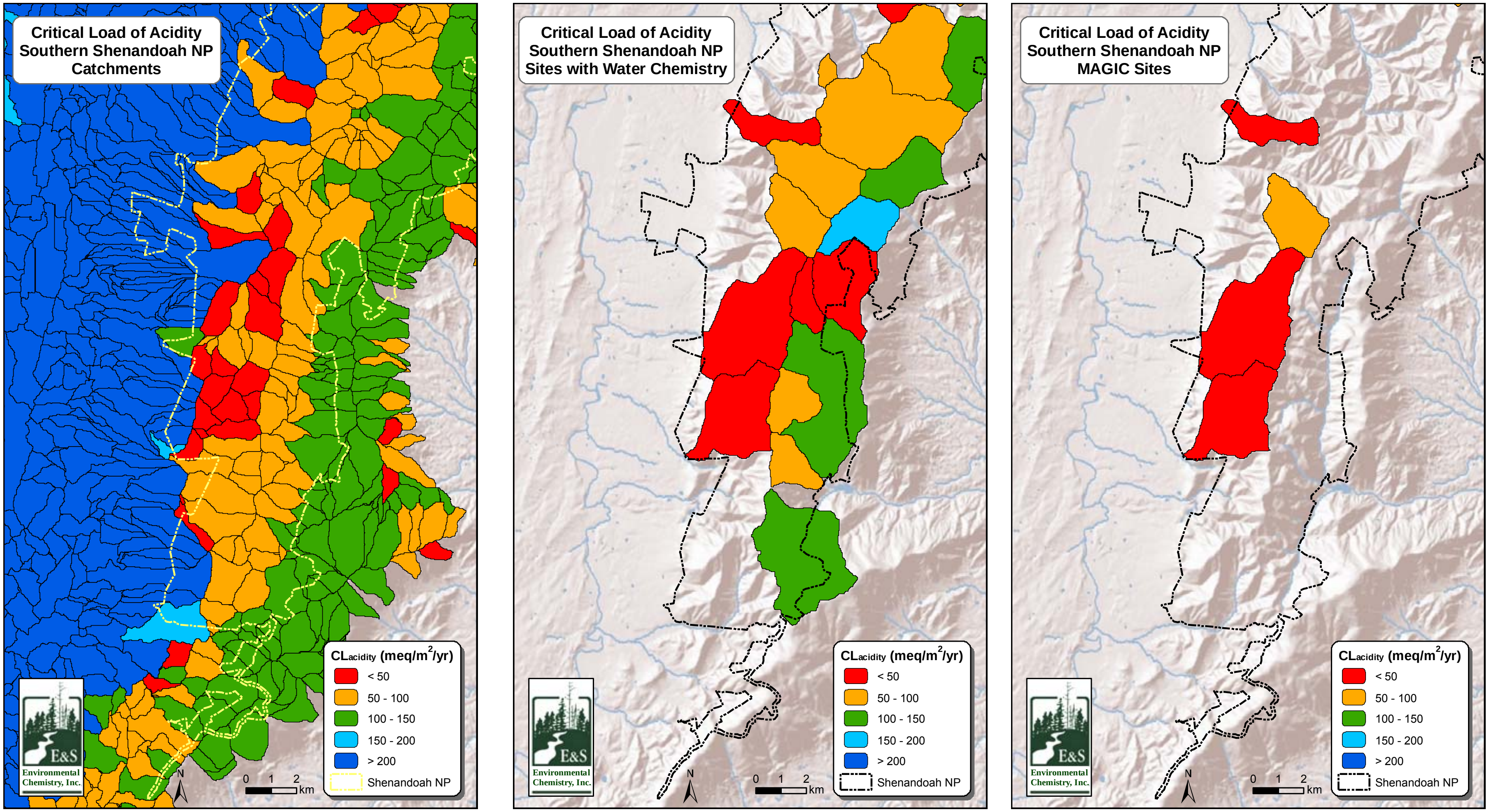

Figure 32. Comparisons among modeling approaches for calculating CL of acidity to prevent ANC from going below 20 μeq/L for watersheds in and around the southern portion of Shenandoah National Park. Calculations are based on: direct MAGIC model estimates of weathering (available for 4 watersheds only; right panel), watersheds for which there exists water chemistry data (20 watersheds; middle panel), and all watersheds (left panel). Watershed boundaries were determined by sampling site locations for the right and center panels, and by inter-pixel flow accumulation for the left panel. Spatial patterns in CL are similar using the three approaches.

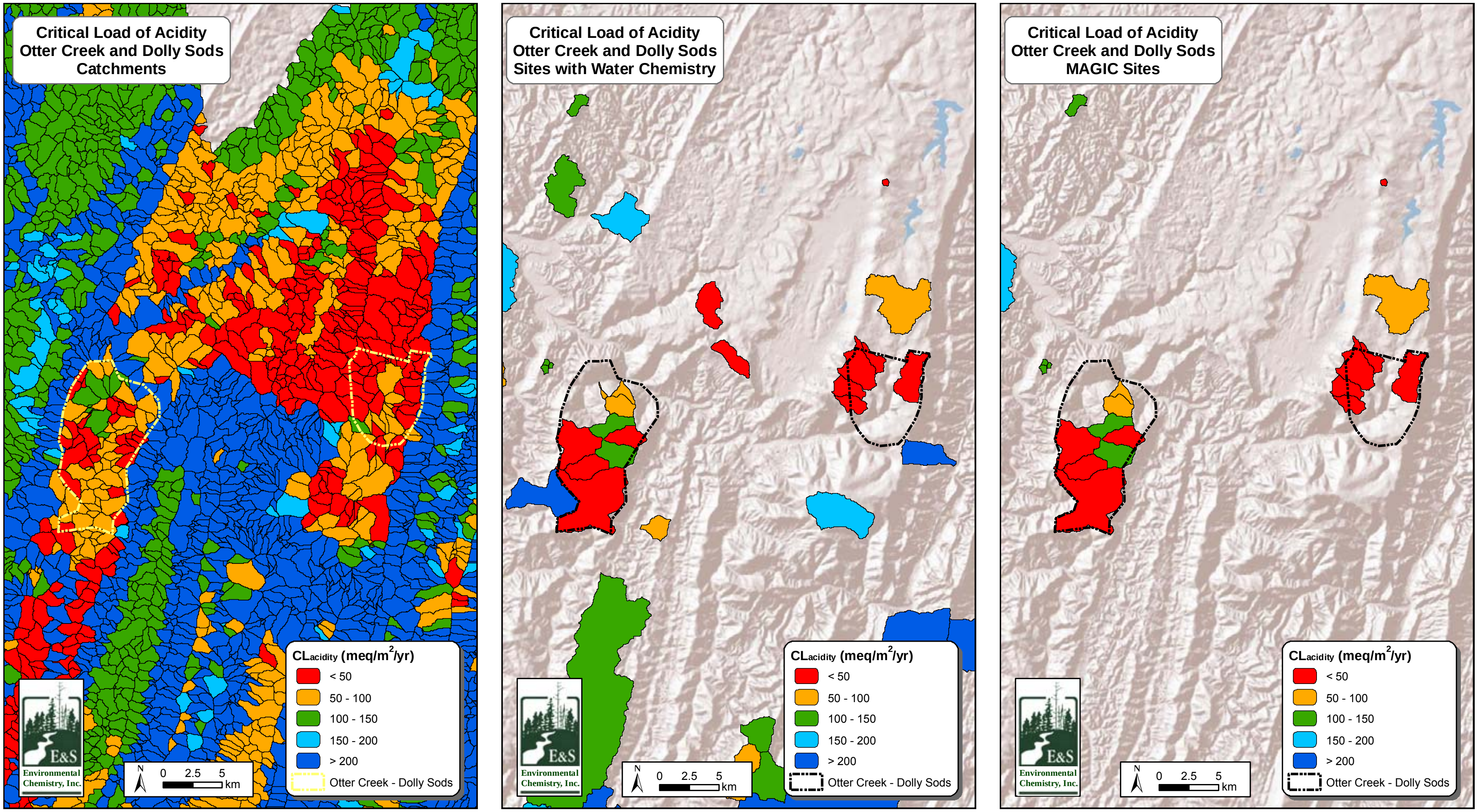

Figure 33. Comparisons among modeling approaches for calculating CL of acidity to prevent ANC from going below 20 µeq/L for watersheds in and around the Otter Creek/Dolly Sods Wilderness areas. Calculations are based on: direct MAGIC model estimates of weathering (available for ~13 watersheds only; right panel), watersheds for which there exists water chemistry data (~ 30 watersheds; middle panel), and all watersheds (left panel). Watershed boundaries were determined by sampling site locations for the right and center panels, and by inter-pixel flow accumulation for the left panel. Spatial patterns in CL are similar using the three approaches.

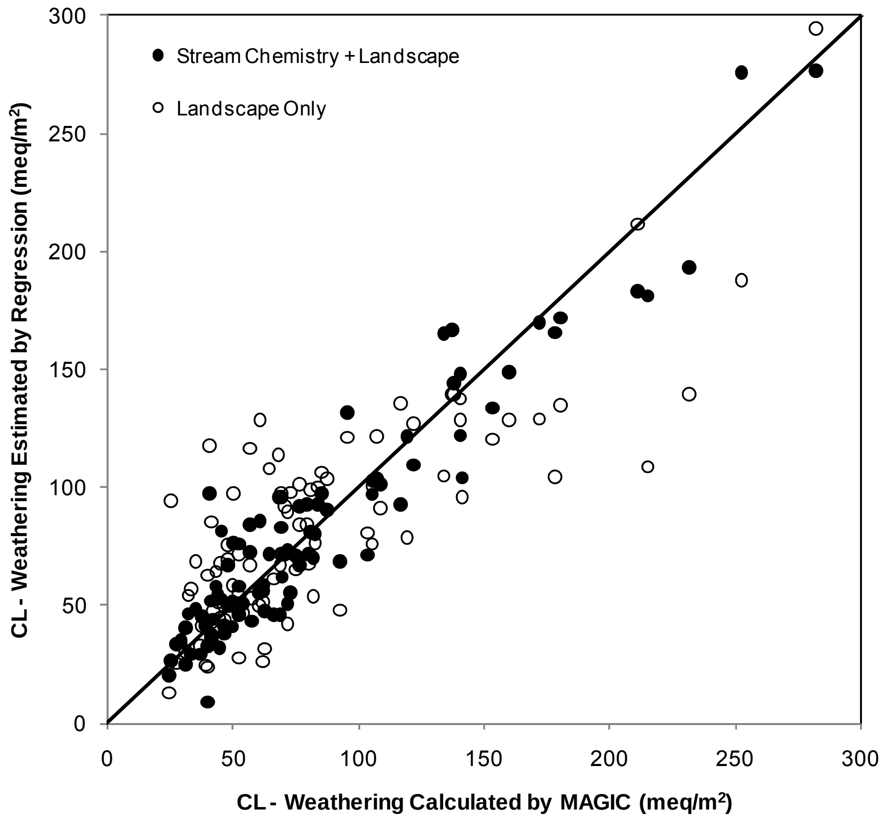

Figure 34. Critical load calculations for the 92 sites modeled with MAGIC. The CL calculations using SSWC, where weathering was calculated with MAGIC, are shown on the x-axis. SSWC CL calculations, where weathering was estimated using regression equations (water chemistry plus landscape data; or landscape 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.

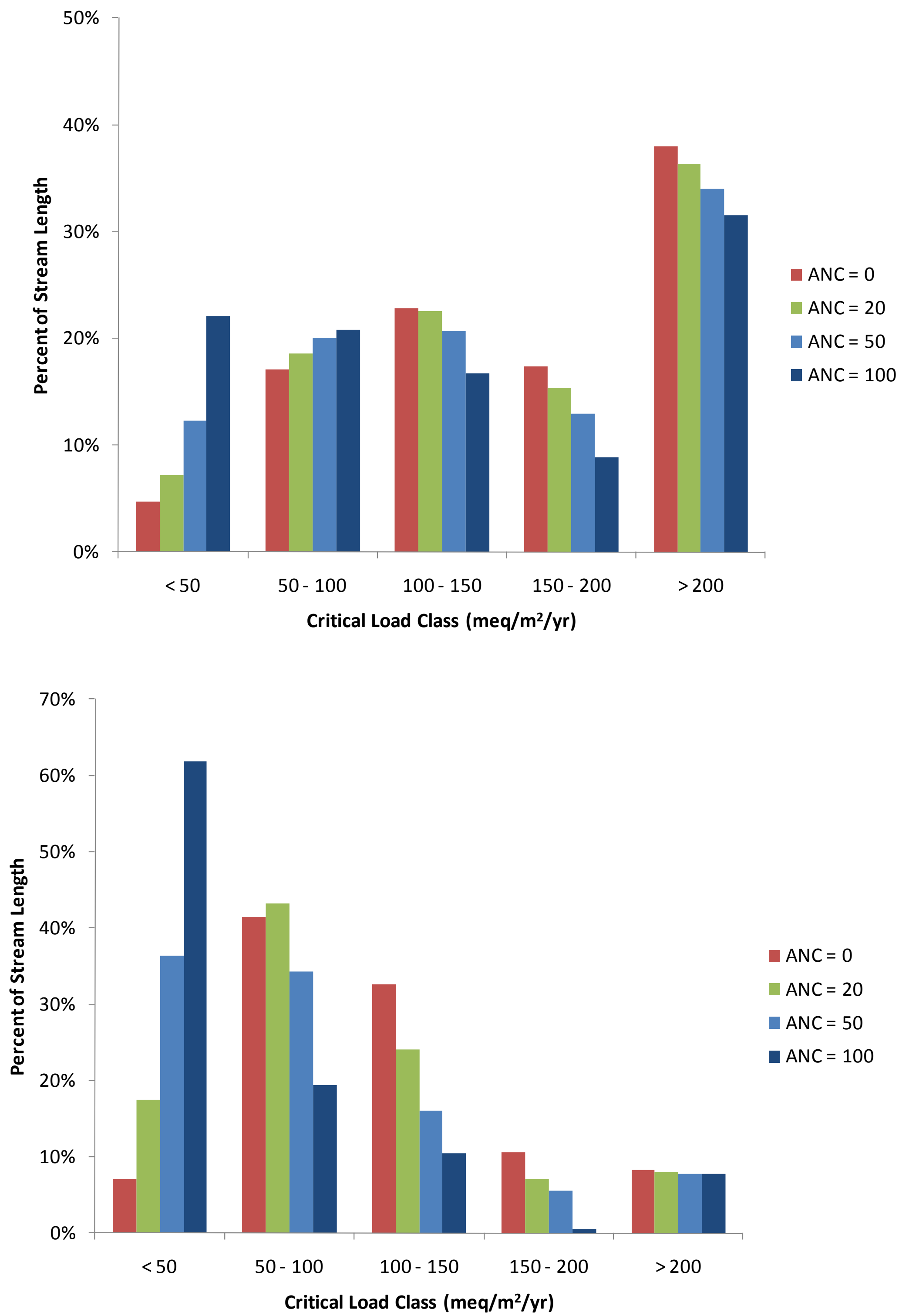

Figure 35. Percent of stream length in various CL classes based on SSWC estimates of critical load of acidity to protect against streamwater ANC below 0, 20, 50, and 100 μeq/L. Results are presented for the entire study area (top panel) and for designated Wilderness areas within the study area (bottom panel).

Table 5. Length and percent of streams within the study region in different CL classes.

Critical ANC Criterion (μeq/L)	Ecoregion	Length (km) and (Percent) of Streams within CL Class (meq/m^2/yr)				
		<50	50-100	100-150	150-200	>200
0	Blue Ridge.	379 (3%)	8,920 (67%)	3,136 (24%)	287 (2%)	525 (4%)
	Ridge & Valley	1,136 (2%)	5,821 (9%)	14,077 (22%)	10,003 (16%)	31,742 (51%)
	Central Appalachian	4,129 (9%)	5,783 (13%)	10,128 (23%)	10,570 (24%)	13,342 (30%)
20	Blue Ridge	1,462 (11%)	9,010 (68%)	2,149 (16%)	101 (1%)	535 (4%)
	Ridge & Valley	1,915 (3%)	6,821 (11%)	14,354 (23%)	8,358 (13%)	31,331 (50%)
	Central Appalachian	5,265 (12%)	6,435 (15%)	10,561 (24%)	9,966 (23%)	11,724 (27%)
50	Blue Ridge	4,436 (33%)	7,113 (54%)	1,125 (8%)	57 (0%)	527 (4%)
	Ridge & Valley	3,156 (5%)	9,161 (15%)	12,943 (21%)	6,712 (11%)	30,806 (49%)
	Central Appalachian	7,132 (16%)	7,795 (18%)	10,807 (25%)	8,733 (20%)	9,485 (22%)
100	Blue Ridge	9,301 (70%)	3,036 (23%)	383 (3%)	16 (0%)	521 (4%)
	Ridge & Valley	6,545 (10%)	11,960 (19%)	9,338 (15%)	4,483 (7%)	30,453 (49%)
	Central Appalachian	10,705 (24%)	9,964 (23%)	10,330 (24%)	6,115 (14%)	6,837 (16%)
0	Study Region	5,644 (5%)	20,524 (17%)	27,341 (23%)	20,860 (17%)	45,619 (38%)
20		8,642 (7%)	22,267 (19%)	27,064 (23%)	18,425 (15%)	43,590 (36%)
50		14,725 (12%)	24,070 (20%)	24,874 (21%)	15,502 (13%)	40,817 (34%)
100		26,551 (22%)	24,960 (21%)	20,052 (17%)	10,614 (9%)	37,811 (32%)

CL ≤ 50 meq/m^2/yr varied by more than a factor of four, depending on which threshold ANC value was selected.

The breakdown of stream length by CL class was quite different for the portions of the study area in designated Wilderness (Figure 35, top panel) as compared with the study area as a whole (Figure 35, bottom panel). Critical loads were generally much lower and more heavily influenced by selection of the threshold ANC value for designated Wilderness streams as compared with non-Wilderness streams. Over 60% of the Wilderness stream length had CL less than 50 meq/m^2/yr to protect to stream ANC above 100 μeq/L. About 70% of the Wilderness stream length had CL less than 100 meq/m^2/yr to protect to stream ANC above 50 μeq/L. Nearly half of the Wilderness stream length had CL less than 100 meq/m^2/yr to protect to stream ANC above zero.

Thus, selection of the threshold ANC value (0, 20, 50, or 100 μeq/L) seems to have more influence on calculation of the CL in Wilderness areas versus the region as a whole. In particular, choice of the threshold ANC value had a large effect on the resulting CL for the most acid-sensitive (CL $\leq$ 50 meq/m^2/yr) stream watersheds in Wilderness settings.

3.7 Critical Load Exceedance

The final step in the CL process is calculation of CL exceedance. This step identifies portions of the landscape where ambient S plus N deposition acidity exceeds the long-term steady state CL. To perform this calculation, total wet plus dry S and N deposition was calculated based on five-year averages of NADP wet (Grimm interpolation) and Community Multiscale Air Quality (CMAQ) model dry deposition centered on the year 2002 (Figures 36 and 37). Total N + S deposition acidity was then processed with the continuous upslope averaging function. Values along topographically determined stream pixels were extracted and averaged on a watershed basis in the same manner that the pixel-by-pixel CL estimates were coded to the watersheds. These watershed averaged values of total ambient deposition of acidity were then overlayed with the CL maps to generate regional estimates of CL exceedance, or areas where ambient deposition exceeds the CL. These are shown in Figures 38-40 for the critical ANC criteria values 20, 50, and 100 μeq/L, respectively (Appendix E shows the CL exceedance map for the ANC criterion value of 0 μeq/L). Broad areas of the study region were found to be in CL exceedance (Table 6). Such areas are disproportionately associated with Class I areas and other public lands. This is largely because public land in the study area tends to be located at relatively high elevation on relatively sensitive geology, and therefore receives higher deposition, and has higher runoff, lower BC_w, and lower Bc_{up}, as compared with lands located at lower elevations and on less sensitive geologies.

About half of the stream length within the study region was calculated to receive current acidic deposition in exceedance of the CL to protect against stream ANC below zero. That percentage increased to between 53% and 63% for the threshold ANC values of 20, 50, and 100 μeq/L. Nearly one-fourth of the stream length in the study region was estimated to be receiving acidic deposition that is more than double the CL for protecting stream ANC from going below 50 μeq/L. Exceedance of the CL was most prevalent in the Blue Ridge ecoregion, followed by the Central Appalachian ecoregion. Streams found to be in exceedance were about 6 times more prevalent in the Blue Ridge ecoregion as compared with the Central Appalachian ecoregion, and about 12 times more prevalent in the Blue Ridge ecoregion as compared with the Ridge and Valley ecoregion.

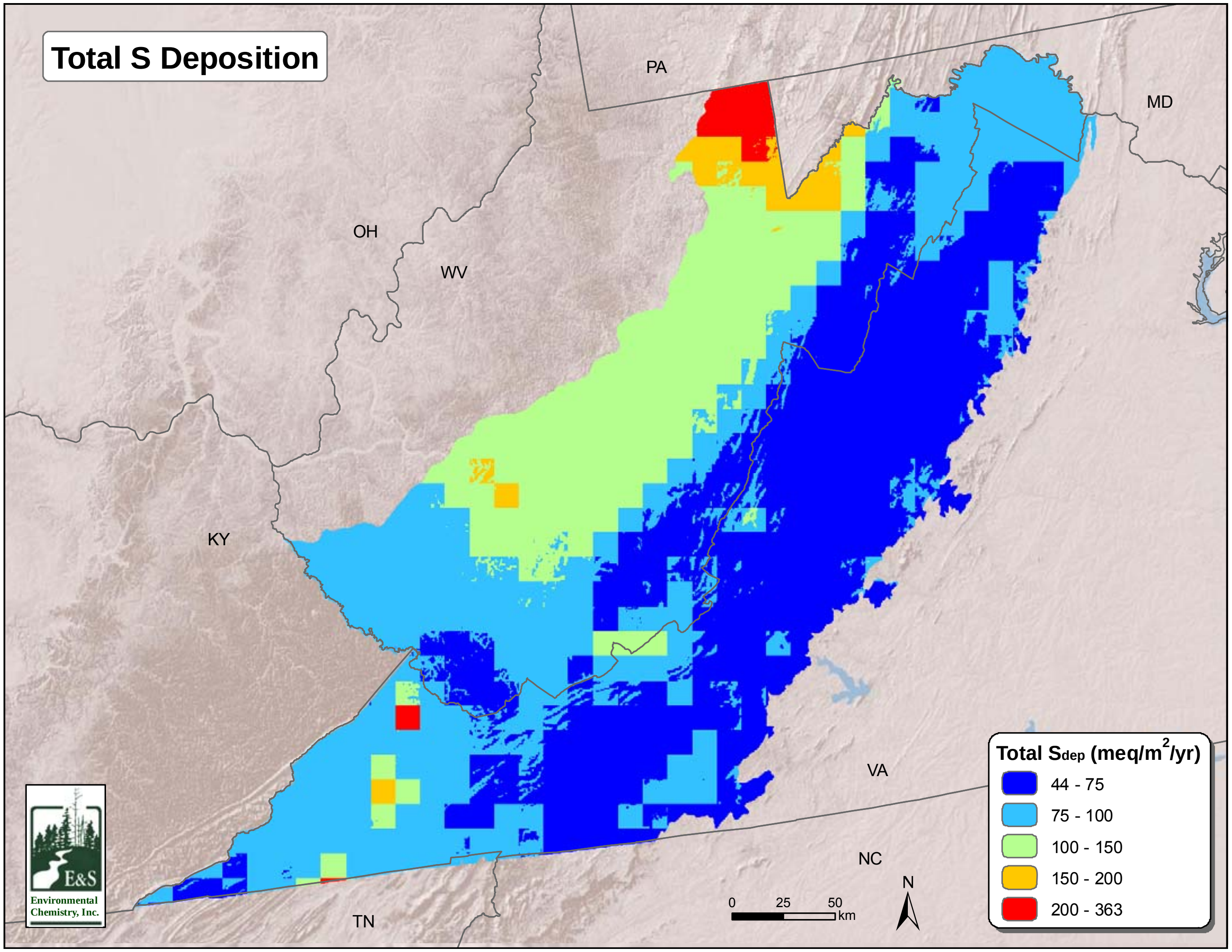

Figure 36. Regional patterns in total S deposition, based on interpolated NADP wet deposition averaged over a five year period centered on 2002 and CMAQ model estimates of dry deposition for 2002. Note that S deposition in units of kg S/ha/yr is equal to S deposition in units of meq/m^2/yr times 0.16.

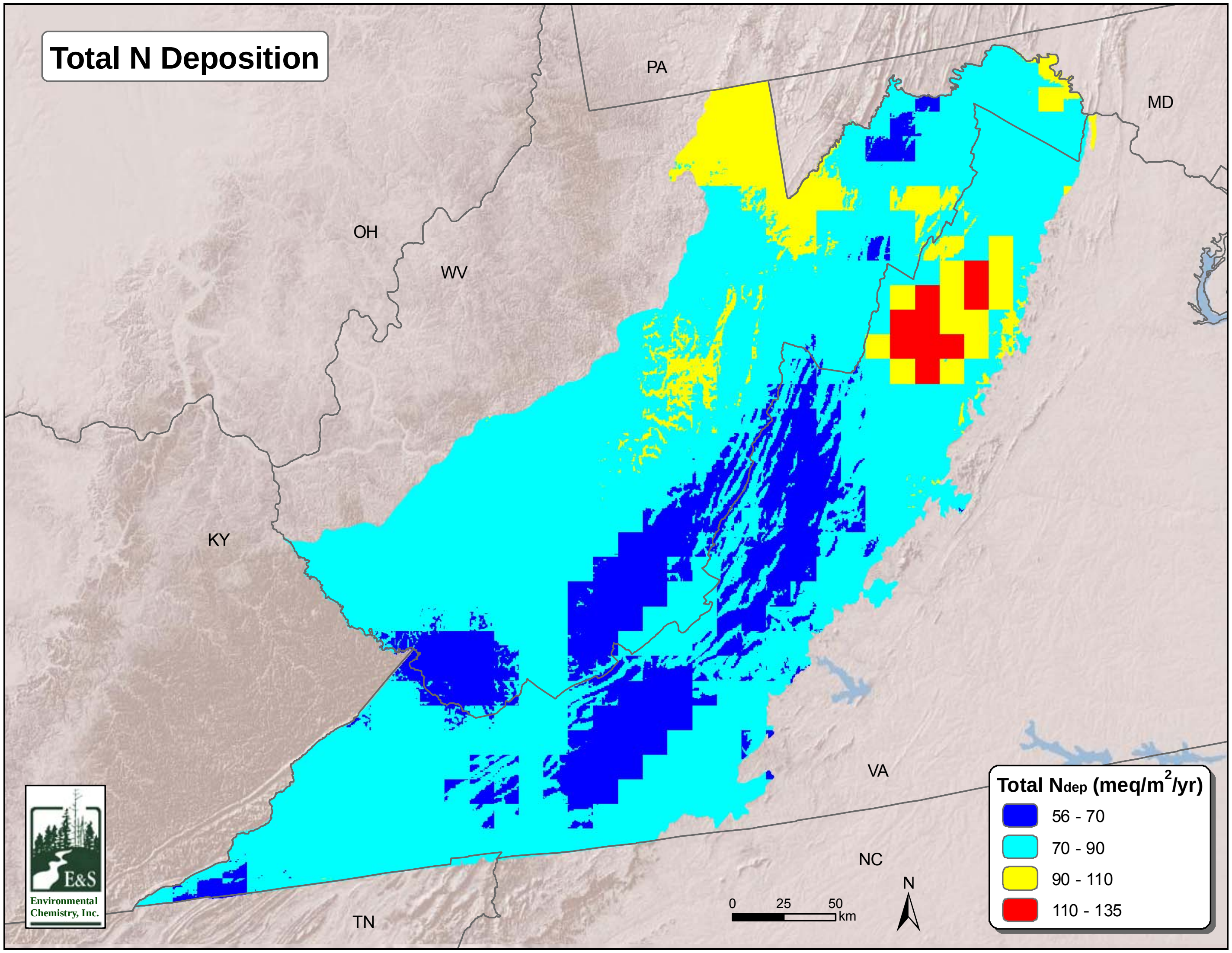

Figure 37. Regional patterns in total N deposition, based on interpolated NADP wet deposition averaged over a five-year period centered on 2002 and CMAQ model estimates of dry deposition for 2002. Note that N deposition in units of kg N/ha/yr is equal to N deposition in units of meq/m^2/yr times 0.14.

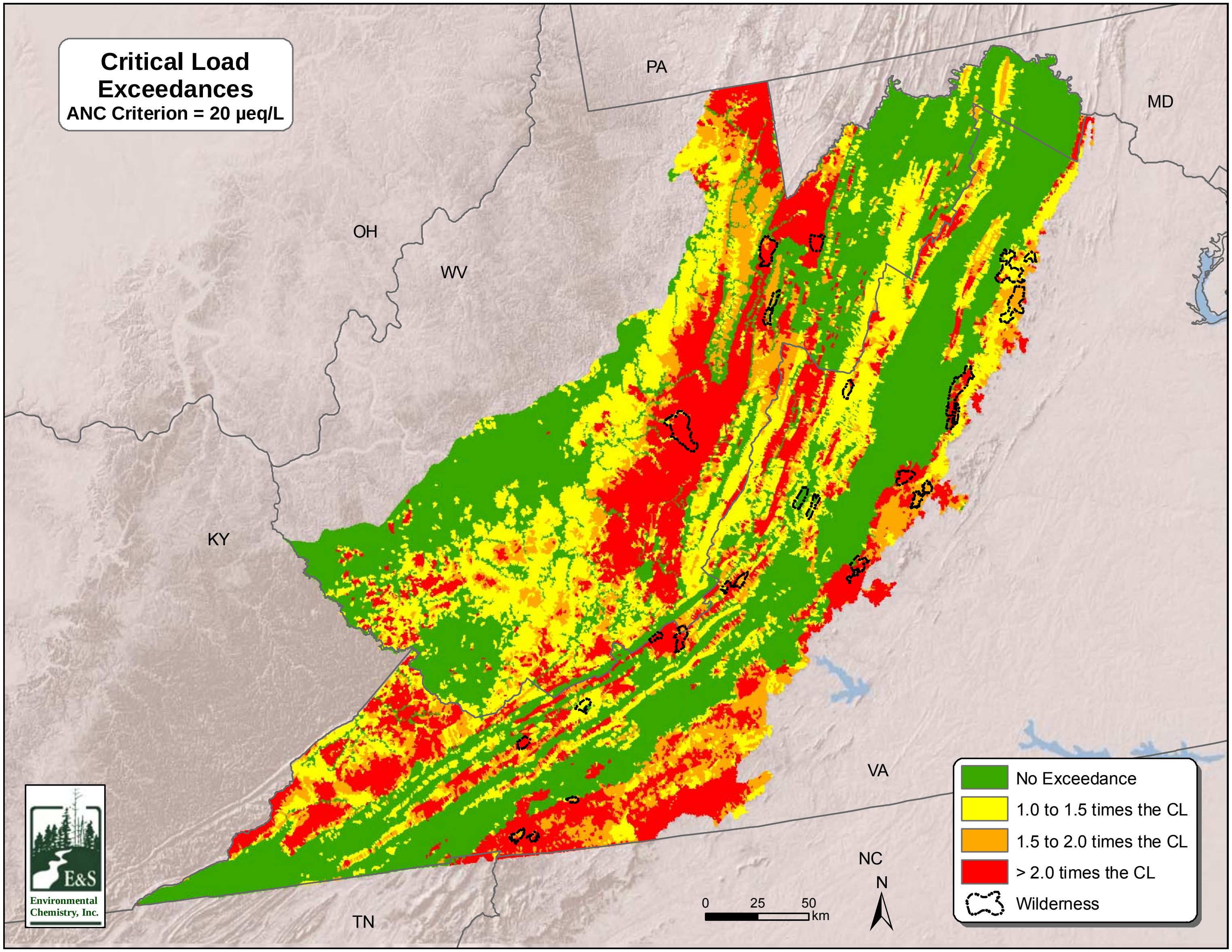

Figure 38. Critical load exceedance map for the ANC criterion 20 µeq/L.

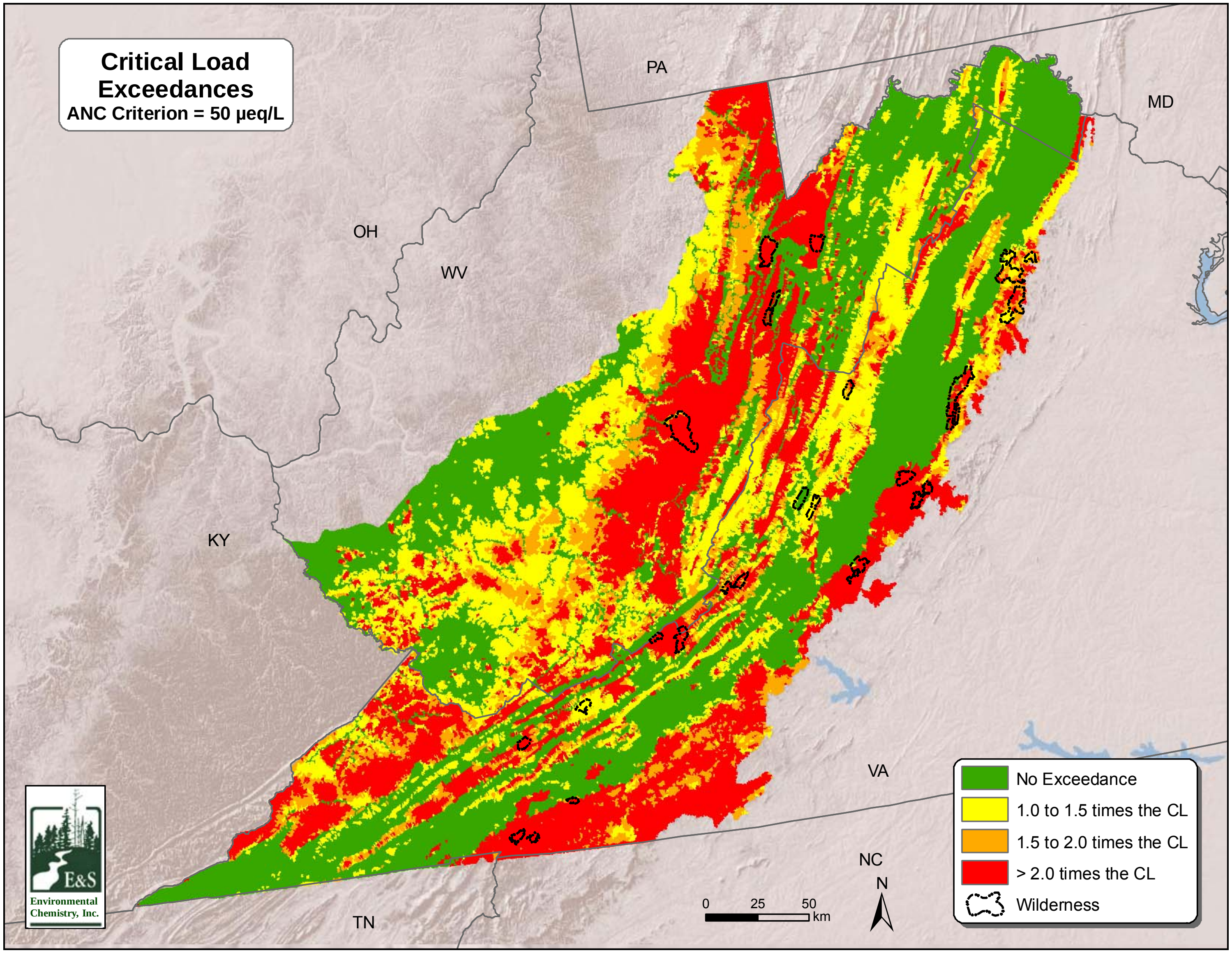

Figure 39. Critical load exceedance map for the ANC criterion 50 µeq/L.

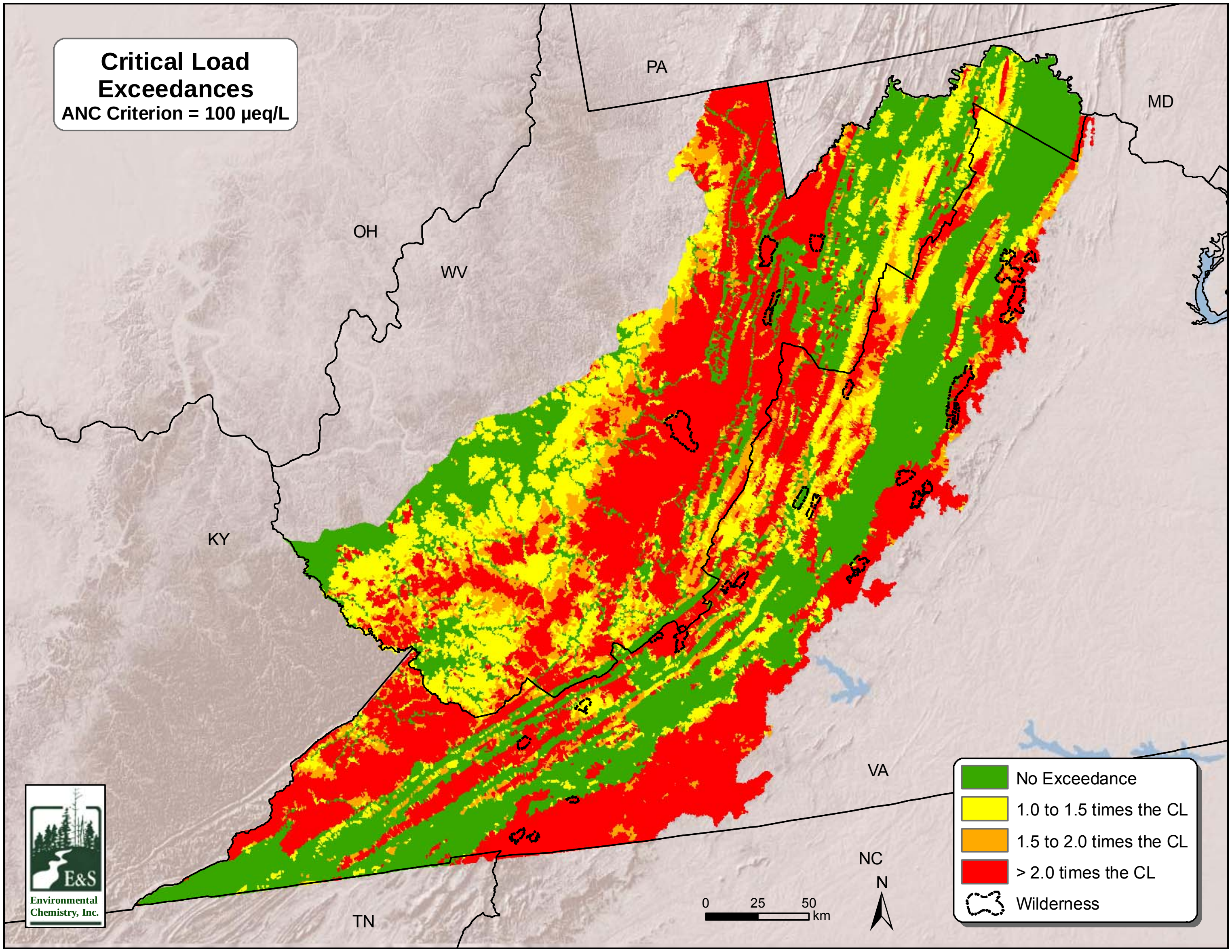

Figure 40. Critical load exceedance map for the ANC criterion 100 µeq/L.

Table 6. Length and percent of stream length within the study region in CL exceedance.

Critical ANC Criterion (μeq/L)	Ecoregion	Length (km) and (Percent) of Stream Length within Exceedance Class			
		Not in Exceedance	1.0 to 1.5 Times the CL	1.5 to 2.0 Times the CL	> 2.0 Times the CL
0	Blue Ridge	758 (6%)	3,921 (25%)	5,682 (43%)	3,523 (27%)
	Ridge & Valley	41,801 (67%)	13,188 (21%)	4,585 (7%)	3,203 (5%)
	Central Appalachian	17,840 (41%)	12,998 (30%)	4,592 (10%)	8,517 (19%)
20	Blue Ridge	651 (5%)	2,081 (16%)	4,308 (32%)	6,217 (47%)
	Ridge & Valley	39,884 (64%)	12,915 (21%)	5,394 (9%)	4,585 (7%)
	Central Appalachian	15,819 (36%)	12,731 (29%)	5,254 (12%)	10,148 (23%)
50	Blue Ridge	610 (5%)	979 (7%)	2,223 (17%)	9,442 (71%)
	Ridge & Valley	37,773 (60%)	12,202 (19%)	5,580 (9%)	7,222 (12%)
	Central Appalachian	13,188 (30%)	11,598 (26%)	6,437 (15%)	12,726 (29%)
100	Blue Ridge	546 (4%)	285 (2%)	691 (5%)	11,737 (89%)
	Ridge & Valley	34,717 (55%)	10,136 (16%)	5,811 (9%)	12,115 (19%)
	Central Appalachian	8,936 (20%)	10,311 (23%)	6,150 (14%)	18,554 (42%)
0	Study Region	60,399 (50%)	29,478 (25%)	14,859 (12%)	15,242 (13%)
20		56,355 (47%)	27,727 (23%)	14,955 (12%)	20,950 (17%)
50		51,571 (43%)	24,779 (21%)	14,240 (12%)	29,389 (24%)
100		44,199 (37%)	20,731 (17%)	12,652 (11%)	42,406 (35%)

3.8 Time to Steady State

The SSWC model estimates the long-term steady-state CL that is expected to allow acidified streams to recover to a designated critical ANC criterion value. No information is provided, however, regarding the amount of time that it may take to affect resource recovery at that CL deposition level. To address this uncertainty, the time to reach steady-state condition was simulated using the MAGIC model at each of the 92 calibration sites. Dynamic responses for the SSWC CL for each stream water criterion were examined.

The calibrated weathering in MAGIC for each site was used in the SSWC model to calculate the CLs for that site for each water quality index value. It is expected, therefore, that a long-term simulation using calibrated MAGIC driven by the SSWC CL should converge on the water quality index value. The time to reach this steady-state value can be extracted from the

MAGIC simulations. Simulations were run for 1000 years at each site starting in 1995 (the calibration year for the modeled sites) and using the protocol described below.

The future deposition of base cations and Cl^- for the MAGIC simulations were assumed to be constant at their 1995 values for the entire 1000 year period. Deposition of SO_4^{2-}, NO_3^-, and NH_4^+ were varied from 1995 to 2007 according to the observed linear trend in wet deposition of each ion at each site using the approach of Grimm et al. (1997) to interpolate observed NADP data during that period. From 2007 to 2010, deposition of S and N were varied according to projected atmospheric deposition, given current emissions control policies. Starting in 2010 and finishing in 2020, the SSWC CL for each site was implemented linearly over the 10 year period. The acidity of deposition was increased or decreased to the SSWC CL value. From 2020 to the end of the 1000 year simulation, the deposition of acidity was held constant at its SSWC CL value.

The 1000-year simulations provided time-series of simulated future calculated ANC values for each critical ANC threshold at each site. The simulation period from 1995 to 2020 was driven by deposition sequences unrelated to the SSWC CL, so that time period was ignored. The SSWC CLs were fully implemented in each simulation by 2020, so the first year examined for dynamic responses of the outputs was chosen to be 2025. Starting in 2025, the simulated time series were sampled every 25 years for the first 300 years, then every 50 years for the next 300 years, and then every 100 years for the final 300 years.

In all cases, the simulations approached the critical water quality index in an asymptotic manner, from either above or below depending on the value of calculated ANC prior to implementation of the SSWC CL. It was necessary, therefore, to define the achievement of "steady-state" in the simulations as the point in the time series when the simulated value approached within some specified distance from the nominal value. This interval was chosen as 2.0 μeq/L for this study.

Results of these time-to-steady-state analyses (Figure 41) suggested that:

- most of the modeled watersheds will not reach steady state for hundreds of years, and
- the time period is somewhat longer if the selected threshold ANC value is higher (more protective).

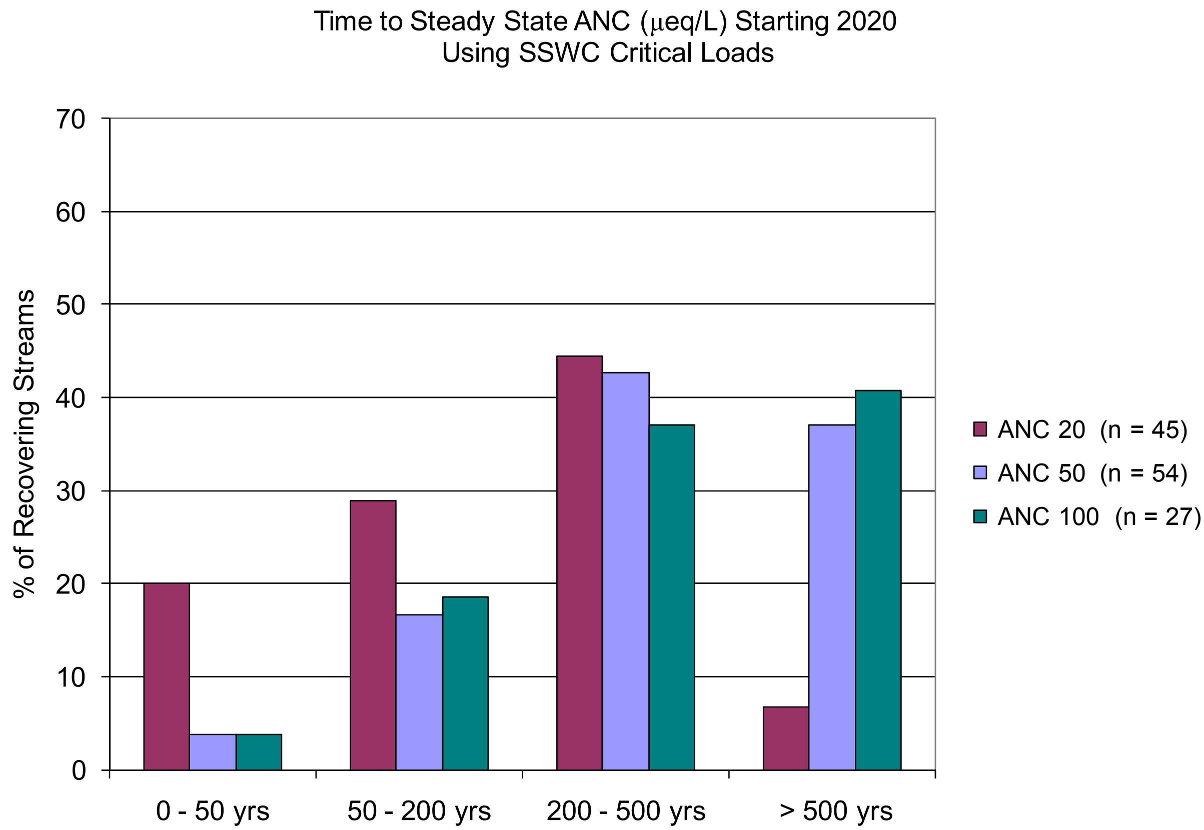

Figure 41. Breakdown for the previously impacted modeled streams (those having current ANC below the respective critical ANC threshold values) of modeled time to reach steady state under continued deposition at the CL level. Three critical ANC criteria thresholds are illustrated: 20, 50, and 100 µeq/L.

The relationships between CL, selection of ANC criterion value, and selection of evaluation year are important. Higher CLs can be tolerated if one only wishes to protect against acidification to the year 2050, as compared with more stringent deposition reductions required to protect systems against acidification for a longer period of time. More substantial emissions and deposition reductions are needed to affect recovery of damaged systems within a short period of time as opposed to a longer period of time. Higher CLs are allowable if one wishes to prevent acidification to ANC = 0 µeq/L (chronic acidification) than if one wishes to be more protective and prevent acidification to ANC below 20 µeq/L (possible episodic acidification) or below 50 or 100 µeq/L (general biological health). Thus, use of these CL calculations for decision making requires an understanding that the majority of the modeled watersheds will likely not come into steady state with the SSWC CL deposition values for more than 200 years.

4.0 DISCUSSION

4.1 Weathering Estimates

A computationally efficient and robust method for estimating BC_w on a continuous basis across a regional landscape was developed. It was based on weathering estimates extracted from a well-tested process-based watershed model of drainage water acid-base chemistry and also on features of the landscape that are available as regional spatial data coverages and that are known to correlate with acid sensitivity.

Results indicate substantial spatial variability in weathering estimates across the study region (Figure 18). Weathering estimates were especially low (less than 50 meq/m^2/yr) in portions of the Blue Ridge ecoregion, including the southern section of Shenandoah National Park in Virginia and portions of the Central Appalachian ecoregion, including much of Otter Creek and Dolly Sods Wilderness areas in West Virginia.

Predictive ability was greater for sites with water chemistry as compared with calculations using landscape variables only (Table 3). Nevertheless, predictive equations developed using only regionally available landscape variables explained 64% to 85% of the variation in simulated weathering derived from the process model. This process provides an approach, with quantifiable uncertainty, for estimating weathering using calibration results from a well-tested process model. Other common methods for estimating BC_w for input into SSWC and other steady state CL models are based on empirical equations with no basis for assessing uncertainty. In addition, the utilization of readily available spatial datasets (i.e., elevation, soil characteristics, lithology), combined with site-specific process modeling to predict weathering on a 30-m grid cell basis, allows for this method of estimating base cation weathering to be extrapolated to a large region and perhaps to be transferred to other regions of the United States.

In general, the independent variables included in the regression equations (Table 3) were logical products of current understanding of catchment weathering and acid-base chemistry. Equations to predict weathering at sites for which stream chemistry data were available consistently selected either SBC in stream water or streamwater calculated ANC as primary predictor variables. In two of the three ecoregions, stream NO_3^- was also selected. This suggests that weathering co-varies to some extent with N leaching. The reason(s) for this are unclear. Weathering estimates increased in all cases with increasing SBC, calculated ANC, and NO_3^- concentration. For those weathering equations that included stream chemistry variables, none of the geologic sensitivity or soil variables were selected for inclusion in the regression equations.

This is likely because stream chemistry effectively integrates soil and geologic condition, and may in fact provide a better reflection of base cation supply than available spatial data on geology and soils.

Equations to predict weathering at sites lacking stream chemistry data in all cases selected soil and/or geologic variables as independent variables. Weathering increased with increasing coverage of carbonate, felsic, and mafic lithologies, but decreased with increasing siliciclastic lithology. This result agrees with geological sensitivity mapping conducted in this region by Sullivan et al. (2007). Weathering increased with decreasing soil depth in the Blue Ridge ecoregion, a counter-intuitive result that may have been driven by cross-correlation with other variables. Weathering decreased, as expected, with increasing soil pH and decreasing soil clay content. Other landscape variables included in the regression equations and their signs (positive or negative) included watershed area (+), elevation (-), and average watershed slope (-). All of these variables, and their signs, agree with current scientific understanding of acidification sensitivity. The most acid-sensitive streams (lowest BC_w) tend to be located in small watersheds, at high elevation, on steep slopes.

The CL calculations using SSWC were similar regardless of which of the three methods of estimating BC_w was used. Critical load calculations using the regression equations to predict BC_w, based on secondary site- specific results (including water chemistry plus landscape characteristics) and also those based on mapped regional results, yielded reasonable agreement with CL calculations using MAGIC estimates of BC_w (Figure 34). Nevertheless, it is important to note that the weathering and CL maps reported here are preliminary maps, not final maps. This project demonstrated one particular technique for estimating weathering. It is based on a well-tested and widely used process-based model. However, there has not been a formal uncertainty analysis, and the confidence in these estimates is unknown. It will be important to continue research efforts to quantify BC_w, the most important and most uncertain variable in CL calculations reported here (cf., McDonnell et al. in review)

4.2 Critical Load and Exceedance Levels

Overall, the calculated CL values were relatively low throughout the study area, especially in the Blue Ridge ecoregion. A third of the stream length in that ecoregion had CL to maintain ANC above 50 μeq/L less than 50 meq/m^2/yr, and 87% of the stream length in the Blue Ridge had CL less than 100 meq/m^2/yr for protection to ANC above 50 μeq/L. For the entire study area, 32% of the stream length exhibited CL (to maintain ANC above 50 μeq/L) below 100 meq/m^2/yr (Table 5). As a consequence of these low calculated CL values, coupled with relatively high levels of acidic deposition (Figure 42), much of the land within the study region was calculated to be in exceedance of the CL. Depending on selection of ANC threshold, 50% to 63% of the stream length within the region was calculated to be in CL exceedance (Table 6). This result suggests the possibility of long-term impacts on aquatic ecosystem health under sustained acidic deposition at levels near current values.

4.3 Temporal Pattern of Response

The CL and CL exceedance values calculated in this project pertain to long-term, steady-state water quality conditions as defined in the algorithm used in the SSWC model. It is known that it may take decades or centuries to reach the steady-state condition with respect to deposition acidity and stream chemistry. Land managers may prefer to affect recovery of damaged stream watersheds within a shorter time period. Conversely, managers may be willing to accept deposition levels that eventually will cause damage but not for a very long time. Thus, the steady state CL and exceedance calculations may not provide managers with all of the information needed to make informed land management decisions. To address this uncertainty, the time to reach the steady-state CL condition was simulated using the MAGIC model at the 92 dynamic calibration sites. Simulations were run for 1000 years at each site after setting the future deposition acidity to the SSWC CL value for each stream threshold criterion at each site.

The results of this dynamic analysis showed clearly that relationships between SSWC CL value, selection of stream ANC criterion value, and selection of evaluation year are important. More substantial emissions and deposition reductions (below that of the SSWC CL) are needed to affect recovery of damaged systems within a short period of time (decades) as opposed to longer periods of time (centuries). The longer one is willing to wait for recovery, the more relevant is the SSWC CL estimate to actual recovery achieved. For the dynamic modeling sites in this pilot study region, the simulations suggest that it can take hundreds of years to reach specified stream water ANC criteria assuming atmospheric deposition of acidity at the SSWC long-term steady-state CL level. The use of these SSWC CL calculations for decision making requires an understanding of this dynamic aspect of recovery.

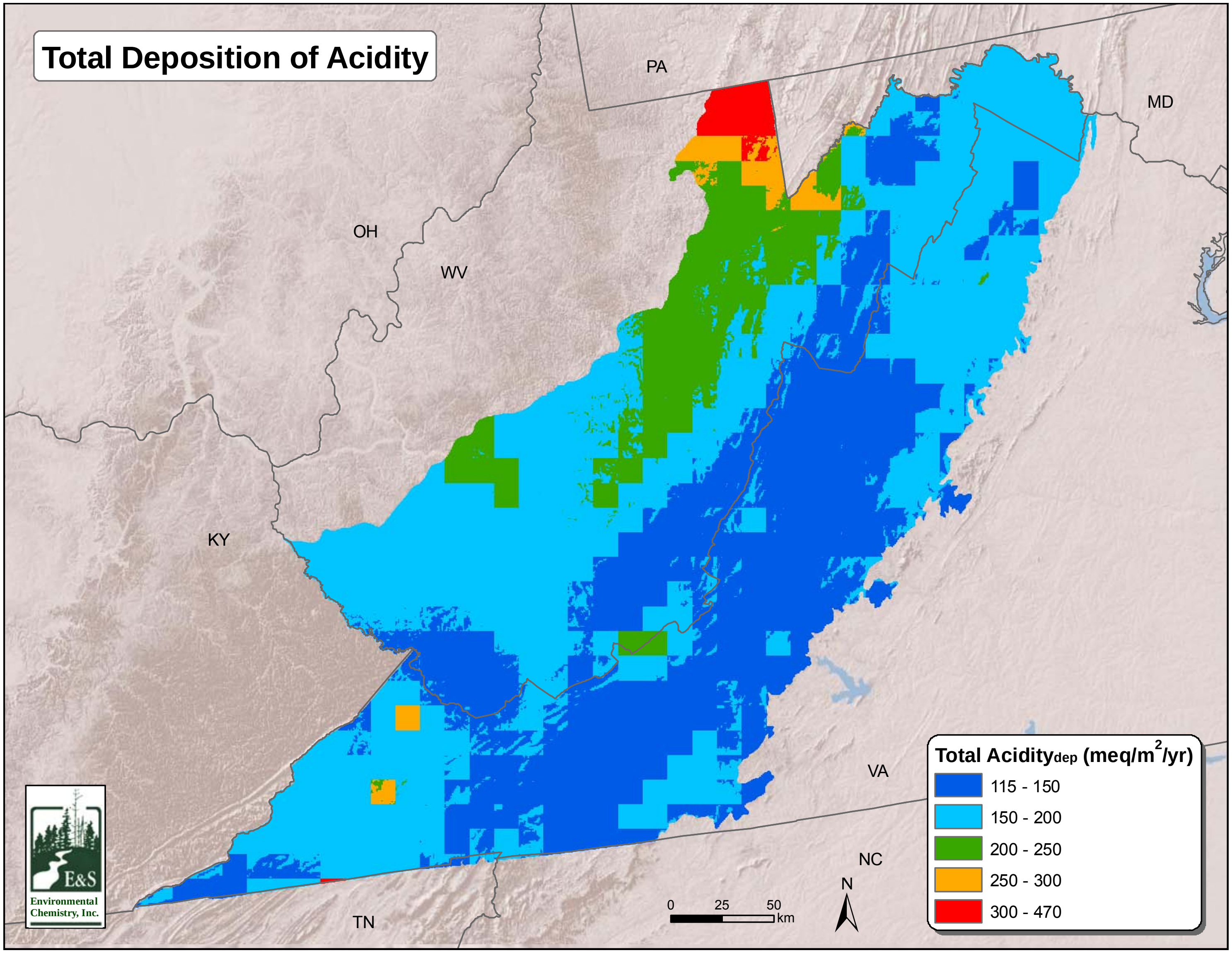

Figure 42. Total deposition of acidity across the study area, estimated from interpolated NADP wet deposition using the Grimm and Lynch (1997) approach (five-year average centered on 2002; E. Grimm, unpublished data) added to dry deposition estimates for 2002 from the CMAQ model (Robin Dennis, U.S. EPA, unpublished data).

4.4 Policy Considerations

Although process-based watershed models such as MAGIC and steady-state models such as SSWC entail uncertainty (cf., Sullivan et al. 2004, Li and McNulty 2007), results of CL calculations presented here will help to inform the development of the CL process as an important assessment and policy tool in the United States. This could aid the management of aquatic resources in acid-sensitive regions throughout the country. The approach may also be useful for addressing transboundary air pollution issues affecting Canada and Mexico. Additional logical steps in the process could include selection of interim (politically-determined) target loads of S deposition which would allow acid-impacted streams to begin the process of chemical recovery and move toward the long-term CL values that would sustain sensitive aquatic life forms. Critical loads models have been important tools for development of control strategies for transboundary air pollution in Europe (Gregor et al. 2001).

Science and policy are closely coupled in the CLs process. The scientific elements include tasks such as relating ambient air quality to pollutant deposition, quantifying the relationships between pollutant deposition and resource responses, identifying the resources at risk to adverse effects, understanding the temporal and spatial responses of resources to pollutant deposition, and more. The policy-dependent elements include tasks such as identifying the environmental resources to be protected, establishing appropriate criteria for different land use areas (e.g., Class I areas, national parks, wildlife refuges), and defining significant harm to protected resources.

There is, therefore, no single “definitive” CL for a natural resource. Critical load estimates are explicitly linked to policy, but their reliability is conditioned on the soundness of the underlying science. As elements of the CL process change, the CL estimates will change to reflect both the current state of knowledge and policy priorities. Changes in scientific understanding may include new dose-response relationships, better resource maps and inventories, larger survey datasets, continuing time series monitoring, improved numerical models, etc. Changes in the policy elements may include new definitions of harm, new mandates for resource protection, focus on new pollutants, or inclusion of perceived new threats that may exacerbate the pollutant effects (e.g., climate change). The CL process is thus an iterative process. As science changes, the scientific content is updated; as policy needs change, the content is re-directed.

The use of CL in resource management always has some time frame of expected response, and some context of management priorities. For instance, it may be that a deposition load well below the CL would hasten the recovery of a receptor that exhibits existing harm. Or, it may be that a receptor that has not yet been damaged can sustain a deposition load above the CL for some finite period before incurring significant harm. Such time frames can be very long (many decades or centuries).

The lack of explicit consideration of time in a steady state CL analysis can lead to assumptions that are not warranted. The CL derived in a steady state analysis is an estimate of the long-term, constant deposition that a receptor can tolerate with no significant harm after it has equilibrated with the CL deposition level. However, as shown by the analyses presented here, biological and geochemical processes that affect a receptor may delay the attainment of equilibrium (steady state condition) for centuries. By definition, steady state CLs do not provide any information on these time scales. Therefore, one cannot assume that reducing deposition to, or below, the steady state CL value will immediately, or within any management time period, eliminate or mitigate significant harm.

Calculated CL, combined with other temporal, economic, and/or political considerations, can be used to set short-term or long-term deposition targets. For example, a target load (TL) can be set on the basis of the CL, also considering issues of recovery response times. A TL can incorporate various management objectives. If the CL for resource recovery has been estimated to be x, one may set a TL equal to 1.5 x (or some other value) as an interim target with the intention of reaching the TL within a certain number of years. This interim target, although higher than the CL, might be considerably lower than ambient deposition, thereby allowing for partial resource recovery within a finite time period. The TL could also be set lower than the CL, for example if managers are unwilling to wait the decades or centuries that it might take to attain the threshold ANC value condition under constant loading at the CL level. The calculated CL values, such as are reported here for streams in Virginia and West Virginia, can provide the scientific foundation for policy judgments and the setting of TLs.

5.0 SUMMARY

Regional aquatic CL modeling was conducted using a modified version of the SSWC steady state model for streams in the Blue Ridge, Ridge and Valley, and Central Appalachian ecoregions in Virginia and West Virginia. A novel approach was employed to estimate the weathering term, the key parameter in the SSWC model, based on calibration of weathering using a dynamic process-based model (MAGIC), with subsequent extrapolation of those weathering estimates to the entire study domain. Results indicated that substantial portions of the study area, and of the stream length within the study area, have relatively low CL values (less than 100 meq/m^2/yr). Ambient levels of atmospheric deposition acidity are in exceedance of the calculated CLs for half or more of the stream length within the region. In general, calculated CLs were lower, and exceedances were higher, in the Blue Ridge ecoregion, as compared with the Ridge and Valley and the Central Appalachian ecoregions. These steady state CL estimates are time invariant. Model projections using the dynamic MAGIC model suggested that most of the modeled watersheds will not reach steady state with respect to deposition acidity for hundreds of years. Therefore, reducing ambient deposition to the calculated CL levels may not result in recovery of water chemistry to levels protective of aquatic biota within the timeline of management decision making.

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APPENDICES

Appendix A

The Responses of Aquatic Biota to Stream Acidification in Shenandoah National Park, VA

1.0 PURPOSE

The purpose of this appendix is to summarize the current state of knowledge of stream acidification effects on aquatic biota within Shenandoah National Park (SHEN). The material presented in this appendix has been excerpted (with modification) from:

Cosby, B.J., J.R. Webb, J.N. Galloway and F.A. Deviney. 2006. Acidic Deposition Impacts on Natural Resources in Shenandoah National Park. Technical Report NPS/NER/NRTR-2006/066. National Park Service. Philadelphia, PA.

The goal of the Acid Impacts Project for SHEN (Cosby et al., 2006) was to develop an assessment of the extent of possible adverse effects of acidic deposition on resources in the park. The assessment approach utilized maps of the park highlighting ***areas of concern*** with respect to adverse effects on aquatic and terrestrial systems.

2.0 LEVELS OF CONCERN FOR ADVERSE EFFECTS OF ACID DEPOSITION ON AQUATIC ECOSYSTEMS IN SHEN

Four categories of concern for surface water conditions were defined based on stream-water acid neutralizing capacity (ANC) and include a number of observed effects for a number of aquatic organisms in SHEN.

Low Concern. (Average ANC greater than 100 μeq/L). Reproducing brook trout populations expected where habitat is suitable. Fish species richness probably unaffected. Diversity and/or evenness of aquatic macroinvertebrate communities unaffected. Number of families and/or number of individuals of aquatic insects unaffected.

Moderate Concern. (Average ANC in the range 50-100 μeq/L). Reproducing brook trout populations expected where habitat is suitable. Fish species richness much reduced. Diversity and/or evenness of aquatic macroinvertebrate communities begin to decline. Number of families and/or number of individuals of aquatic insects begin to decline.

Elevated Concern. (Average ANC in the range 0-50 μeq/L). Brook trout populations sensitive and variable; lethal and/or sub-lethal effects possible. Fish species richness much reduced. Diversity and/or evenness of macroinvertebrate communities decline markedly. Number of families of aquatic insects declines markedly. Number of individuals in most aquatic insect families declines markedly. Number of individuals of acidophilic aquatic insect families increases sharply.

Acute Concern. (Average ANC less than 0 μeq/L). Lethal effects on brook trout populations probable. Complete extirpation of fish populations expected (species richness equals zero). Extremely low diversity and/or evenness of aquatic macroinvertebrate communities. Extremely reduced number of families of aquatic insects. Extremely reduced number of individuals of most aquatic insect families. Large number of individuals of acidophilic aquatic insect families.

3.0 OVERVIEW OF STREAM ACIDIFICATION EFFECTS

Aquatic biodiversity in the southern Appalachian Mountain region is high. Southern Appalachian streams contain a rich diversity of invertebrate and fish species. Local species richness depends on thermal regime, water chemistry, patterns of discharge, plus substrate type and geomorphology (Wallace et al. 1992).

Acidification of waters in the southern Appalachian Mountains region occurs against a backdrop of highly modified streams and rivers. About 98% of the free-flowing freshwater communities in the United States have been drastically altered, and only about 20% are of high enough quality to warrant Federal protection (Sullivan et al., 2003). To date, only about 1,600 km of streams and rivers have been given conservation status; only about 10% of these are east of the Mississippi River (Sullivan et al., 2003).

Acidification of streams in the region primarily affects two groups of aquatic organisms – macroinvertebrates and fish. Responses for each group are discussed below.

3.1 Aquatic Macroinvertebrates

Macroinvertebrates are defined as animals without backbones, which can be seen with the unaided eye, and are usually larger than 0.025 cm (0.01 inches) in at least one dimension. Aquatic benthic macroinvertebrates occur on the bottoms of streams or lakes, in or among substrates such as stones, gravel, plants, or wood. In lower order streams, the immature aquatic insects represent most of the macroinvertebrates, together with mollusks and crustaceans. The stream benthic community contains many species of known sensitivity to stresses such as acidification or sedimentation. As with other groups, counts of taxa (such as families, genera or species) at impacted sites are often lower than at unimpacted sites due to loss of sensitive taxa. Therefore, lower species richness or absence of specific taxa is often taken to indicate impacts (SAMAB, 1996).

Macroinvertebrate ecological roles in aquatic communities are diverse. Invertebrate species richness in the southern Appalachian Mountain region is probably greater than in other regions in North America, with many endemic species. Indeed, the regional invertebrate fauna includes many as yet undescribed species. The cool, high mountain streams in the region contain species that are usually only found further north. Many regional taxa have evolved rather elaborate morphological and behavioral adaptations for maintaining their positions in high-gradient streams with high current velocity (Wallace et al. 1992).

3.2 Fish

Fish diversity is high in the southern Appalachian Mountain region, which is widely regarded as one of the most diverse landscapes in the Temperate Zone (SAMAB, 1996). There are about 950 freshwater fish species in North America (Jenkins and Burkhead 1993), of which about 485 species can be found in the Southeast, including about 210 species in Virginia (Jenkins and Burkhead 1993), and more than 30 species in SHEN. Regional habitat diversity and intraspecific genetic diversity are also regarded as high. Thus, the Southeast is a unique national biodiversity resource for fish.

These unique characteristics have been extensively documented by the Southern Appalachian Assessment (SAA) (SAMAB, 1996). The SAA was a comprehensive, interagency assessment, begun in 1994 and completed in 1996. It was designed to collect and analyze ecological, social and economic data. The information was intended to facilitate an ecosystem-based approach to management of the natural resources on public lands within the assessment area (which includes SHEN). Unfortunately, the Southern Appalachian Assessment concluded that 70% of sampled stream locations showed moderate to severe fish community degradation, and that about 50% of the stream length in West Virginia and Virginia showed habitat impairment (SAMAB, 1996).

Fish communities of high-gradient southern Appalachian streams may contain a variety of species, but are often dominated by trout, especially brook trout. Of the 15.1 million ha (37.4 million ac) in the southern Appalachian region (as defined by SAMAB, 1996), 5.9 million ha (14.6 million ac [39%]) are in the range of native brook trout, with up to 53,000 km (33,000 mi) of potential native brook trout streams. This includes over 19,000 km (12,000 mi) of trout streams in Virginia (SAMAB, 1996). There has been little regional ecological research on other species except in biogeographic and systematic studies, although Jenkins and Burkhead (1993) provided much ecological information on the fish species of Virginia.

There are, nevertheless, clear patterns in species distribution from headwaters to rivers, which can also be seen in community comparisons among reaches at different elevations; the clearest pattern is that species richness increases in a downstream direction. This is thought to result from the rather small number of upstream species, which must tolerate simultaneously highest current velocities and lowest pH values. The highest-elevation fish species is usually brook trout, typically joined downstream by dace (e.g., blacknose dace, *Rhinichthys atratulus*), a sculpin (e.g. mottled sculpin, *Cottus bairdi*) and a darter (e.g. fantail darter, *Etheostoma flabellare*), and perhaps by introduced brown (*Salmo trutta*) or rainbow (*Oncorhynchus mykiss*) trout (Wallace et al. 1992). In the context of acidification, the introduced trout are both more acid-sensitive than brook trout, and will not be present in acidified waters. Proceeding downstream, other dace, darters, chubs, shiners, suckers and others are often present.

The fish of the southern Appalachians are primarily insect predators. Trout, some dace, and some chubs are midwater and surface feeders, catching drifting aquatic invertebrates and terrestrial insects. Sculpins, darters, most chubs and minnows, and some dace feed primarily on benthic invertebrates, searching on and in the rock and gravel streambed, and some overturn rocks in their search. Because of limited primary production in such streams (due to shading across their entire width in summer), herbivores such as stonerollers occur only in somewhat larger streams with open canopy and lower gradient. Detritivore fish are uncommon in high-gradient streams in the region (Wallace et al. 1992).

Estimates of fish predation pressure on stream invertebrates suggest that pressure is substantial, but not more than invertebrate production. The fish community as a whole and brook trout in particular depend heavily on allochthonous (terrestrial) production, and terrestrial insects may make up 50% of trout diets. This terrestrial connection is direct in the case of fish feeding on terrestrial insects, and indirect in the case of stream invertebrate prey feeding on terrestrial detritus. Thus, effects on fish resources can be attributed in part to the alterations of water quality (acidification, sedimentation) and also to removal of terrestrial energy and food additions through activities such as forest removal. Most small, high-gradient southern Appalachian streams, especially those that drain crystalline bedrock, have low invertebrate production. A considerable portion of this production goes to predaceous invertebrates. In small, fishless, headwater streams, production of salamanders is similar to fish production in larger downstream reaches. Secondary production of carnivorous invertebrates is likely to be strongly influenced by local availability of food resources (Wallace et al. 1992).

4.0 EFFECTS OF STREAM ACIDIFICATION IN SHEN

A number of studies have been conducted within SHEN and throughout western Virginia examining the effects of stream acidification on aquatic biota. Whole system experiments, mesocosm experiments, and field surveys have demonstrated major shifts in species composition and decreases in species richness with increasing acidity. The range of sensitivity to acidification varies among fish species, and to a greater extent among invertebrate species. These experiments were summarized and their relevance to SHEN were detailed by Sullivan et al. (2003).

4.1 Acidification Effects on Aquatic Invertebrates in SHEN

Benthic macroinvertebrates have been monitored in SHEN streams since 1986 as part of the Long-Term Ecological Monitoring System (LTEMS). They have several characteristics that make them useful for biomonitoring (Moeykens and Voshell, 2002):

- Benthic macroinvertebrates occur in almost all types of freshwater habitats.
- There are many different taxa which include a wide range of sensitivity to environmental stress.
- They have mostly sedentary habits and are therefore likely to be exposed to ambient pollution or environmental stress.
- The duration of their life histories are sufficiently long such that they will likely be exposed to the environmental stress that is present, and the community will not recover so quickly that the impact will go undetected.

- Sampling the benthic macroinvertebrate assemblage is relatively simple and does not require complicated equipment or great effort.
- Taxonomic identification is almost always easy to the family level and usually easy to the genus level.

Since 1986, the benthic macroinvertebrate community at 17 core LTEMS sites in SHEN has been sampled at least once per year, and in 1995 SHEN personnel began to sample other sites with the goal of eventually sampling every permanent stream within park boundaries (Moeykens and Voshell, 2002). The sampling techniques and LTEMS protocols were described by Voshell and Hiner (1990). The data summarized here cover samples taken between June 1988 and June 2000 (12 years) and include 43 streams.

There are five phyla of benthic macroinvertebrates represented in the samples from SHEN streams: Annelida (principally Oligochaeta), Arthropoda (including Insecta, Arachnida, and Crustacea), Mollusca (including Bivalvia and Gastropoda), Nematoda, and Platyhelminthes (principally Turbellaria).

Of particular importance to the ecology of the streams in the park are the aquatic insects (Class Insecta). There are nine orders of aquatic insects present in the SHEN LTEMS samples: Coleoptera, Collembola, Diptera, Ephemeroptera (mayflies), Hemiptera, Megaloptera, Odonata, Plecoptera (stoneflies), and Trichoptera (caddisflies). From these nine orders of aquatic insects, 79 families have been collected in SHEN streams. Not all families are present in each stream. The total number of insect families found in a given stream during the sampling period varies from 21 to 56 (Sullivan et al., 2003).

Some aquatic insect families are represented in only a few streams and some families are found in all streams (Sullivan et al., 2003). Nine families (Helicopsychidae, Ptychopteridae, Stratiomyiidae, Potamanthidae, Siplonuridae, Belostomatidae, Notonectidae, Haliplidae, and Helophoridae) have each been found in only one stream within SHEN (not all in the same stream). On the other hand, nine other families (Hydropsychidae, Chironomidae, Tipulidae, Baetidae, Ephemerellidae, Heptageniidae, Leuctridae, Perlodidae, and Psephenidae) have been found in all 43 streams sampled.

Moeykens and Voshell (2002) examined the LTEMS data, comparing them with streamwater chemistry in the park. Their analysis was based on interpretation of 10 chemical and physical variables measured at 89 sites in SHEN (28 low-ANC sites and 61 higher-ANC sites) for which macroinvertebrate data were available. They compared their results for SHEN streams with similar analyses for 45 sites (13 low-ANC sites and 32 higher-ANC sites) elsewhere in the Blue Ridge ecoregion of Virginia. The macroinvertebrate communities in both data sets were characterized with 12 robust variables thought to represent the ecological function and composition of these communities. Moeykens and Voshell (2002) concluded that the higher-ANC streams in SHEN had “superior ecological condition” which was comparable to the best that can be found among the streams in the broader Blue Ridge ecoregion. However, they also concluded that acidification of streamwater causes the only conspicuous degradation of macroinvertebrate communities in some low-ANC SHEN streams. Other disturbances, such as fire and flood, did not appear to have had noticeable long-term effects on the stream macroinvertebrate communities. Moeykens and Voshell (2002) concluded that acidified streams in SHEN host fewer invertebrate taxa and fewer functional groups than streams with higher pH and ANC. Similar findings were reported earlier for SHEN streams by Feldman and Connor (1992).

Though not part of SHEN, the proximity of the St. Mary's River (30 km south of SHEN) makes the recent analyses of changes in macroinvertebrate communities in that stream pertinent to this analysis for SHEN streams. As described by Kauffman et al. (1999), the record for St. Mary's River provides a unique opportunity to compare reliable macroinvertebrate data on an acidified stream over a 60-year time span. Surber (1951) collected the earliest benthic biological data for St. Mary's River. Starting in August of 1935, and continuing for two years, he collected 20 samples per month from the river's main stem. Subsequent data were collected by the Virginia Department of Game and Inland Fisheries (VDGIF) in 1976 and then biennially beginning in 1986 (Kauffman et al. 1999) using methods comparable to those used for the 1930's collections. The VDGIF data were collected at six evenly spaced locations extending the length of the main stem above the Wilderness boundary. The later collections were made in June, and only June data are used in the following comparisons.

As summarized by Kauffman et al. (1999), changes in the St. Mary's River benthic community are consistent with streamwater acidification. Whereas 29-32 benthic taxa were documented in the 1930s, no more than 22 benthic taxa were observed in the 1990s. Acid-sensitive taxa have generally declined in abundance and some may have been extirpated. In contrast, certain acid-tolerant taxa have increased in abundance, apparently due to less competition from acid-sensitive taxa.

The total abundance of mayfly (Ephemeroptera) larva in the St. Mary's River has dramatically decreased over the 60-year period, and two of the mayfly genera, Paraleptophlebia and Epeorus, were last collected in 1976. Mayflies are known to decline in species abundance and richness with increasing acidity (Peterson and Van Eeckhautz 1992, Kobuszewski and Perry 1993). The total abundance of caddisfly (Trichoptera) larva also declined dramatically over the 60-year period of record. Baker et al. (1990b) indicated that caddisflies exhibit a wide range of response to acidity, with some species affected by even moderate acidity levels. The total abundance of the larva of the stonefly (Plecoptera) genera Leuctra/Alloperla has dramatically increased over the 60-year period. Increased abundance of these stoneflies in acidified waters has been well documented (Kimmel and Murphy 1985). Another insect family that has prospered in St. Mary's River is the midge (Chironomidae), whose larval population has increased tenfold since the 1930s collections. Increased midge abundance in acidified waters has also been well documented (Kimmel and Murphy 1985, Baker et al. 1990b).

Many stream invertebrate communities are dominated by early life stages of insects that have great dispersal abilities as flying adults. Thus, with many local sources of colonists and the possibility of continual re-colonization, it would be expected that invertebrate biodiversity would continuously remain high in such streams. However, in acidified streams in SHEN it is likely that diversity is continually being suppressed by acidity levels. By analogy to the St. Mary's study, currently acidified SHEN streams probably hosted more diverse invertebrate communities in pre-industrial times. Given the relatively rapid recovery time (about 3 years) of stream invertebrate communities from disturbance, more productive and diverse invertebrate communities might be among the first positive results of lower acid deposition. On the other hand, if streamwater ANC declines further, we can expect macroinvertebrate diversity to further decrease in affected streams (Sullivan et al., 2003).

4.2 Streamwater ANC Relationships for Aquatic Invertebrates in SHEN Streams

Cosby et al. (2006) established quantitative relationships between invertebrate communities and streamwater quality in SHEN streams. The data from the SHEN-LTEMS aquatic macroinvertebrate data base and the SWAS quarterly streamwater data were used in this study to derive such relationships for aquatic invertebrates. The objective was to describe and quantify the correlations between streamwater chemistry (primarily ANC) and various measures of invertebrate community status in the streams.

The 14 SWAS streams in the park have quarterly water quality data extending back to 1988 (see Cosby et al., 2006). The means, maxima, and minima of solute concentrations in these streams were calculated for the period 1988 to 2001 for use in the analyses reported here (Table 1). The LTEMS benthic invertebrate data for the period June 1988 through June 2000 for the 14 SWAS streams were selected for comparison with water quality data. Because of their importance to park streams and the known sensitivity of many taxa to acidification, this analysis was limited to the data collected on aquatic insects (class Insecta of the phylum Arthropoda).

Of the nine orders of aquatic insects found in SHEN streams, there were three which were most abundant both in terms of frequency of occurrence in samples and total numbers of individuals collected: Ephemeroptera (mayflies); Plecoptera (stoneflies); and Trichoptera (caddisflies). The use of these three orders as indicators of acidification response in streams is well established (c.f., SAMAB, 1996). Strong relationships for all three orders were observed between mean and minimum streamwater ANC and the average *numbers of families* in each order (Figure 1), and between mean and minimum streamwater ANC and the average *numbers of individuals* in each order (Figure 2).

The dashed lines on the plots of numbers *vs* average ANC are intended to draw attention to the relationships in the ANC regions above and below ANC = 100 μeq/L. The number of families within an order declines in many streams as average ANC falls below 100 μeq/L (Figure 1). Changes in the number of individuals within an order are more pronounced and more complex as average ANC falls below 100 μeq/L (Figure 2).

Numbers of individuals of Ephemeroptera and Trichoptera decline (as do the number of families in these orders) as average ANC falls below about 100 μeq/L. The order Plecoptera, however, has a number of acidophilic families and even though the number of families declines as average ANC falls below 100 μeq/L, the number of individuals actually increases as the acidophilic families become better established.

Table 1. Minimum, average and maximum ANC values in the 14 SWAS study streams during the period 1988 to 2001 for all quarterly samples. The data cover 14 water years except for VT75 (11 years).

Site ID	Watershed	ANC (μeq/L) Minima	Mean	Maxima
Siliciclastic Bedrock Class				
DR01	Deep Run	-9.5	2.9	24.4
VT35 (PAIN)	Paine Run	-1.3	7.0	19.5
VT36	Meadow Run	-11.4	-1.3	6.2
VT53	Twomile Creek	2.8	15.2	38.6
WOR1	White Oak Run	3.6	27.7	58.6
Granitic Bedrock Class				
NFDR	North Fork Dry Run	22.5	65.6	187.8
VT58	Brokenback Run	44.0	87.9	155.4
VT59 (STAN)	Staunton River	46.1	87.3	189.4
VT62	Hazel River	54.4	95.6	163.6
Basaltic Bedrock Class				
VT51	Jeremys Run	93.7	217.2	542.5
VT60 (PINE)	Piney River	118.7	228.4	382.9
VT61	North Fork Thornton River	156.2	286.6	452.9
VT66	Rose River	94.4	150.2	229.2
VT75	White Oak Canyon Run	81.2	138.6	237.2

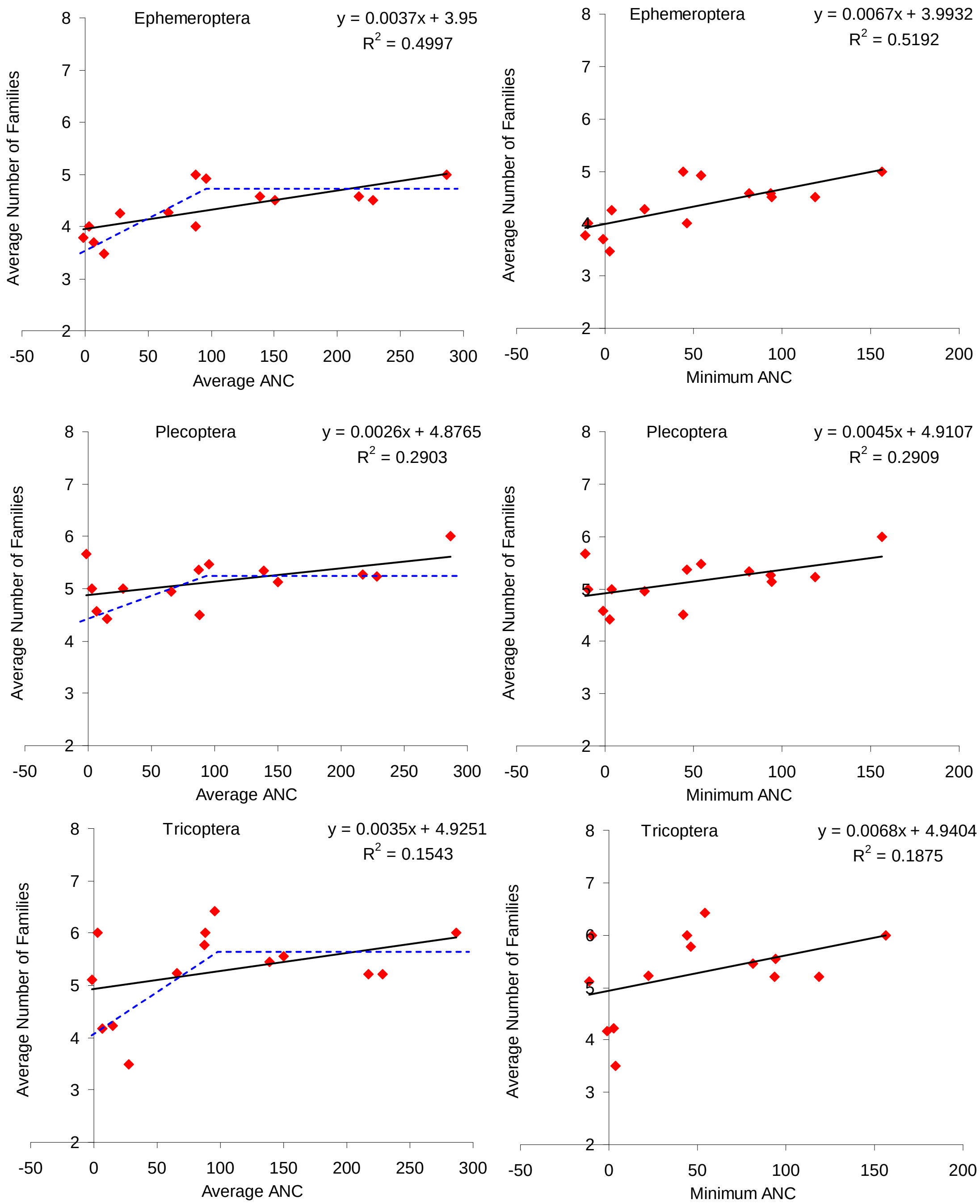

Figure 1. Average number of families in a sample of a given order of aquatic insects for each of the 14 SWAS study streams in SHEN versus the mean (left) or minimum (right) ANC of each stream . The stream ANC values are based on quarterly samples from 1988 to 2001. Invertebrate samples are contemporaneous. Results are presented for the orders Ephemeroptera (top), Plecoptera (center), and Tricoptera (bottom). Linear regression (black line) equations and correlations are given on each diagram. Dashed lines are discussed in the text.

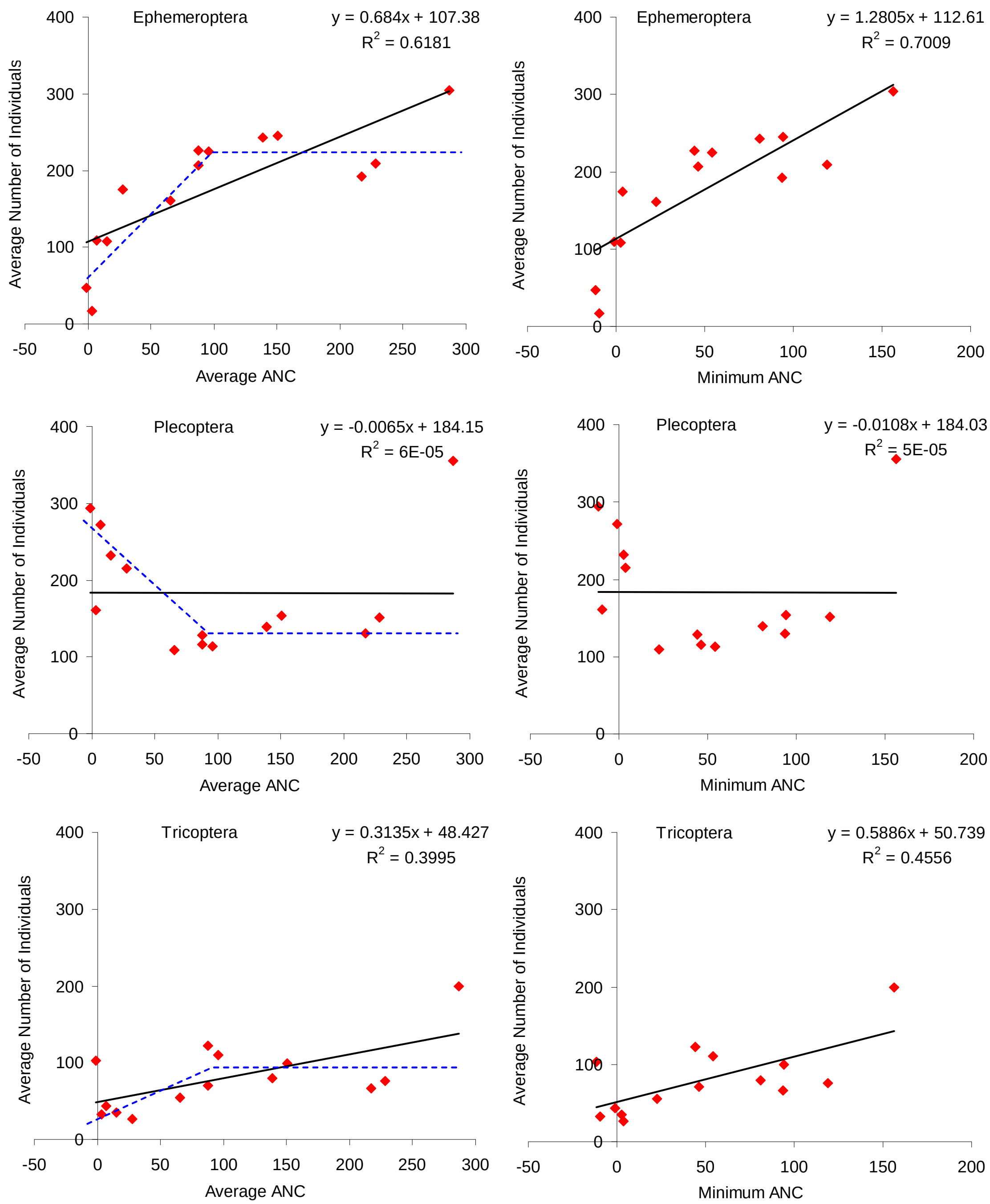

Figure 2. Average number of individuals in a sample of a given order of aquatic insects for each of the 14 SWAS study streams in SHEN versus the mean (left) or minimum (right) ANC of each stream . The stream ANC values are based on quarterly samples from 1988 to 2001. Invertebrate samples are contemporaneous. Results are presented for the orders Ephemeroptera (top), Plecoptera (center), and Tricoptera (bottom). Linear regression (black line) equations and correlations are given on each diagram. Dashed lines are discussed in the text.

These differences in aquatic invertebrate responses above and below average ANC of 100 μeq/L are consistent with the definitions of the stream response categories that are used to map areas of concern for adverse effects of acidic deposition in SHEN. In those definitions, streams with average ANC above 100 μeq/L are categorized as of "Low Concern", streams with average ANC in the range 50-100 μeq/L are categorized as of "Moderate Concern", streams with average ANC in the range 0-50 μeq/L are categorized as of "Elevated Concern", and streams with average ANC below 0 μeq/L are categorized as of "Acute Concern". The use of *average* ANC (rather than minimum ANC) in this analysis is important for linking the aquatic invertebrate responses to the MAGIC model forecasts of future stream ANC because the model forecasts the *average* ANC of a stream in any year (rather than the minimum).

Two additional measures of aquatic invertebrate community structure were also used to examine acidification effects on all nine orders (and associated families) of insects present in the streams. Diversity and evenness values were calculated using the Shannon-Weaver indices (Diversity = $- \sum(i=1,S)\ P_i \ln(P_i)$ and Evenness = $D / D_{max} = D / \ln S$ where P is the probability of an individual belonging to the group (i), and S is the total number of groups). Diversity and evenness values were calculated in terms of both orders and families. The Shannon-Weaver diversity index has effectively quantified the differences (Kimmel and Murphy, 1985; Smith et al., 1990), or lack of differences (Rosemond et al., 1992), in diversity between high and low ANC in earlier aquatic insect studies.

As with the simple measures of family or individual richness examined above, these measures of diversity and evenness were also strongly related to the ANC of streamwater for the 14 SWAS streams (Figures 3 and 4). Diversity and evenness both decline as streamwater ANC declines. This pattern is the same whether the indices are calculated based on the Orders of the insects present in the streams or the Families of the insects present in the streams.

The dashed lines on the plots of diversity *vs* average ANC and evenness *vs* average ANC are intended to draw attention to the relationships in the ANC regions above and below ANC = 100 μeq/L. Both diversity and evenness decline in many streams as average ANC falls below about 100 μeq/L (Figures 3 and 4). This is consistent with the responses seen above for family and individual richness – as the number of families decreases and the numbers of individuals in the remaining families also decreases (except for the few acidophilic families) the diversity and evenness of the community declines.

These differences in aquatic invertebrate community structure above and below average ANC of 100 μeq/L are also consistent with the definitions of the stream response categories that are used to map areas of concern with respect to adverse effects from acidic deposition in SHEN. Streams with average ANC above 100 μeq/L are of "Low Concern", and the diversity and evenness of these communities appears generally unaffected, while streams in the other concern categories ("Moderate", Elevated" and Acute") show decreases in diversity and evenness. As before, the use of *average* ANC (rather than minimum ANC) in this analysis is important for linking the aquatic invertebrate responses to the MAGIC model forecasts of future stream ANC.

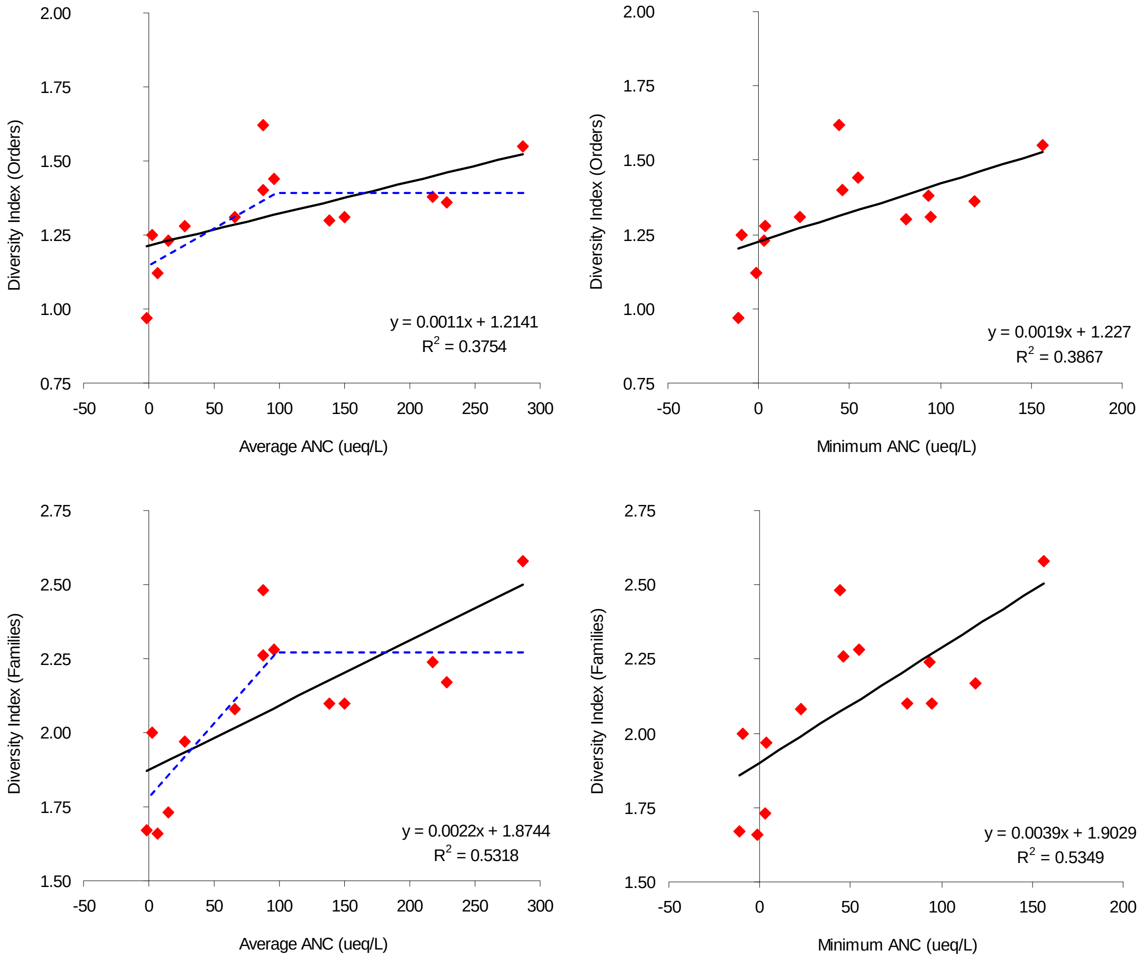

Figure 3. Shannon-Weaver diversity index for each of the 14 SWAS study streams in SHEN versus the mean (left) or minimum (right) ANC of each stream. The diversity index was calculated for Orders (upper panels) and for Families (lower panels).The stream ANC values are based on quarterly samples from 1988 to 2001. Invertebrate samples are contemporaneous. Linear regression (black line) equations and correlations are given on each diagram. Dashed lines are discussed in the text.

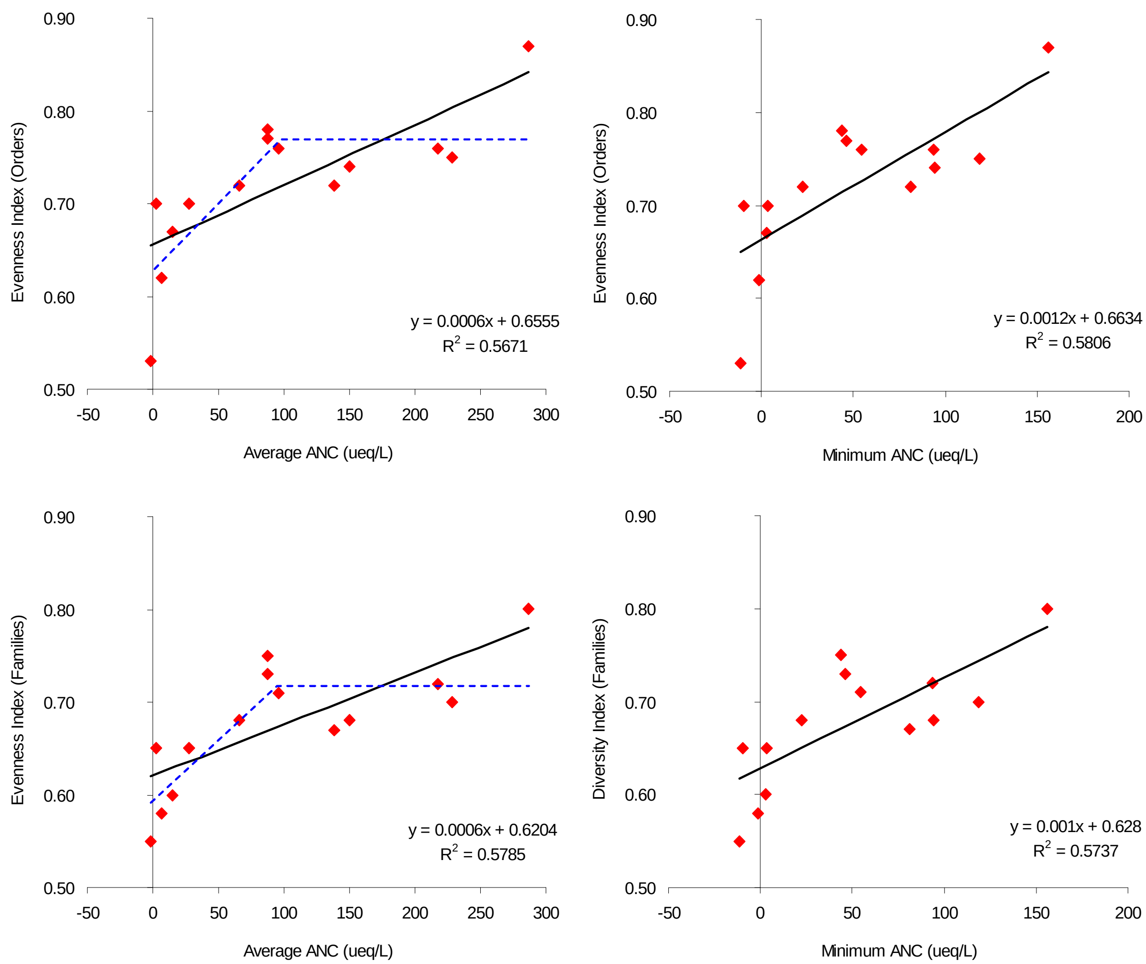

Figure 4. Shannon-Weaver evenness index for each of the 14 SWAS study streams in SHEN versus the mean (left) or minimum (right) ANC of each stream. The evenness index was calculated for Orders (upper panels) and for Families (lower panels). The stream ANC values are based on quarterly samples from 1988 to 2001. Iinvertebrate samples are contemporaneous. Linear regression (black line) equations and correlations are given on each diagram. Dashed lines are discussed in the text.

4.3 Acidification Effects on Fish in SHEN

Although there are known differences in acid sensitivity among fish species, experimentally-determined acid sensitivities are available for only a minority of freshwater fish species. For example, of 35 species of fish found in SHEN, the critical pH is known for only nine (Table 2). Baker and Christensen (1991) reported critical pH values for 25 species of fish. They defined critical pH as the threshold for significant adverse effects on fish populations. The range of response within species depends on differences in sensitivity among life stages, and on different exposure concentrations of calcium (Ca^{2+}) and Al. These ranges, based on multiple studies for each species, are shown in Table 2. To cite a few examples, blacknose dace is regarded as very sensitive to acid stress, because population loss due to acidification has been documented in this species at pH values as high as 6.1; in field bioassays, embryo mortality has been attributed to acid stress at pH values as high as 5.9. Embryo mortality has occurred in common shiner (*Luxilus cornutus*) at pH values as high as 6.0. Although the critical pH range for rainbow trout is designated as 4.9-5.6, adult and juvenile mortality have occurred at pH values as high as 5.9. Brown trout population loss has occurred over the pH range of 4.8-6.0, and brook trout fry mortality has occurred over the range of 4.8-5.9 (Baker and Christensen 1991).

It is the difference in acid tolerance among species that produces a gradual decline in species richness as acidification progresses, with the most sensitive species lost first. Some Blue Ridge streams can become too acidic even for brook trout, as evidenced by the absence of the species from streams with mean pH < 5.0 in Great Smoky Mountains National Park (Elwood et al. 1991).

Relatively less is known about changes in fish biomass, density and condition (robustness of individual fish) which occur in the course of acidification. Such changes result in part from both indirect and direct interactions within the fish community. Loss of sensitive individuals within species (such as early life stages) may reduce competition for food among the survivors, resulting in better growth rates, survival, or condition. Similarly, competitive release (increase in growth or abundance subsequent to removal of a competitor) may result from the loss of a sensitive species, with positive effects on the density, growth, or survival of competitor population(s) of other species (Baker et al. 1990b). In some cases where acidification continued, transient positive effects on size of surviving fish were shortly followed by extirpation (Bulger et al. 1993).

The three-year FISH study of stream acidification in SHEN demonstrated negative effects on fish from both chronic and episodic acidification (Bulger et al. 1999). Biological differences in low- versus high-ANC streams included species richness, population density, condition factor (a measure of robustness in individual fish), age, size, and field bioassay survival. Of particular note is that both episodic and chronic mortality occurred in young brook trout exposed in a low-ANC stream, but not in a high-ANC stream (MacAvoy and Bulger 1995), and that blacknose dace in low-ANC streams were in poor condition relative to blacknose dace in higher-ANC streams (Dennis et al 1995, Dennis and Bulger 1995).

Table 2. Critical pH thresholds for fish species of SHEN. (Source: Bulger et al. 1999)			
Common Name	**Latin Name**	**Family**	**Threshold**[A]
American Eel	*Anguilla rostrata*	Anguillidae	
Mtn. Redbelly Dace	*Phoxinus oreas*	Cyprinidae	
Rosyside Dace	*Clinostomus funduloides*	Cyprinidae	
Longnose Dace	*Rhinichthys cataractae*	Cyprinidae	
Blacknose Dace	*Rhinichthys atratulus*	Cyprinidae	5.6 to 6.2
Central Stoneroller	*Campostoma anomalum*	Cyprinidae	
Fallfish	*Semotilus corporalis*	Cyprinidae	
Creek Chub	*Semotilus atromaculatus*	Cyprinidae	5.0 to 5.4
Cutlips Minnow	*Exoglossum maxillingua*	Cyprinidae	
River Chub	*Nocomis micropogon*	Cyprinidae	
Bluehead Chub	*Nocomis leptocephalus*	Cyprinidae	
Common Shiner	*Luxilus cornutus*	Cyprinidae	5.4 to 6.0
Common Carp	*Cyprinus carpio*	Cyprinidae	
Potomac Sculpin	*Cottus girardi*	Cottidae	
Northern Hogsucker	*Hypentelium nigricans*	Catostomidae	
Torrent Sucker	*Thoburnia rhothocea*	Catostomidae	
White Sucker	*Catastomus commersoni*	Catostomidae	4.7 to 5.2
Margined Madtom	*Noturus insignis*	Ictaluridae	
Brook Trout	*Salvelinus fontinalis*	Salmonidae	4.7 to 5.2
Brown Trout	*Salmo trutta*	Salmonidae	4.8 to 5.4
Tiger Trout[B]	*Salmo X Salvelinus*	Salmonidae	
Rainbow Trout	*Oncorhynchus mykiss*	Salmonidae	4.9 to 5.6
Mottled Sculpin	*Cottus bairdi*	Cottidae	
Bluntnose Minnow	*Pimephales notatus*	Cyprinidae	
Rock Bass	*Ambloplites rupestris*	Centrarchidae	4.7 to 5.2
Smallmouth Bass	*Micropterus dolomieui*	Centrarchidae	5.0 to 5.5
Largemouth Bass	*Micropterus salmoides*	Centrarchidae	
Redbreast Sunfish	*Lepomis auritus*	Centrarchidae	
Pumpkinseed	*Lepomis gibbosus*	Centrarchidae	
Bluegill	*Lepomis macrochirus*	Centrarchidae	
Tesselated Darter	*Etheostoma olmstedi*	Percidae	
Fantail Darter	*Etheostoma flabellare*	Percidae	
Johnny Darter[C]	*Etheostoma nigrum*	Percidae	
Greenside Darter[C]	*Etheostoma blennioides*	Percidae	
Satinfin Shiner[C]	*Cyprinella analostana*	Cyprinidae	

[A] Threshold for serious adverse effects on populations (from Baker & Christensen 1991)
[B] Progeny of female brown and male brook trout
[C] Rare or occasional

The effects of acidification on fish have been well documented for the St. Mary's River (Bugas et al. 1999). Fourteen fish species have been collected in St. Mary's River since 1976; only four remained as of 1998. Rosyside dace (*Clinostomus funduloides*) and torrent sucker (*Thoburnia rhothocea*) were last present in 1996; Johnny darter (*Etheostoma nigrum*) and brown trout were last present in 1994; rainbow trout and longnose dace (*Rhinichthys cataractae*) were last present in 1992; bluehead chub (*Nocomis leptocephalus*) and smallmouth bass (*Micropterus dolomieui*) were last present in 1990 and 1988, respectively; white sucker (*Catastomus commersoni*) and central stoneroller (*Campostoma anomalum*) were last present in 1986. Of the four remaining species, three (blacknose dace, fantail darter, and mottled sculpin) have declined in density and/or biomass; the fourth remaining species is brook trout, the region's most acid tolerant species; this population has fluctuated, and reproductive success has been sporadic. Blacknose dace, once abundant throughout the river, remain only at the lowest sampling station, which has the highest pH, and at such low numbers (five individuals in 1998) that they might be strays from downstream. For some of the species (smallmouth bass, white sucker, the three trout, and blacknose dace) the critical pH is known (see Table 2), and their decline and/or extirpation, given the pH of the river, is not surprising. Based on trend analysis over the period 1987-1997, the St. Mary's River, near SHEN, is continuing to acidify (Webb and Deviney 1999).

Recent analyses (Bulger et al. 1998, 2000) divided Virginia's mountain streams into four categories of acid-base status, to compare the number of streams in each category at present with estimated numbers in pre-industrial times and in the future. Within SHEN, streams that are chronically or episodically acidic are the most likely to have experienced adverse biological effects from acidic deposition to date. They are also the streams most at risk for future damage. These streams are found primarily on siliciclastic bedrock.

Cosby et al. (2006) extended the SNP:FISH project (Bulger et al., 1999) to evaluate the acid sensitivity of five additional species of fish in SHEN using *in situ* bioassays -blacknose dace, longnose dace, mottled sculpin, mountain redbelly dace, and rosyside dace (Krawczel, 2004). Paired bioassays (acidic treatment, neutral control) were conducted in Meadow Run (acidic treatment stream) and the Rapidan River (non-acidic control stream). The bioassays were repeated twice during two different time periods in the autumn of 2003. An analysis of stream chemistry during the two periods verified that the stream chemistry was more acidic in the treatment stream (Meadow Run) during the second bioassay time period (mean pH=5.17) than the first (mean pH=5.32).

Mortality was not observed for any species during the first bioassay time period in either stream, although a statistical analysis suggested sub-lethal stresses occurred for longnose dace and rosyside dace in Meadow Run. Mortality was observed during the second bioassay time period in Meadow Run for all species except mottled sculpin, which may have experienced sub-lethal stress in that period. No mortality was observed during either bioassay time period in the Rapidan River (the neutral control).

The study concluded that fish can exhibit two types of response to stream chemistry that lead to mortality. In an acute response, fish die when chemical conditions reach a certain threshold level. In a cumulative dose response, fish die due to chronic exposure to low pH or high Al^{3+} over time (accumulation of H^+ or Al^{3+} on the gill epithelium over time). This study suggests a cumulative dose mortality response in which fish begin to die when the total Al^{3+} exposure reaches 900 μg/L in less than 15 days (stream Al^{3+} concentrations > 60 μg/L per day for 15 days).

Differential fish mortality was observed across the five species used in this study. From most to least sensitive, the relative ranking of the five species is as follows: longnose dace, mountain redbelly dace, blacknose dace, rosyside dace, and mottled sculpin (Krawczel, 2004).

4.4 Streamwater ANC Relationships for Fish in SHEN Streams

ANC criteria have often been used in place of pH and/or aluminum criteria for evaluation of potential acidification effects on fish communities. The utility of these criteria lies in the association between ANC and the surface water constituents that directly contribute to or ameliorate acidity-related stress, in particular pH, Ca^{2+}, and Al. The use of ANC criteria facilitates the coupling of models of fish response to acidification to the biogeochemical models that are used to estimate past of future streamwater conditions because, in general, the biogeochemical models provide more reliable estimates of ANC than of pH. This section summarizes what is known concerning fish responses to streamwater ANC in SHEN in two ways – those that relate individual species mortality to ANC (focusing on brook trout as the most important recreational species in SHEN) and those that relate community species richness to ANC (focusing on the biodiversity of all fish species with SHEN).

Brook Trout

The early life stages of brook trout are most sensitive to adverse impacts from acidification (Bulger et al. 2000). These early life stages occur in SHEN throughout the cold season in general, and the winter in particular. For this reason, data suggesting ongoing winter season acidification trends for streams within SHEN (Cosby et al., 2006) are of particular concern.

Bulger et al. (2000) developed ANC thresholds for brook trout response to acidification in forested headwater catchments in western Virginia (Table 3). Note that because brook trout are comparatively acid tolerant, adverse effects on many other fish species should be expected at relatively higher ANC values.

The brook trout response categories in 3 are consistent with definitions of the stream response categories that are used to map areas of concern with respect to adverse effects of acidic deposition in SHEN. Streams with average ANC greater than 50 μeq/L have “suitable” brook trout conditions and are categorized as of either “Low Concern” (average ANC > 100 μeq/L) or “Moderate Concern” (average ANC 50-100 μeq/L). Streams with average ANC in the ranges 0-

Table 3. Streamwater acid neutralizing capacity (average ANC, μeq/L) categories for brook trout response (after Bulger et al. 2000).

Category	ANC Class	ANC Range	Brook Trout Response
Suitable	Not acidic	>50	Reproducing brook trout populations expected where habitat suitable
Indeterminate	Indeterminate	20-50	Extremely sensitive to acidification; brook trout response variable
Marginal	Episodically acidic	0-20	Sub-lethal and/or lethal effects on brook trout possible
Unsuitable	Chronically acidic	<0	Lethal effects on brook trout probable

20 and 20-50 μeq/L have "indeterminate" and "marginal" brook trout conditions and are categorized on the maps as of "Elevated Concern" (average ANC 0-50 μeq/L). Streams with average ANC less than 0 μeq/L have "unsuitable" brook trout conditions and are categorized as of "Acute Concern".

Fish Species Richness

A statistically robust relationship between the ANC of streamwater and fish species richness was shown in SHEN as well. As an element of the FISH project (Bulger et al. 1999), numbers of fish species were compared among 13 SHEN streams spanning a range of pH/ANC conditions (Table 1). The 13 streams were a subset of the 14 SWAS study streams in SHEN (no fish data were available for Deep Run). There was a highly significant ($p<0.0001$) relationship between stream acid-base status (during the seven-year period of record) and fish species richness among the 13 streams, such that the streams having the lowest ANC hosted the fewest species (Figure 5). The relationship was strong regardless of whether the average or the minimum ANC was used.

The dashed lines on the plots of fish species richness *vs* average ANC are intended to draw attention to the relationships in the ANC regions above and below ANC = 100 μeq/L. In a semi-quantitative analysis similar to that presented above for invertebrates, it can be seen that the number of fish species in SHEN streams apparently declines sharply as average ANC falls below about 100 μeq/L (Figure 5). In the ANC range from 0-100 μeq/L there is much reduced species richness. In streams with average ANC below 0 μeq/L (although not included in the study sites) the expectation would be complete extirpation of fish species (i.e. richness equal to zero).

These differences in observed fish species over the observed range of average ANC are consistent with the definitions of the stream response categories that are used to map areas of concern with respect to adverse effects of acidic deposition in SHEN. Streams with average ANC above 100 μeq/L are mapped as of "Low Concern" and species richness in these streams appears not to be strongly affected by acidic deposition.

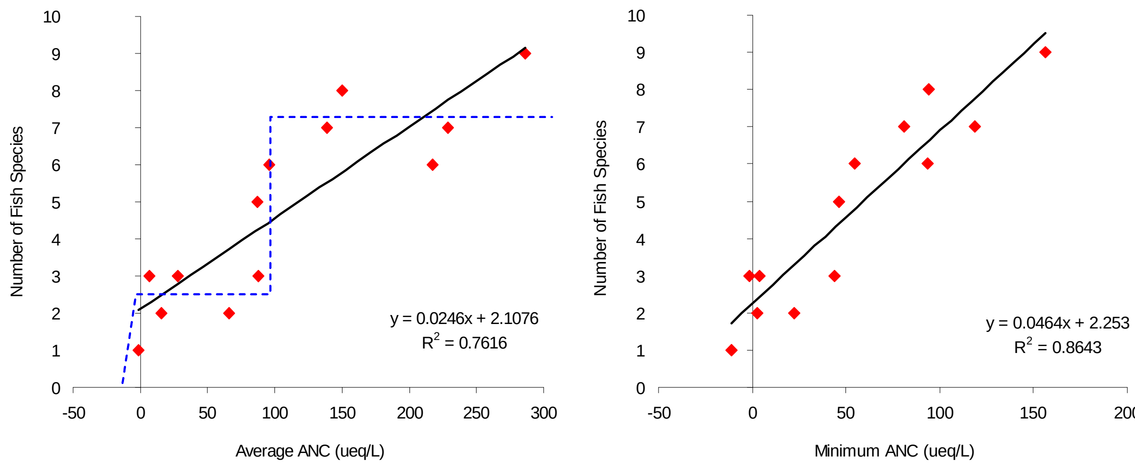

Figure 5. Number of fish species (species richness) in each of 13 SWAS study streams in SHEN versus the mean (left) or minimum (right) ANC of each stream. The stream ANC values are based on quarterly samples from 1988 to 2001. The fish species richness samples are contemporaneous. Linear regression (black line) equations and correlations are given on each diagram. The dashed line is discussed in the text.

Streams with average ANC in the range 0-100 µeq/L (streams of "Moderate" and "Elevated" concern on the maps) have significantly reduced fish species richness. Streams with average ANC below 0 µeq/L (streams of "Acute Concern" on the maps) would be expected to have minimal species richness (zero or at most one fish species).

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Appendix B

Regional Distribution of Candidate Predictor Variables for Estimating BC_w, by Ecoregion

Table B-1. BC_w candidate predictor variables summary statistics across 92 MAGIC modeling sites.

Variable[1]	n	Mean	Standard Dev.	Minimum	Maximum
Blue Ridge					
Calculated ANC (µeq/L)	26	47.1	42.9	-2.6	148.3
Elevation (m)	26	787	198	515	1,513
NO3 (µeq/L)	26	8.4	14.4	0.0	50.6
% Carbonate (as fraction)	26	0.0	0.0	0.0	0.2
% Felsic (as fraction)	26	0.3	0.4	0.0	1.0
% Mafic (as fraction)	26	0.1	0.2	0.0	0.9
% Siliciclastic (as fraction)	26	0.6	0.5	0.0	1.0
SBC (µeq/L)	26	138.6	50.1	78.4	265.3
% Slope	26	19.8	3.0	14.4	26.2
% Soil Clay	26	18.1	5.3	7.8	28.4
Soil Depth (m)	26	1.2	0.4	0.7	1.9
Soil pH	26	5.1	0.3	4.7	5.6
Watershed Area (ha)	26	787	755	19	2,733
Central Appalachian					
Calculated ANC (µeq/L)	24	-2.0	44.9	-74.1	130.8
Elevation (m)	24	1,017	155	624	1,210
NO3 (µeq/L)	24	14.5	12.6	0.0	39.9
% Carbonate (as fraction)	24	<0.01	<0.01	0.0	<0.01
% Felsic (as fraction)	24	0.0	0.0	0.0	0.0
% Mafic (as fraction)	24	0.0	0.0	0.0	0.0
% Siliciclastic (as fraction)	24	0.8	0.3	<0.01	1.0
SBC (µeq/L)	24	166.4	97.5	64.4	488.2
% Slope	24	10.6	3.9	4.1	16.8
% Soil Clay	24	18.6	3.1	11.2	22.8
Soil Depth (m)	24	0.8	0.1	0.7	1.1
Soil pH	24	4.8	0.2	4.6	5.1
Watershed Area (ha)	24	1,744	3,925	28	18,917
Ridge and Valley					
Calculated ANC (µeq/L)	42	42.0	44.1	-36.3	141.2
Elevation (m)	42	908	168	572	1,255
NO3 (µeq/L)	42	13.0	15.9	0.0	54.5
% Carbonate (as fraction)	42	<0.01	<0.01	0.0	0.0
% Felsic (as fraction)	42	0.0	0.0	0.0	0.0

Variable[1]	n	Mean	Standard Dev.	Minimum	Maximum
% Mafic (as fraction)	42	0.0	0.0	0.0	0.0
% Siliciclastic (as fraction)	42	0.5	0.4	0.0	1.0
SBC (µeq/L)	42	176.3	88.6	58.2	389.6
% Slope	42	16.0	2.8	9.4	23.2
% Soil Clay	42	18.4	4.1	11.2	31.4
Soil Depth (m)	42	0.9	0.2	0.6	1.7
Soil pH	42	4.9	0.2	4.6	5.3
Watershed Area (ha)	42	1,220	2,114	15	11,814

[1] Variables that entered into the regression equations are indicated in boldface type

Appendix C

Standard Error of Regression Coefficients for Predicting BC_w

Table C-1. Standard error of regression coefficients used to predict BC_w from water chemistry plus landscape variables and from landscape variables alone.

Ecoregion	Variable	Coefficient	Standard Error
Water Chemistry Plus Landscape Variables			
Central Appalachian	Constant	-37.5	9.290
	SBC	0.6	0.048
	NO3	0.9	0.353
	WS Area	0.006	0.001
Ridge and Valley	Constant	106.7	33.146
	SBC	0.5	0.042
	Elevation	-0.06	0.022
	Slope	-3.2	0.938
Blue Ridge	Constant	27.1	3.236
	CALK	0.6	0.057
	NO3	0.6	0.169
Landscape Variables Only			
Central Appalachian	Constant	1186.2	342.974
	WS Area	0.01	0.003
	Elevation	-0.3	0.064
	Soil pH	-179.3	67.921
Ridge and Valley	Constant	219.7	28.974
	% Siliciclastic	-74.6	12.935
	% Carbonate	6632.4	3167.700
	Elevation	-0.1	0.031
Blue Ridge	Constant	57.9	11.967
	% Felsic	32.7	7.005
	% Mafic	69.6	13.009
	Soil Depth	-40.2	10.479
	% Soil Clay	2	0.642

Appendix D

Model Estimates of Pre-Industrial Stream ANC

Table D-1. MAGIC model estimates of pre-industrial (1860) calculated ANC for each of the 92 MAGIC model stream sites.

Name	Site ID	Model Estimates of Calculated Pre-Industrial ANC (μeq/L)
Elk Run	2B047032	197.2
Buffalo Creek	2C041039	189.3
Thunderstruck Creek	2C041040	169.8
Right Fork Clover Run	2C041045	264.3
Coal Run	2C041051	56.0
Johnson Run	2C046033	56.7
Hateful Run	2C046034	87.2
North Fork Cherry River	2C046043L	94.3
North Fork Cherry River	2C046043U	73.0
Hedricks Creek	2C046050	186.8
Crawford Run	2C047007	181.1
Clubhouse Run	2C047010L	90.2
Clubhouse Run	2C047010U	92.1
Butler Branch	2C057004	88.4
Belfast Creek	BLFC	62.2
Deep Run	DR01	82.0
Little Stonecoal Run	DS04	47.8
Stonecoal Run (Right Branch)	DS09	46.0
Fisher Spring Run	DS19	64.8
Unnamed	DS50	43.6
Fernow - WS10	FN1	161.2
Fernow - WS13	FN2	155.7
Fernow - WS4	FN3	135.9
Lewis Fork	LEWF	82.6
Sulphur Spring Creek	M037	91.5
Big Hellcat Creek	M038	96.0
Little Hellgate Creek	M039	65.7
North Fork Dry Run	NFD	169.5
Condon Run	OC02	70.3
Unnamed	OC08	40.8
Coal Run	OC35	71.5
Otter Creek (Upper)	OC79	110.8
Noname Trib Stony Cr.	VA524S	81.3
Bearpen Branch	VA526S	247.0
Ragged Run	VA531S	119.1
Noname Trib Gap Cr	VA548S	119.8
Little Mill Cr	VA555S	73.2
Little Walker Cr	VA821S	293.0
Raccoon Branch	VT05	107.4
Cove Branch	VT07	76.3
Roaring Fork-Upper	VT08	91.2
Roaring Fork-Lower	VT09	70.2
Laurel Run	VT10	63.6
Mare Run	VT11	66.7
Panther Run	VT12	168.2
Porters Creek	VT15	59.8

Name	Site ID	Model Estimates of Calculated Pre-Industrial ANC (µeq/L)
Bearwallow Run	VT18	112.8
Lost Run	VT19	117.1
Hipes Branch	VT20	188.9
Shawvers Run	VT24	76.9
Cove Branch	VT25	48.4
Pine Swamp Branch	VT26	75.4
NF Stony Creek	VT28	45.0
No Business Creek	VT31	33.1
Laurel Creek	VT32	79.0
Laurel Run	VT34	104.7
Paine Run	VT35	85.4
Meadow Run	VT36	65.0
North River	VT37	75.0
Ramseys Draft	VT38	141.5
St Marys R-Lower	VT41	51.8
Little Cove Creek	VT46	111.7
Big Mack Creek	VT48	100.4
Little Stony Creek	VT49	110.6
Laurel Run	VT50	68.1
Two Mile Run	VT53	89.0
German River-Upper	VT54	127.0
Beech Lick Run	VT55	203.9
Wolf Run	VT56	55.1
Black Run-Lower	VT57	89.5
Brokenback Run	VT58	118.9
Staunton River	VT59	114.2
Hazel Run	VT62	136.3
Rose River	VT66	190.4
Bear Branch (Smr)	VT70	48.0
Hogback Br (Smr)	VT72	43.2
Sugartree Br (Smr)	VT73	74.6
St Marys R-Middle	VT74	44.5
White Oak Canyon R	VT75	178.2
Matts Creek	VT77	94.5
Little Tumbling Creek	VT78	34.9
White Oak Run	WOR	114.9
Noname Trib Stony	WV523S	61.5
Otter Cr	WV531S	60.5
Gauley	WV547S	187.6
Noname Trib S Fork Cherry R.	WV548S	86.4
Nnt Laurel Run	WV769S	159.9
Moss Run	WV770S	206.8
Left Fork Clover Run	WV771S	276.9
Nnt Glade Cr	WV785S	79.1
White Oak Fork	WV788S	71.6
Red Cr	WV796S	76.6

Appendix E

Mapped CL and Exceedance for the ANC Threshold Value of 0 µeq/L

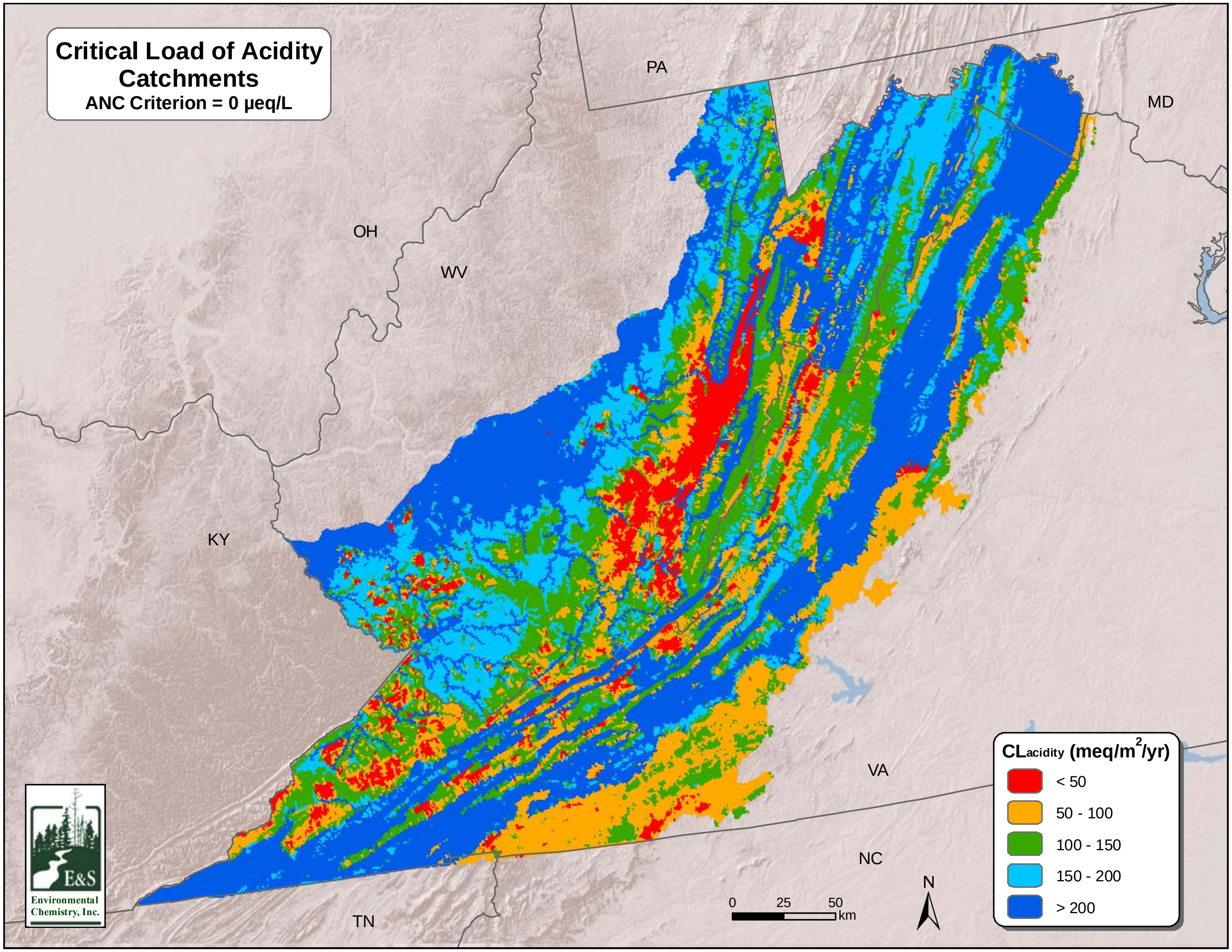

Figure E-1. Final map of CL of acidity to protect stream ANC from falling below 0 µeq/L.

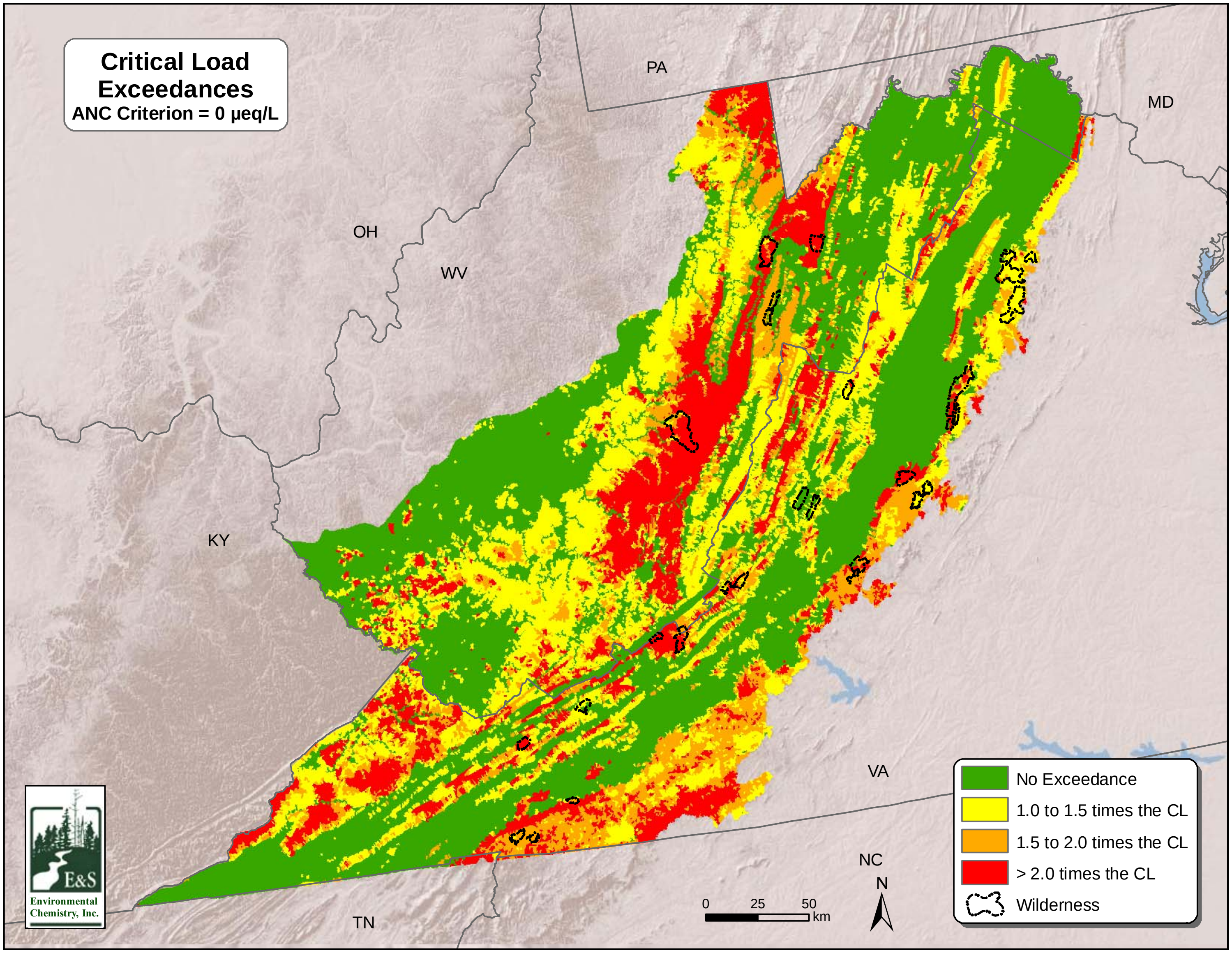

Figure E-2. Critical load exceedance map for the ANC criterion 0 µeq/L.

Appendix F

Values for All Parameters of the CL Equation for Each Study Stream

Table F-1. General stream sampling site information.

ID	Name	MAGIC Site?	Ecoregion[1]	State	WS Area[2]	Year[3]
2B047032	Elk Run	Yes	RV	WV	1073	1985
2C041039	Buffalo Creek	Yes	RV	WV	580	1985
2C041040	Thunderstruck Creek	Yes	RV	WV	178	1985
2C041045	Right Fork Clover Run	Yes	RV	WV	1983	1985
2C041051	Coal Run	Yes	CA	WV	502	1985
2C046033	Johnson Run	Yes	CA	WV	425	1985
2C046034	Hateful Run	Yes	CA	WV	155	1985
2C046043L	North Fork Cherry River	Yes	CA	WV	4260	1985
2C046043U	North Fork Cherry River	Yes	CA	WV	3986	1985
2C046050	Hedricks Creek	Yes	CA	WV	289	1985
2C047007	Crawford Run	Yes	RV	WV	348	1985
2C047010L	Clubhouse Run	Yes	RV	WV	822	1985
2C047010U	Clubhouse Run	Yes	RV	WV	687	1985
2C057004	Butler Branch	Yes	CA	WV	318	1985
AU28	St. Mary's River (Lower)	Yes	BR	VA	2733	1990
BLFC	Belfast Creek	Yes	BR	VA	19	1991
BO02	Hipes Branch	Yes	RV	VA	598	1990
DR	Deep Run	Yes	BR	VA	357	1990
DS04	Little Stonecoal Run	Yes	CA	WV	266	1994
DS09	Stonecoal Run (Right Branch)	Yes	CA	WV	757	1994
DS19	Fisher Spring Run	Yes	CA	WV	731	1994
DS50	Unnamed 1	Yes	CA	WV	204	1994
FN1	Fernow - WS10	Yes	RV	WV	23	1994
FN2	Fernow - WS13	Yes	RV	WV	15	1994
FN3	Fernow - WS4	Yes	RV	WV	34	1994
LEWF	Lewis Fork	Yes	BR	VA	279	1991
M037	Sulphur Spring Creek	Yes	BR	VA	201	1991
M038	Big Hellgate Creek	Yes	BR	VA	175	1991
M039	Little Hellgate Creek	Yes	BR	VA	191	1991
NFD	North Fork Dry Run	Yes	BR	VA	113	1994
OC02	Condon Run	Yes	CA	WV	381	1994
OC08	Unnamed 2	Yes	CA	WV	2198	1994
OC35	Coal Run	Yes	CA	WV	357	1994
OC79	Otter Creek (Upper)	Yes	CA	WV	126	1994
PAIN	Paine Run	Yes	BR	VA	1255	1990
RA05	Hazel River	Yes	BR	VA	1134	1990
RH53	Twomile Run 2	Yes	BR	VA	560	1990
STAN	Staunton River	Yes	BR	VA	1067	1990
VA524S	Noname Trib Stony Creek 2	Yes	RV	VA	69	1994
VA526S	Bearpen Branch	Yes	CA	VA	473	1994
VA531S	Ragged Run	Yes	BR	VA	220	1994
VA548S	Noname Trib Gap Creek	Yes	RV	VA	20	1994
VA555S	Little Mill Cr	Yes	RV	VA	612	1994
VA821S	Little Walker Creek	Yes	RV	VA	11814	1994
VT05	Raccoon Branch	Yes	BR	VA	435	1990
VT07	Cove Branch 1	Yes	RV	VA	308	1990
VT08	Roaring Fork-Upper	Yes	RV	VA	864	1990
VT09	Roaring Fork-Lower	Yes	RV	VA	2508	1990

ID	Name	MAGIC Site?	Ecoregion[1]	State	WS Area[2]	Year[3]
VT10	Laurel Run 4	Yes	RV	VA	335	1990
VT11	Mare Run	Yes	RV	VA	1001	1990
VT12	Panther Run	Yes	RV	VA	387	1990
VT15	Porters Creek	Yes	RV	VA	220	1990
VT18	Bearwallow Run 2	Yes	RV	VA	420	1990
VT19	Lost Run	Yes	RV	VA	239	1990
VT24	Shawvers Run	Yes	RV	VA	592	1990
VT25	Cove Branch 2	Yes	RV	VA	1080	1990
VT26	Pine Swamp Branch	Yes	RV	VA	200	1990
VT28	N.F. Stony Creek	Yes	RV	VA	2110	1990
VT31	Nobusiness Creek	Yes	RV	VA	1735	1990
VT32	Laurel Branch of Stony Creek	Yes	RV	VA	498	1990
VT34	Laurel Run 5	Yes	RV	VA	850	1990
VT36	Meadow Run	Yes	BR	VA	890	1990
VT37	North River	Yes	RV	VA	1257	1990
VT38	Ramseys Draft	Yes	RV	VA	2384	1990
VT46	Little Cove Creek	Yes	BR	VA	353	1990
VT48	Big Mack Creek	Yes	BR	VA	1952	1990
VT49	Little Stony Creek (Lower)	Yes	RV	VA	1120	1990
VT50	Laurel Run	Yes	RV	VA	434	1990
VT54	German River (Upper)	Yes	RV	VA	523	1990
VT55	Beech Lick Run	Yes	RV	VA	146	1990
VT56	Wolf Run	Yes	RV	VA	582	1990
VT57	Black Run - Lower	Yes	RV	VA	2911	1990
VT58	Brokenback Run	Yes	BR	VA	1167	1990
VT66	Rose River	Yes	BR	VA	2350	1990
VT70	Bear Branch (Smr)	Yes	BR	VA	221	1990
VT72	Hogback Branch (Smr)	Yes	BR	VA	221	1990
VT73	Sugartree Br (Smr)	Yes	BR	VA	410	1990
VT74	St Marys R-Middle	Yes	BR	VA	1957	1990
VT75	White Oak Canyon River	Yes	BR	VA	1401	1990
VT77	Matts Creek	Yes	BR	VA	283	1990
VT78	Little Tumbling Creek	Yes	RV	VA	1796	1990
WOR	White Oak Run	Yes	BR	VA	509	1994
WV523S	Noname Trib Stony Creek 1	Yes	CA	WV	28	1994
WV531S	Otter Creek	Yes	CA	WV	5032	1994
WV547S	Gauley	Yes	CA	WV	18917	1994
WV548S	Noname Trib S.F. Cherry River	Yes	CA	WV	160	1994
WV769S	Nnt Laurel Run	Yes	CA	WV	176	1994
WV770S	Moss Run	Yes	RV	WV	189	1994
WV771S	Left Fork Clover Run	Yes	RV	WV	7677	1994
WV785S	Nnt Glade Cr	Yes	CA	WV	125	1994
WV788S	White Oak Fork	Yes	CA	WV	312	1994
WV796S	Red Creek	Yes	CA	WV	1669	1994
2A068015U	Grasses Creek-Dry Branch	No	BR	VA	68	1985
2B041020L	Sprigs Hollow	No	RV	WV	181	1985
2B041032U	No Name 1	No	RV	WV	15	1985
2B041049U	No Name 2	No	RV	VA	34	1985
2B047044U	Straight Fork	No	RV	VA	1031	1985
2B047076U	Lower Lewis Run	No	BR	VA	70	1985

ID	Name	MAGIC Site?	Ecoregion[1]	State	WS Area[2]	Year[3]
2B058015U	Whites Run	No	BR	VA	180	1985
2C040006U	Shoals Run	No	CA	WV	18	1985
2C041033U	No Name 4	No	CA	WV	33	1985
2C041043U	No Name 5	No	RV	WV	23	1985
2C046013L	Right Fork Holly River	No	CA	WV	4530	1985
2C046041	No Name 7	No	CA	WV	250	1985
2C046048U	Little Righthand Fork	No	CA	WV	14	1985
2C046053L	Laurel Creek 1	No	CA	WV	5321	1985
2C046062L	Little Clear Creek	No	CA	WV	1079	1985
AB01	North Fork of Mormans River	No	BR	VA	2624	2000
AB02	N.F. of Mormans River (Blackrock Gap)	No	BR	VA	234	2000
AB04	N.F. of Mormans River (Upper Reach)	No	BR	VA	678	2000
AB05	Big Branch of Mormans River	No	BR	VA	360	2000
AB06	Doyle River	No	BR	VA	545	2000
AB07	Jones Run	No	BR	VA	450	2000
AB08	S.F. of Mormans River	No	BR	VA	1265	2000
AB09	Pond Ridge Branch of Mormans River	No	BR	VA	296	2000
AG03	Smith Creek 1	No	RV	VA	1803	2000
AG04	Piney Branch 1	No	RV	VA	1163	2000
AG05	Crow Run	No	RV	VA	551	2000
AG06	Little Crow Run	No	RV	VA	310	2000
AG07	Nelse Branch	No	RV	VA	74	2000
AG10	Downy Branch	No	RV	VA	410	2000
AM02	Nicholson Run	No	BR	VA	210	2000
AM03	Lady Slipper Run	No	BR	VA	171	2000
AM05	S.F. of Piney River (Upper Reach)	No	BR	VA	345	2000
AM06	Little Piney River (Upper Reach)	No	BR	VA	455	2000
AM10	Wheelers Run	No	BR	VA	229	2000
AM11	Pedlar River (Middle Reach)	No	BR	VA	4726	2000
AM12	Roberts Creek	No	BR	VA	257	2000
AM13	Brown Mountain Creek	No	BR	VA	856	2000
AM15	Enchanted Creek	No	BR	VA	670	2000
AM18	N.F. of Buffalo Creek (Upper Reach)	No	BR	VA	715	2000
AM19	Rocky Branch	No	BR	VA	191	2000
AM24	Little Piney River (Lower Reach)	No	BR	VA	1980	2000
AU04	Left Prong of Ramseys Draft	No	RV	VA	431	2000
AU05	Right Prong of Ramseys Draft	No	RV	VA	322	2000
AU07	Ramseys Draft (Middle Reach)	No	RV	VA	2576	2000
AU08	Chestnut Lick Hollow	No	RV	VA	186	2000
AU09	Jerkemtight Branch	No	RV	VA	921	2000
AU10	Still Run	No	RV	VA	343	2000
AU13	Toms Branch	No	BR	VA	556	2000
AU14	Loves Creek	No	BR	VA	463	2000
AU16	Coles Run	No	BR	VA	629	2000
AU17	Kennedy Creek	No	BR	VA	586	1990
AU19	North Fork Back Creek	No	BR	VA	571	2000
AU20	S.F. Back Creek	No	BR	VA	263	2000
AU29	Spy Run	No	BR	VA	837	2000
AU30	North Fork Little River	No	RV	VA	1800	2000
AU31	S.F. Little River	No	RV	VA	1214	2000

ID	Name	MAGIC Site?	Ecoregion[1]	State	WS Area[2]	Year[3]
AU32	Little River	No	RV	VA	3963	2000
AU33	Jennings Branch	No	RV	VA	588	2000
AU34	Buffalo Branch	No	RV	VA	696	2000
AU35	Orebank Creek	No	BR	VA	550	2000
BA01	Big Lick Run	No	RV	VA	468	2000
BA02	Shop Hollow Branch	No	RV	VA	367	2000
BA09	Cub Run	No	RV	VA	190	2000
BA11	Dry Run (Lower Reach)	No	RV	VA	5958	2000
BA12	Jordan Run	No	RV	VA	608	2000
BA14	Little Wilson Creek 1	No	RV	VA	400	2000
BA16	Wilson Creek (Upper Reach)	No	RV	VA	1143	2000
BA17	Left Prong of Wilson Creek	No	RV	VA	1537	2000
BA21	Long Spring Run	No	RV	VA	1257	2000
BA22	Wildcat Hollow 1	No	RV	VA	331	2000
BA25	Sawmill Run	No	RV	VA	270	2000
BA26	Spring Run	No	RV	VA	504	2000
BA27	Jim Dave Run	No	RV	VA	633	2000
BA28	Mill Creek 2	No	RV	VA	2020	2000
BD01	Dry Fork	No	RV	VA	293	2000
BD02	Laurel Creek 2	No	RV	VA	366	2000
BD04	Hunting Camp Creek	No	RV	VA	1713	2000
BE01	Stony Creek 1	No	BR	VA	485	2000
BE02	Overstreet Creek	No	BR	VA	198	2000
BO01	Stony Run	No	RV	VA	362	2000
BO04	Furnace Branch	No	RV	VA	826	2000
BO07	Smith Creek 2	No	RV	VA	1129	2000
BO08	North Creek (Upper Reach)	No	BR	VA	1068	2000
BO11	Middle Creek 1	No	BR	VA	652	2000
BO12	Jennings Creek	No	BR	VA	433	2000
BO13	Fallingwater Creek (Upper Reach)	No	BR	VA	490	2000
CA01	Little Fisher Creek	No	BR	VA	347	2000
CA02	S.F. Stewarts Creek	No	BR	VA	566	2000
CR02	Eliber Springs Branch	No	RV	VA	440	2000
CR03	Negro Branch	No	RV	VA	229	2000
CR05	Valley Branch	No	RV	VA	851	2000
CR08	Barbours Creek (Upper Reach)	No	RV	VA	1160	2000
CR09	South Prong of Barbours Creek	No	RV	VA	713	2000
CR10	Lipes Branch	No	RV	VA	246	2000
CR11	Barbours Creek (Lower Reach)	No	RV	VA	3448	2000
CR12	Paxton Branch	No	RV	VA	115	2000
CR13	Laurel Creek of Sinking Creek	No	RV	VA	426	2000
CR14	Corner Branch	No	RV	VA	556	2000
DS06	Stonecoal Run (Left Branch)	No	CA	WV	333	1994
FL01	Long Mountain Creek	No	BR	VA	587	2000
FL02	East Prong of Furnace Creek	No	BR	VA	755	2000
FR01	Roaring Run 1	No	BR	VA	605	2000
FR02	Brogran Branch	No	BR	VA	350	2000
FR03	Rennet Bag Creek	No	BR	VA	902	2000
GL02	Saltpeter Branch	No	RV	VA	338	2000
GL03	White Rock Branch	No	RV	VA	814	2000

ID	Name	MAGIC Site?	Ecoregion[1]	State	WS Area[2]	Year[3]
GL06	Meredith Branch	No	RV	VA	310	2000
GL08	North Fork of Stony Creek	No	RV	VA	1458	2000
GL10	Dismal Branch	No	RV	VA	547	2000
GL12	Wildcat Hollow 2	No	RV	VA	155	2000
GL13	Sartain Branch	No	RV	VA	185	2000
GL14	Johns Creek (Upper Reach)	No	RV	VA	747	2000
GL16	Little Stony Creek (Lower Reach)	No	RV	VA	4707	2000
GL18	Panther Den Branch	No	RV	VA	104	2000
GL19	Pearis Thompson Branch	No	RV	VA	275	2000
GL20	Standrock Branch	No	RV	VA	404	2000
GL21	Dismal Creek	No	RV	VA	2741	2000
GL24	Dixon Branch	No	RV	VA	521	2000
GR01	Conway River (Upper Reach)	No	BR	VA	603	2000
GR02	Bootens Run	No	BR	VA	183	2000
GR03	Devils Ditch	No	BR	VA	585	2000
GR06	Entry Run	No	BR	VA	434	2000
GR07	South River	No	BR	VA	642	2000
GR08	Ivy Creek	No	BR	VA	707	2000
GR09	Swift Run	No	BR	VA	1323	2000
GY04	Tributary of Fox Creek	No	BR	VA	95	2000
GY05	Oppossum Creek	No	BR	VA	276	2000
GY06	Solomon Branch	No	BR	VA	281	2000
GY07	Mill Creek (Upper Reach)	No	BR	VA	264	2000
GY08	Ripshin Creek	No	BR	VA	402	2000
GY09	Tributary To Ripshin Creek	No	BR	VA	167	2000
GY10	Wilson Creek	No	BR	VA	1326	2000
GY11	Wilburn Branch	No	BR	VA	385	2000
GY13	Jerry Creek (Upper Reach)	No	BR	VA	478	2000
GY14	Big Horse Creek	No	BR	VA	298	2000
GY16	Bournes Branch	No	BR	VA	721	2000
HI01	Mullenax Run (of Laurel Fork)	No	RV	VA	245	2000
HI02	Newman Run (of Laurel Fork)	No	RV	VA	331	2000
HI05	Laurel Fork (Middle Reach)	No	RV	VA	2453	2000
HI06	Slabcamp Run (of Laurel Fork)	No	RV	VA	5643	2000
HI07	Locust Spring Run (of Laurel Fork)	No	RV	VA	568	2000
HI08	Buck Run (of Laurel Fork)	No	RV	VA	460	2000
HI09	Laurel Fork (Lower Reach)	No	RV	VA	7157	2000
HI10	Collins Run	No	RV	VA	332	2000
HI11	Blights Run	No	RV	VA	229	2000
HI12	Benson Run	No	RV	VA	658	2000
HI13	Left Prong Benson Run	No	RV	VA	335	2000
HI14	Right Prong Benson Run	No	RV	VA	236	2000
M002	Laurel Bed Creek	No	RV	VA	213	2000
M034	Snow Creek	No	BR	VA	493	2000
M036	E.Fork-Elk Creek (Upper)	No	BR	VA	94	2000
MA04	Brokenback Run	No	BR	VA	1011	2000
MA05	Hannah Run	No	BR	VA	235	2000
MA06	Hughes Run	No	BR	VA	1894	2000
MA07	Cedar Run	No	BR	VA	547	2000
MA10	Berry Hollow	No	BR	VA	130	2000

ID	Name	MAGIC Site?	Ecoregion[1]	State	WS Area[2]	Year[3]
MA12	Mill Prong	No	BR	VA	437	2000
MA13	Laurel Prong	No	BR	VA	561	2000
MA14	Kinsey Run	No	BR	VA	292	2000
MA18	Garth Run	No	BR	VA	959	2000
MAD2	Madison Run	No	BR	VA	671	2000
MAIA98-167	Unknown	No	RV	WV	1054	1994
MNF101	Seneca Creek (Upper)	No	RV	WV	989	2001
MNF102	Briggs Run	No	RV	WV	1618	2001
MNF103	Stewart Run	No	RV	WV	1218	2001
MNF104	S. Branch Haddix Run	No	RV	WV	476	2001
MNF105	Swallow Rock Run	No	RV	WV	572	2001
MNF108	North Fork Anthony Creek	No	RV	WV	4368	2001
MNF109	Tumbling Rock Run	No	CA	WV	740	2001
MNF110	Red Run 1	No	CA	WV	486	2001
MNF111	Rough Run	No	CA	WV	681	2001
MNF112	Hanging Rock Branch	No	CA	WV	289	2001
MNF113	Aldrich Branch	No	CA	WV	273	2001
MNF114	Queer Branch	No	CA	WV	383	2001
MNF115	Mill Branch	No	CA	WV	233	2001
MNF116	Foxtree Run	No	CA	WV	743	2001
MNF117	Bear Run 1	No	CA	WV	432	2001
MNF118	Hinkle Branch	No	CA	WV	396	2001
MNF119	Jakeman Run	No	CA	WV	716	2001
MNF120	Windy Run	No	CA	WV	199	2001
MNF121	Morris Creek	No	CA	WV	1023	2001
MNF122	Holcomb Run	No	CA	WV	572	2001
MNF123	Buckheart Run	No	CA	WV	351	2001
MNF124	Coal Siding Run	No	CA	WV	311	2001
MNF125	Curtain Run	No	CA	WV	250	2001
MNF126	Un-Named Trib To Otter Creek	No	CA	WV	31	2001
MNF13	Tygart Valley River	No	CA	WV	1985	2001
MNF15	Shavers Run	No	RV	WV	1514	2001
MNF16	Shavers Fork River	No	CA	WV	3228	2001
MNF18	Second Fork	No	CA	WV	1530	2001
MNF19	Beaver Creek 2	No	CA	WV	437	2001
MNF2	Little Low Place Hollow	No	RV	WV	436	2001
MNF20	First Fork	No	CA	WV	2269	2001
MNF22	Fish Hatchery Run	No	CA	WV	655	2001
MNF24	Crouch Run	No	CA	WV	546	2001
MNF26	Glade Run	No	CA	WV	506	2001
MNF29	Little Black Fork	No	CA	WV	1229	2001
MNF3	Big Run 1	No	RV	WV	977	2001
MNF30	Laurel Run 1	No	RV	WV	751	2001
MNF35	Big Run of Gandy Creek	No	RV	WV	1034	2001
MNF37	Camp Five Run	No	RV	WV	553	2001
MNF38	Laurel Fork	No	RV	WV	3311	2001
MNF40	East Fork Glady Fork	No	RV	WV	1901	2001
MNF41	Glady Fork	No	RV	WV	9893	2001
MNF42	Five Lick Creek	No	RV	WV	311	2001

ID	Name	MAGIC Site?	Ecoregion[1]	State	WS Area[2]	Year[3]
MNF45	Lindy Run	No	CA	WV	594	2001
MNF5	Long Run 1	No	RV	WV	1363	2001
MNF50	S.F. Red Run of Dry Fork	No	CA	WV	422	2001
MNF51	Yellow Creek	No	CA	WV	85	2001
MNF56	Maxwell Run	No	RV	WV	977	2001
MNF57	Mike Run	No	RV	WV	1037	2001
MNF59	Left Fork Clover Run	No	RV	WV	586	2001
MNF6	High Ridge Run	No	RV	WV	691	2001
MNF60	Crooked Fork	No	CA	WV	1052	2001
MNF62	Laurel Run 2	No	CA	WV	780	2001
MNF63	Props Run	No	CA	WV	346	2001
MNF64	Elk River	No	CA	WV	14466	2001
MNF66	Mikes Run	No	RV	WV	418	2001
MNF67	Hinkle Run	No	RV	WV	803	2001
MNF68	West Fork Greenbrier River	No	RV	WV	13511	2001
MNF69	Mullenax Run	No	RV	WV	906	2001
MNF70	East Fork Greenbrier R	No	RV	WV	6370	2001
MNF71	Long Run (of Poca Run)	No	RV	WV	606	2001
MNF72	North Fork Deer Creek	No	RV	WV	4710	2001
MNF73	Greenbrier River	No	RV	WV	39170	2001
MNF74	Knapp Creek	No	RV	WV	1334	2001
MNF75	Twomile Run 1	No	RV	WV	630	2001
MNF76	Black Mountain Run	No	CA	WV	419	2001
MNF77	Williams River	No	CA	WV	3555	2001
MNF78	Sugar Creek	No	CA	WV	78	2001
MNF8	N. Fork S. Branch Potomac River	No	RV	WV	44074	2001
MNF80	Tea Creek	No	CA	WV	2984	2001
MNF81	Beechy Run	No	CA	WV	1252	2001
MNF82	Middle Fork of Williams River	No	CA	WV	5652	2001
MNF83	Little Fork	No	CA	WV	1091	2001
MNF84	S.F. Cranberry River	No	CA	WV	2403	2001
MNF85	North Fork Cranberry River	No	CA	WV	1195	2001
MNF87	Dogway Fork	No	CA	WV	429	2001
MNF88	Cranberry River	No	CA	WV	20789	2001
MNF89	Barrenshe Run	No	CA	WV	898	2001
MNF91	Bear Run 2	No	CA	WV	947	2001
MNF92	North Fork Cherry River	No	CA	WV	222	2001
MNF93	Carpenter Run	No	CA	WV	293	2001
MNF95	Rabbit Run	No	CA	WV	68	2001
MNF98	Hunters Run	No	CA	WV	862	2001
MNF99	Desert Branch	No	CA	WV	384	2001
NE01	Mill Creek 3	No	BR	VA	439	2000
NE02	Rodes Creek	No	BR	VA	270	2000
NE03	Stony Creek 2	No	BR	VA	1680	2000
NE05	White Rock Creek	No	BR	VA	393	2000
NE06	Durhan Run	No	BR	VA	536	2000
NE07	N.F. of Tye River (Middle Reach)	No	BR	VA	2542	2000
NE08	Mill Creek 4	No	BR	VA	295	2000
NE10	N.F. of Piney River (Upper Reach)	No	BR	VA	714	2000
NE11	Louisa Spring Branch	No	BR	VA	295	2000

ID	Name	MAGIC Site?	Ecoregion[1]	State	WS Area[2]	Year[3]
NE15	S.F. of Piney River	No	BR	VA	1729	2000
NE16	Rocky Run 2	No	BR	VA	685	2000
NE18	Coxs Creek	No	BR	VA	431	2000
NE22	Campbell Creek	No	BR	VA	567	2000
NE23	North Fork of Tye River	No	BR	VA	4326	2000
NE25	S.F. of Tye River (Upper Reach)	No	BR	VA	1636	2000
OC05	Yellow Creek	No	CA	WV	774	1994
OC09	Devils Gulch	No	CA	WV	511	1994
OC31	Possession Camp Run	No	CA	WV	419	1994
OC32	Moores Run	No	CA	WV	959	1994
PG03	Pitt Spring Run	No	RV	VA	891	2000
PG04	Roaring Run 2	No	RV	VA	721	2000
PG05	Fultz Run	No	BR	VA	597	2000
PG08	East Branch of Naked Creek	No	BR	VA	932	2000
PG09	Big Creek	No	BR	VA	313	2000
PT01	Rock Castle Creek	No	BR	VA	1363	2000
PT02	Widgeon Creek	No	BR	VA	483	2000
PT03	Little Rock Castle Creek	No	BR	VA	358	2000
PT04	Roaring Creek	No	BR	VA	494	2000
PT05	Little Dan River (Upper Reach)	No	BR	VA	237	2000
PT07	Hookers Creek	No	BR	VA	315	2000
PT08	South Mayo River (Upper Reach)	No	BR	VA	441	2000
PT09	Rye Cove Creek	No	BR	VA	566	2000
PT11	Brushy Fork	No	BR	VA	333	2000
PT12	Rhody Creek	No	BR	VA	272	2000
PU01	Tract Fork	No	RV	VA	617	2000
PU02	Little Macks Creek	No	BR	VA	677	2000
PU03	Big Mack Creek (Upper Reach)	No	BR	VA	1376	2000
PU06	Rock Creek	No	BR	VA	1221	2000
RA06	Sams Run	No	BR	VA	191	2000
RA07	Broad Hollow	No	BR	VA	236	2000
RA09	Rush River	No	BR	VA	217	2000
RA10	S.F. Thornton River	No	BR	VA	1662	2000
RA12	Jordan River	No	BR	VA	722	2000
RB01	Nettle Spring Branch	No	BR	VA	500	2000
RB02	Nettle Creek	No	BR	VA	1321	2000
RB03	Irish Creek	No	BR	VA	2217	2000
RB04	Big Marys Creek	No	BR	VA	339	2000
RB05	Dark Hollow	No	RV	VA	46	2000
RB07	Gochenour Branch	No	RV	VA	632	2000
RB08	Piney Branch 2	No	RV	VA	344	2000
RB09	Guys Run	No	RV	VA	1142	2000
RB11	South Buffalo Creek (Upper Reach)	No	RV	VA	1689	2000
RB12	Cedar Creek 1	No	RV	VA	559	2000
RB13	North Fork of Bennetts Run	No	BR	VA	351	2000
RB14	S.F. of Bennetts Run	No	BR	VA	297	2000
RB15	Poplar Cove Hollow	No	BR	VA	422	2000
RB16	Lowrey Run	No	BR	VA	456	2000
RB18	Pedlar Gap Run	No	BR	VA	258	2000
RB19	East Fork Elk Creek	No	BR	VA	564	2000

ID	Name	MAGIC Site?	Ecoregion[1]	State	WS Area[2]	Year[3]
RB26	Little Mary's Creek	No	BR	VA	780	2000
RB28	Belle Cove Creek	No	BR	VA	686	2000
RB29	Alum Creek	No	RV	VA	708	2000
RB30	Brattons Run	No	RV	VA	1087	2000
RH02	German River (Upper Reach)	No	RV	VA	586	2000
RH03	Camp Rader Run	No	RV	VA	912	2000
RH06	Carr Run	No	RV	VA	596	2000
RH07	Clay Lick Hollow	No	RV	VA	836	2000
RH08	Rattlesnake Run	No	RV	VA	144	2000
RH09	Spruce Run	No	RV	VA	266	2000
RH12	Low Place Run	No	RV	VA	721	2000
RH13	Laural Run	No	RV	VA	972	2000
RH14	Dry River	No	RV	VA	3737	2000
RH15	Long Run 2	No	RV	VA	743	2000
RH16	Briery Run	No	RV	VA	1331	2000
RH17	Mines Run	No	RV	VA	874	2000
RH18	Hone Quarry	No	RV	VA	2042	2000
RH20	Little Laurel	No	RV	VA	680	2000
RH21	Sand Run	No	RV	VA	367	2000
RH22	Miller Spring Run	No	RV	VA	648	2000
RH23	Dry Run 1	No	RV	VA	920	2000
RH24	Kephart Run	No	RV	VA	868	2000
RH25	Gum Run	No	RV	VA	552	2000
RH26	Maple Spring Run	No	RV	VA	494	2000
RH27	Rocky Run of Dry River	No	RV	VA	1138	2000
RH28	Hopkins Hollow	No	RV	VA	792	2000
RH30	Black Run (North Fork)	No	RV	VA	249	2000
RH33	Rocky Run of Briery Branch	No	RV	VA	290	2000
RH34	Union Springs Run (of Beaver Creek)	No	RV	VA	889	2000
RH36	Black Run (Middle Fork)	No	RV	VA	903	2000
RH40	Boones Run (North Branch)	No	RV	VA	852	2000
RH42	Dry Run 2	No	BR	VA	282	2000
RH49	Big Run (Upper Reach)	No	BR	VA	1500	2000
RH50	Rocky Mountain Run	No	BR	VA	846	2000
RH51	Bearwallow Run 1	No	BR	VA	261	2000
RN01	Big Laurel Creek	No	BR	VA	483	2000
SC01	Stock Creek	No	CA	VA	484	2000
SC02	Cove Creek (Upper)	No	CA	VA	487	2000
SC04	Devils Fork	No	CA	VA	1568	2000
SC05	Straight Fork (Lower)	No	CA	VA	1600	2000
SC08	Little Stony Creek (Upper)	No	CA	VA	65	2000
SH02	Poplar Run	No	RV	VA	524	2000
SH03	Laurel Run 3	No	RV	VA	1017	2000
SH04	Cedar Creek 2	No	RV	VA	1136	2000
SH06	Anderson Run	No	RV	VA	70	2000
SY01	Tramroad Hollow	No	BR	VA	198	2000
SY02	Rocky Hollow	No	BR	VA	290	2000
SY03	Nicks Creek	No	BR	VA	383	2000
SY04	East Fork of Nicks Creek	No	BR	VA	320	2000
SY05	Quarter Branch	No	BR	VA	342	2000

ID	Name	MAGIC Site?	Ecoregion[1]	State	WS Area[2]	Year[3]
SY06	Tributary of Cressy Creek	No	BR	VA	117	2000
SY07	Houndshell Branch	No	BR	VA	512	2000
SY08	Parks Creek	No	BR	VA	402	2000
SY09	Dry Creek (Upper Reach)	No	BR	VA	309	2000
SY10	Crigger Creek	No	BR	VA	443	2000
SY11	Middle Creek 2	No	BR	VA	450	2000
SY13	White Rock Creek (Upper Reach)	No	BR	VA	514	2000
SY14	Jerrys Creek	No	BR	VA	427	2000
SY15	Cold Branch	No	BR	VA	88	2000
SY16	Long Branch	No	BR	VA	139	2000
SY17	Bark Camp Branch 2	No	BR	VA	133	2000
SY18	Rowland Creek (Upper Reach)	No	BR	VA	339	2000
SY19	Incline Hollow	No	BR	VA	195	2000
SY20	St Clair Creek	No	BR	VA	264	2000
SY22	Pennington Branch	No	BR	VA	275	2000
SY23	Grassy Branch	No	BR	VA	247	2000
SY25	Scott Branch	No	BR	VA	148	2000
SY27	Hutton Branch	No	BR	VA	197	2000
TA01	Cox Branch	No	RV	VA	497	2000
TA06	Unnamed Trib of E. Fork Cove Creek	No	RV	VA	172	2000
TA07	Oneida Branch	No	RV	VA	246	2000
TA13	Coon Branch	No	RV	VA	403	2000
VA538S	North	No	RV	VA	3859	1994
VA546S	Mill Run	No	RV	VA	462	1994
VA550S	Noname Trib Craig Cr (Maple Spring)	No	RV	VA	136	1994
VA567S	Jones Branch	No	BR	VA	68	1994
VA756S	Holloway Draft	No	RV	VA	398	1994
VA769S	North Fork Kimberling Creek	No	RV	VA	1014	1994
VA772S	Whiteman Run	No	RV	VA	35	1994
VA774S	Little Brush Creek	No	RV	VA	1547	1994
VA788S	Nnt Johns Cr	No	RV	VA	64	1994
VA789S	Eliber Springs Br	No	RV	VA	331	1994
VA793S	North Fork Long Br Buffalo River	No	BR	VA	31	1994
VA794S	Nnt Reed Cr	No	BR	VA	92	1994
VA822S	Buckeye Br	No	BR	VA	642	1994
VT01	Helton Creek	No	BR	VA	379	2000
VT03	Fox Creek	No	BR	VA	351	1990
VT04	Little Wilson Creek 2	No	BR	VA	543	2000
VT13	Bear Hole	No	RV	VA	265	2000
VT16	N. Branch Simpson Creek	No	RV	VA	713	2000
VT17	Blue Suck Branch	No	RV	VA	584	2000
VT22	Cornelius Creek	No	BR	VA	495	2000
VT23	Fallingwater Cr	No	BR	VA	472	1990
VT29	War Spur Branch	No	RV	VA	343	1990
VT40	Mills Creek	No	BR	VA	659	2000
VT42	Hunting Creek	No	BR	VA	563	2000
VT43	Greasy Spring Branch	No	BR	VA	265	2000
VT44	Georges Creek	No	BR	VA	353	2000
VT45	Otter Creek	No	BR	VA	374	2000
VT51	Jeremys Run	No	BR	VA	2204	2000

ID	Name	MAGIC Site?	Ecoregion[1]	State	WS Area[2]	Year[3]
VT52	Morgan Run	No	RV	VA	332	2000
VT60	Piney River 2	No	BR	VA	1269	2000
VT61	North Fork Thornton River	No	BR	VA	1891	2000
VT63	Shoe Creek	No	BR	VA	1265	2000
VT64	Crabtree Creek	No	BR	VA	356	2000
VT65	Meadow Creek	No	BR	VA	276	2000
VT68	St Marys R-Middle	No	BR	VA	401	1990
VT69	Chimney Br (Smr)	No	BR	VA	203	2000
VT71	Mine Bank Creek (Smr)	No	BR	VA	206	2000
VT76	Belfast Creek	No	BR	VA	268	2000
WA01	Creasy Hollow	No	BR	VA	160	2000
WA02	Rush Creek (Upper Reach)	No	BR	VA	411	2000
WA04	London Bridge Branch	No	BR	VA	297	2000
WE01	Powell River (Upper Left Fork)	No	CA	VA	169	2000
WE02	Powell River (Upper Right Fork)	No	CA	VA	216	2000
WE03	Clear Creek	No	CA	VA	1223	2000
WN01	Overall Run	No	BR	VA	1040	2000
WV525S	Hog Run	No	BR	WV	278	1994
WV543S	Burning Run	No	RV	WV	473	1994
WV545S	Mill Creek 1	No	CA	WV	591	1994
WY01	Venrick Run	No	BR	VA	594	2000
WY02	Kinser Creek	No	BR	VA	573	2000
WY03	West Fork of Dry Run	No	BR	VA	621	2000
WY04	East Fork of Dry Run	No	BR	VA	782	2000
WY05	Jones Creek	No	BR	VA	468	2000

1 Ecoregion containing the greatest proportion of the watershed; RV = Ridge and Valley, CA = Central Appalachian, BR = Blue Ridge
2 Watershed area (WS Area) is expressed in hectares
3 Year is year of water sampling

Table F-2. SSWC model input data for study streams (all units in $meq/m^2/yr$).[1]

ID	BC_{dep}[1]			N Terms				ANC_{limit}			
	1995	2000	2001	Uptake	Immob.	Denitr.	BC_{up}	0	20	50	100
2B047032	20.4	15.3	14.2	10.3	4.3	7.1	20.7	0.0	10.3	25.7	51.4
2C041039	23.4	18.7	18.1	10.6	4.3	7.1	25.6	0.0	14.1	35.3	70.5
2C041040	19.7	16.4	16.6	10.4	4.3	7.1	22.9	0.0	14.8	37.1	74.1
2C041045	22.8	18.5	17.8	10.6	4.3	7.1	26.1	0.0	12.9	32.2	64.4
2C041051	22.5	17.5	16.9	0.1	4.3	7.1	0.3	0.0	14.3	35.7	71.4
2C046033	17.8	18.8	18.5	10.4	4.3	7.1	21.7	0.0	16.9	42.3	84.7
2C046034	19.7	18.4	17.6	0.0	4.3	7.1	0.1	0.0	20.2	50.4	100.8
2C046043L	17.4	17.6	17.0	10.1	4.3	7.1	19.0	0.0	18.2	45.6	91.2
2C046043U	17.4	17.6	17.0	10.1	4.3	7.1	19.0	0.0	18.4	45.9	91.8
2C046050	15.1	16.9	16.9	9.0	4.3	7.1	23.0	0.0	10.3	25.8	51.6
2C047007	18.8	16.0	16.1	10.6	4.3	7.1	26.5	0.0	11.6	29.0	58.0
2C047010L	19.5	15.8	15.2	10.2	4.3	7.1	19.9	0.0	13.9	34.8	69.6
2C047010U	19.4	15.6	15.0	10.2	4.3	7.1	19.7	0.0	14.4	36.1	72.2
2C057004	15.7	17.5	17.4	10.7	4.3	7.1	26.6	0.0	12.8	31.9	63.8
AU28	13.2	11.0	11.3	0.2	4.3	7.1	0.5	0.0	10.2	25.6	51.2
BLFC	12.3	10.8	10.9	0.0	4.3	7.1	0.0	0.0	14.1	35.3	70.6
BO02	14.9	13.7	13.5	10.8	4.3	7.1	27.8	0.0	6.0	15.0	30.0
DR	11.5	8.9	9.4	0.8	4.3	7.1	2.0	0.0	7.6	19.0	38.1
DS04	24.1	17.3	16.5	2.3	4.3	7.1	4.3	0.0	15.5	38.8	77.5
DS09	23.1	16.7	16.1	0.9	4.3	7.1	1.9	0.0	16.0	39.9	79.9
DS19	22.3	16.7	16.2	1.2	4.3	7.1	2.2	0.0	13.8	34.5	69.0
DS50	23.6	16.9	16.3	0.0	4.3	7.1	0.0	0.0	15.8	39.5	79.1
FN1	21.6	17.9	17.5	10.4	4.3	7.1	22.7	0.0	15.3	38.1	76.3
FN2	20.9	17.4	17.1	10.8	4.3	7.1	27.8	0.0	15.1	37.8	75.5
FN3	19.4	16.5	16.4	10.8	4.3	7.1	27.8	0.0	15.4	38.5	76.9
LEWF	14.0	13.4	13.5	0.2	4.3	7.1	0.4	0.0	18.8	47.0	94.1
M037	12.8	11.1	11.1	0.0	4.3	7.1	0.0	0.0	13.7	34.2	68.4
M038	11.9	10.8	11.4	0.0	4.3	7.1	0.0	0.0	10.5	26.1	52.3
M039	11.9	10.8	11.4	0.1	4.3	7.1	0.2	0.0	10.3	25.7	51.4
NFD	12.6	9.8	10.6	0.0	4.3	7.1	0.0	0.0	11.7	29.3	58.7
OC02	23.4	17.2	16.1	1.0	4.3	7.1	1.9	0.0	16.4	41.0	81.9
OC08	23.7	17.8	16.6	0.5	4.3	7.1	0.9	0.0	16.9	42.3	84.5

ID	BC_{dep}[1]			N Terms			BC_{up}	ANC_{limit}			
	1995	2000	2001	Uptake	Immob.	Denitr.		0	20	50	100
OC35	22.8	17.3	16.5	0.0	4.3	7.1	0.0	0.0	15.6	39.0	78.1
OC79	22.8	17.8	16.9	0.7	4.3	7.1	1.3	0.0	16.4	41.0	82.1
PAIN	11.3	8.9	9.8	0.0	4.3	7.1	0.0	0.0	10.4	26.1	52.2
RA05	13.2	10.4	10.8	0.0	4.3	7.1	0.1	0.0	14.0	34.9	69.8
RH53	11.4	9.0	9.5	0.0	4.3	7.1	0.1	0.0	7.5	18.6	37.3
STAN	13.0	10.7	11.4	1.1	4.3	7.1	2.8	0.0	10.9	27.1	54.3
VA524S	15.5	15.3	15.4	0.4	4.3	7.1	1.1	0.0	10.7	26.7	53.5
VA526S	16.9	17.6	16.9	9.3	4.3	7.1	24.1	0.0	10.3	25.7	51.3
VA531S	10.9	9.7	10.7	0.0	4.3	7.1	0.0	0.0	12.2	30.5	61.0
VA548S	10.0	8.8	9.6	10.8	4.3	7.1	27.8	0.0	6.6	16.6	33.1
VA555S	12.4	11.0	11.0	10.8	4.3	7.1	27.7	0.0	11.2	28.0	55.9
VA821S	15.9	15.2	15.1	10.1	4.3	7.1	25.4	0.0	6.6	16.5	33.1
VT05	12.7	13.2	13.3	10.8	4.3	7.1	27.8	0.0	12.3	30.8	61.6
VT07	16.5	14.8	14.3	0.0	4.3	7.1	0.0	0.0	11.9	29.6	59.3
VT08	17.1	15.3	14.5	0.5	4.3	7.1	1.2	0.0	11.9	29.6	59.3
VT09	17.1	15.3	14.5	1.7	4.3	7.1	4.3	0.0	9.5	23.8	47.6
VT10	14.9	12.2	11.7	10.8	4.3	7.1	27.8	0.0	8.7	21.8	43.7
VT11	14.8	12.8	12.3	10.8	4.3	7.1	27.7	0.0	8.4	20.9	41.8
VT12	15.3	13.0	12.4	10.8	4.3	7.1	27.8	0.0	8.4	20.9	41.9
VT15	15.5	13.2	12.5	10.8	4.3	7.1	27.8	0.0	8.1	20.2	40.5
VT18	18.8	14.7	13.7	0.8	4.3	7.1	1.4	0.0	11.5	28.8	57.6
VT19	18.9	14.6	13.5	0.0	4.3	7.1	0.0	0.0	11.6	29.1	58.1
VT24	15.0	14.2	14.4	1.2	4.3	7.1	3.1	0.0	6.5	16.3	32.5
VT25	15.7	14.5	14.0	7.9	4.3	7.1	20.2	0.0	9.6	23.9	47.8
VT26	15.6	15.4	15.5	0.3	4.3	7.1	0.9	0.0	9.9	24.6	49.3
VT28	15.8	15.3	15.3	10.2	4.3	7.1	26.2	0.0	10.3	25.7	51.4
VT31	15.6	14.9	15.0	10.8	4.3	7.1	27.3	0.0	7.8	19.4	38.9
VT32	16.9	16.0	15.9	10.8	4.3	7.1	27.8	0.0	12.1	30.2	60.4
VT34	12.3	11.0	11.1	11.0	4.3	7.1	27.6	0.0	9.2	23.0	45.9
VT36	11.4	8.9	9.7	0.0	4.3	7.1	0.0	0.0	10.7	26.7	53.5
VT37	14.4	10.8	10.3	1.4	4.3	7.1	3.6	0.0	10.6	26.5	52.9
VT38	13.8	10.6	10.1	0.1	4.3	7.1	0.4	0.0	9.3	23.3	46.6
VT46	12.7	10.6	10.7	10.8	4.3	7.1	27.8	0.0	14.6	36.5	73.0
VT48	16.1	14.3	14.4	10.8	4.3	7.1	27.7	0.0	9.2	23.1	46.2

ID	BC_{dep}[1]			N Terms			BC_{up}	ANC_{limit}			
	1995	2000	2001	Uptake	Immob.	Denitr.		0	20	50	100
VT49	12.0	10.1	10.7	10.8	4.3	7.1	27.8	0.0	8.1	20.3	40.6
VT50	12.4	10.4	10.8	10.8	4.3	7.1	27.8	0.0	7.2	18.1	36.2
VT54	16.3	12.0	11.5	1.8	4.3	7.1	4.6	0.0	9.6	24.0	48.1
VT55	12.3	10.4	10.7	10.8	4.3	7.1	27.8	0.0	7.7	19.1	38.3
VT56	12.8	10.8	10.6	7.1	4.3	7.1	18.3	0.0	7.1	17.8	35.7
VT57	13.2	10.6	10.4	7.5	4.3	7.1	19.3	0.0	6.7	16.7	33.4
VT58	12.9	10.6	11.3	0.0	4.3	7.1	0.0	0.0	11.7	29.3	58.6
VT66	13.7	10.6	11.3	0.6	4.3	7.1	1.5	0.0	10.8	26.9	53.8
VT70	13.1	11.0	11.4	0.5	4.3	7.1	1.3	0.0	13.7	34.2	68.3
VT72	13.6	11.1	11.1	0.0	4.3	7.1	0.0	0.0	14.4	36.0	71.9
VT73	12.7	10.9	11.3	0.6	4.3	7.1	1.6	0.0	12.4	31.1	62.1
VT74	13.6	11.2	11.3	0.1	4.3	7.1	0.2	0.0	12.2	30.6	61.2
VT75	14.3	10.7	11.2	0.0	4.3	7.1	0.0	0.0	11.4	28.5	56.9
VT77	13.0	11.3	11.9	0.0	4.3	7.1	0.0	0.0	9.4	23.5	47.0
VT78	14.5	15.2	14.7	10.6	4.3	7.1	27.1	0.0	13.8	34.6	69.2
WOR	12.2	9.4	10.1	0.0	4.3	7.1	0.0	0.0	11.3	28.2	56.4
WV523S	21.1	15.5	15.2	10.7	4.3	7.1	26.1	0.0	16.1	40.3	80.7
WV531S	23.6	17.6	16.6	0.2	4.3	7.1	0.4	0.0	16.2	40.5	81.0
WV547S	18.0	18.1	17.8	10.4	4.3	7.1	23.1	0.0	15.1	37.8	75.6
WV548S	17.1	18.4	17.9	10.5	4.3	7.1	24.5	0.0	16.1	40.3	80.7
WV769S	20.4	17.0	16.8	10.7	4.3	7.1	27.3	0.0	14.4	36.0	71.9
WV770S	17.9	16.0	16.5	10.5	4.3	7.1	23.3	0.0	12.1	30.4	60.7
WV771S	21.8	17.9	17.4	10.6	4.3	7.1	25.5	0.0	12.8	32.1	64.2
WV785S	14.2	15.9	16.1	8.7	4.3	7.1	22.5	0.0	10.2	25.4	50.8
WV788S	17.9	18.0	17.3	10.5	4.3	7.1	24.2	0.0	17.8	44.5	88.9
WV796S	24.3	17.2	16.4	3.8	4.3	7.1	7.5	0.0	15.7	39.2	78.5
2A068015U	12.8	12.6	13.1	10.8	4.3	7.1	27.8	0.0	14.1	35.3	70.6
2B041020L	11.7	9.9	10.7	10.8	4.3	7.1	27.7	0.0	6.0	15.0	30.0
2B041032U	12.1	10.1	10.6	4.4	4.3	7.1	11.3	0.0	6.0	15.0	30.0
2B041049U	12.2	10.0	10.6	10.8	4.3	7.1	27.8	0.0	6.0	15.0	30.0
2B047044U	18.1	14.0	13.0	10.5	4.3	7.1	23.9	0.0	10.4	26.1	52.1
2B047076U	11.9	9.0	9.5	0.0	4.3	7.1	0.0	0.0	11.4	28.4	56.8
2B058015U	11.5	10.3	10.5	10.8	4.3	7.1	27.8	0.0	10.4	26.0	52.1
2C040006U	20.2	16.8	16.3	8.5	4.3	7.1	21.8	0.0	12.5	31.2	62.4

ID	BC_{dep}[1] 1995	2000	2001	N Terms Uptake	Immob.	Denitr.	BC_{up}	ANC_{limit} 0	20	50	100
2C041033U	20.9	17.8	17.8	9.6	4.3	7.1	22.6	0.0	15.4	38.6	77.2
2C041043U	20.2	14.5	13.7	10.8	4.3	7.1	27.8	0.0	8.4	21.0	42.1
2C046013L	17.9	18.1	18.5	10.7	4.3	7.1	26.3	0.0	14.8	37.0	74.0
2C046041	16.0	17.7	17.5	6.0	4.3	7.1	15.2	0.0	13.9	34.9	69.7
2C046048U	12.9	15.7	16.2	10.8	4.3	7.1	27.8	0.0	9.4	23.5	47.0
2C046053L	16.6	17.8	17.4	10.6	4.3	7.1	24.8	0.0	16.5	41.1	82.3
2C046062L	16.3	17.7	17.7	10.7	4.3	7.1	26.2	0.0	16.5	41.3	82.6
AB01	12.7	9.9	10.7	3.2	4.3	7.1	8.3	0.0	14.1	35.2	70.4
AB02	13.0	9.8	10.5	0.1	4.3	7.1	0.3	0.0	16.1	40.2	80.4
AB04	12.9	9.9	10.4	5.7	4.3	7.1	14.8	0.0	16.0	40.1	80.2
AB05	12.8	9.7	10.2	0.0	4.3	7.1	0.0	0.0	15.9	39.8	79.6
AB06	12.1	9.5	10.1	0.0	4.3	7.1	0.0	0.0	16.6	41.5	82.9
AB07	12.1	9.4	10.1	0.0	4.3	7.1	0.1	0.0	16.5	41.3	82.6
AB08	12.4	9.9	10.8	4.2	4.3	7.1	10.7	0.0	14.4	35.9	71.8
AB09	12.9	9.8	10.4	0.0	4.3	7.1	0.0	0.0	14.0	35.0	70.0
AG03	14.8	13.4	12.7	10.2	4.3	7.1	26.3	0.0	9.2	23.1	46.2
AG04	14.6	13.6	13.4	10.8	4.3	7.1	27.7	0.0	9.1	22.9	45.7
AG05	14.2	14.1	14.3	10.8	4.3	7.1	27.8	0.0	6.0	15.0	30.0
AG06	14.2	14.1	14.2	10.8	4.3	7.1	27.8	0.0	6.0	15.0	30.0
AG07	14.8	14.2	14.4	10.8	4.3	7.1	27.8	0.0	7.4	18.5	37.1
AG10	12.5	11.8	11.9	10.9	4.3	7.1	27.7	0.0	7.6	19.0	38.1
AM02	11.9	10.4	10.6	10.8	4.3	7.1	27.8	0.0	10.8	27.1	54.2
AM03	12.4	10.6	10.7	10.8	4.3	7.1	27.8	0.0	10.8	27.1	54.2
AM05	13.0	10.6	10.9	10.8	4.3	7.1	27.8	0.0	18.7	46.9	93.7
AM06	13.9	11.1	11.5	10.8	4.3	7.1	27.8	0.0	16.5	41.2	82.5
AM10	11.9	10.5	10.7	10.8	4.3	7.1	27.8	0.0	11.6	29.1	58.2
AM11	11.8	10.5	10.9	10.9	4.3	7.1	27.4	0.0	10.8	27.0	53.9
AM12	11.4	10.2	10.6	10.8	4.3	7.1	27.8	0.0	10.3	25.8	51.7
AM13	10.9	10.2	10.9	10.7	4.3	7.1	27.4	0.0	9.4	23.5	46.9
AM15	12.3	10.5	10.8	10.6	4.3	7.1	27.2	0.0	9.3	23.1	46.3
AM18	13.4	10.8	10.9	10.8	4.3	7.1	27.8	0.0	16.1	40.2	80.5
AM19	13.1	10.7	10.7	10.8	4.3	7.1	27.8	0.0	16.0	40.1	80.1
AM24	13.0	10.9	11.6	10.8	4.3	7.1	27.8	0.0	13.1	32.8	65.5
AU04	13.5	10.2	9.8	0.2	4.3	7.1	0.4	0.0	11.0	27.4	54.8

ID	BC_{dep}[1]			N Terms			BC_{up}	ANC_{limit}			
	1995	2000	2001	Uptake	Immob.	Denitr.		0	20	50	100
AU05	15.3	11.1	10.4	0.3	4.3	7.1	0.8	0.0	11.0	27.4	54.8
AU07	13.8	10.6	10.1	0.2	4.3	7.1	0.4	0.0	9.4	23.5	46.9
AU08	13.9	10.8	10.4	10.9	4.3	7.1	27.7	0.0	9.2	23.1	46.1
AU09	13.5	11.0	10.6	10.8	4.3	7.1	27.8	0.0	11.2	28.1	56.2
AU10	11.8	10.0	10.0	10.6	4.3	7.1	26.7	0.0	8.4	21.0	42.0
AU13	12.2	10.4	10.8	10.8	4.3	7.1	27.8	0.0	12.9	32.3	64.6
AU14	12.6	10.6	10.9	0.0	4.3	7.1	0.0	0.0	9.9	24.7	49.4
AU16	13.9	11.3	11.5	0.0	4.3	7.1	0.0	0.0	9.8	24.5	49.0
AU17	13.7	11.3	11.4	0.0	4.3	7.1	0.0	0.0	10.2	25.6	51.2
AU19	13.3	11.1	11.4	10.7	4.3	7.1	27.6	0.0	16.4	40.9	81.8
AU20	12.3	10.9	11.5	10.8	4.3	7.1	27.8	0.0	16.2	40.5	80.9
AU29	12.2	10.6	11.0	1.9	4.3	7.1	4.9	0.0	9.9	24.7	49.3
AU30	14.7	11.5	11.1	5.3	4.3	7.1	13.4	0.0	8.2	20.4	40.8
AU31	14.4	11.3	10.9	5.5	4.3	7.1	14.1	0.0	8.2	20.4	40.8
AU32	14.1	11.3	11.0	5.9	4.3	7.1	15.2	0.0	7.7	19.2	38.4
AU33	11.9	10.1	10.2	10.9	4.3	7.1	27.7	0.0	7.6	19.0	38.1
AU34	13.0	10.6	10.6	10.8	4.3	7.1	27.8	0.0	8.7	21.9	43.7
AU35	12.0	10.6	10.9	7.4	4.3	7.1	19.0	0.0	11.0	27.6	55.1
BA01	14.8	13.9	13.9	10.8	4.3	7.1	27.8	0.0	8.1	20.4	40.7
BA02	15.2	13.9	13.7	10.8	4.3	7.1	27.8	0.0	8.4	21.0	42.1
BA09	14.3	12.3	11.9	10.8	4.3	7.1	27.7	0.0	8.5	21.1	42.3
BA11	14.2	12.4	12.2	10.5	4.3	7.1	27.0	0.0	6.9	17.4	34.7
BA12	14.5	12.3	11.9	10.8	4.3	7.1	27.7	0.0	9.0	22.5	45.0
BA14	15.5	13.1	12.4	10.8	4.3	7.1	27.8	0.0	8.0	20.0	40.1
BA16	14.7	13.0	12.5	10.7	4.3	7.1	27.5	0.0	8.2	20.5	40.9
BA17	15.6	13.5	12.8	10.2	4.3	7.1	26.1	0.0	8.2	20.5	40.9
BA21	16.1	13.8	13.3	5.6	4.3	7.1	14.3	0.0	10.4	26.0	52.1
BA22	15.2	13.7	13.5	10.8	4.3	7.1	27.7	0.0	9.2	23.1	46.1
BA25	13.3	13.0	13.5	10.8	4.3	7.1	27.8	0.0	8.0	19.9	39.8
BA26	13.6	12.6	12.8	10.7	4.3	7.1	27.4	0.0	8.1	20.3	40.5
BA27	13.2	13.4	14.1	10.8	4.3	7.1	27.8	0.0	7.4	18.4	36.8
BA28	14.5	14.5	15.0	10.8	4.3	7.1	27.8	0.0	6.6	16.5	32.9
BD01	15.0	14.6	14.9	10.8	4.3	7.1	27.8	0.0	9.2	22.9	45.8
BD02	14.3	14.7	14.8	10.8	4.3	7.1	27.7	0.0	8.3	20.7	41.3

ID	BC_{dep}[1]			N Terms			BC_{up}	ANC_{limit}			
	1995	2000	2001	Uptake	Immob.	Denitr.		0	20	50	100
BD04	15.9	15.4	14.9	10.7	4.3	7.1	27.5	0.0	9.1	22.8	45.7
BE01	13.5	11.8	11.6	10.8	4.3	7.1	27.8	0.0	16.7	41.7	83.4
BE02	13.4	11.6	11.5	10.8	4.3	7.1	27.8	0.0	17.7	44.2	88.3
BO01	15.1	13.8	13.4	10.8	4.3	7.1	27.7	0.0	6.2	15.4	30.8
BO04	14.7	14.1	13.9	10.8	4.3	7.1	27.8	0.0	6.0	15.0	30.0
BO07	13.5	12.2	11.5	10.8	4.3	7.1	27.8	0.0	9.4	23.6	47.2
BO08	13.5	11.6	11.5	9.6	4.3	7.1	24.9	0.0	13.0	32.6	65.2
BO11	12.8	11.4	11.5	10.8	4.3	7.1	27.8	0.0	11.3	28.1	56.3
BO12	13.4	11.7	11.6	10.8	4.3	7.1	27.7	0.0	14.0	35.0	70.1
BO13	12.5	11.4	11.5	10.8	4.3	7.1	27.8	0.0	14.2	35.5	70.9
CA01	15.5	14.6	14.5	10.8	4.3	7.1	27.8	0.0	14.0	34.9	69.9
CA02	15.6	14.6	14.6	10.6	4.3	7.1	27.2	0.0	13.6	34.1	68.2
CR02	16.5	14.9	15.3	3.8	4.3	7.1	9.4	0.0	6.9	17.3	34.6
CR03	16.9	15.3	15.6	2.4	4.3	7.1	5.7	0.0	7.8	19.5	39.0
CR05	15.1	14.2	14.4	3.8	4.3	7.1	9.8	0.0	7.7	19.2	38.5
CR08	14.5	14.1	13.7	7.4	4.3	7.1	19.1	0.0	10.1	25.2	50.5
CR09	14.8	14.4	13.8	9.5	4.3	7.1	24.6	0.0	11.1	27.7	55.4
CR10	15.0	14.4	13.9	0.3	4.3	7.1	0.9	0.0	9.5	23.7	47.3
CR11	14.8	14.4	14.1	6.9	4.3	7.1	17.8	0.0	8.6	21.4	42.8
CR12	16.0	14.2	14.0	10.8	4.3	7.1	27.8	0.0	9.3	23.2	46.5
CR13	16.1	14.5	14.5	8.6	4.3	7.1	22.2	0.0	7.9	19.7	39.3
CR14	16.7	15.1	15.4	1.3	4.3	7.1	3.2	0.0	6.9	17.4	34.7
DS06	23.2	16.6	16.0	4.6	4.3	7.1	8.7	0.0	16.7	41.7	83.3
FL01	17.0	15.4	15.9	10.5	4.3	7.1	27.0	0.0	13.3	33.2	66.4
FL02	16.4	14.9	15.6	10.3	4.3	7.1	26.7	0.0	18.6	46.4	92.8
FR01	17.0	14.9	15.4	9.7	4.3	7.1	25.0	0.0	8.3	20.7	41.3
FR02	16.7	14.8	15.3	10.8	4.3	7.1	27.8	0.0	8.3	20.7	41.3
FR03	16.8	14.8	15.2	10.8	4.3	7.1	27.7	0.0	8.8	22.0	44.0
GL02	17.6	15.6	15.6	1.3	4.3	7.1	3.3	0.0	9.2	22.9	45.8
GL03	16.6	15.3	15.7	3.3	4.3	7.1	8.5	0.0	10.9	27.2	54.4
GL06	16.4	15.5	15.6	10.8	4.3	7.1	27.4	0.0	11.9	29.6	59.3
GL08	15.9	15.3	15.2	9.9	4.3	7.1	25.6	0.0	10.8	26.9	53.8
GL10	16.3	15.8	15.6	2.9	4.3	7.1	7.3	0.0	9.8	24.4	48.8
GL12	16.3	16.0	16.5	10.8	4.3	7.1	27.8	0.0	9.7	24.2	48.4

ID	BC_{dep}[1] 1995	2000	2001	N Terms Uptake	Immob.	Denitr.	BC_{up}	ANC_{limit} 0	20	50	100
GL13	17.6	15.6	15.6	1.1	4.3	7.1	2.9	0.0	10.6	26.4	52.8
GL14	18.1	16.0	15.8	3.9	4.3	7.1	10.0	0.0	9.6	23.9	47.8
GL16	17.2	15.8	15.7	9.9	4.3	7.1	25.2	0.0	10.0	25.1	50.1
GL18	17.2	16.1	15.6	10.8	4.3	7.1	27.8	0.0	7.3	18.3	36.6
GL19	16.8	15.7	15.4	8.4	4.3	7.1	20.9	0.0	7.2	18.0	36.0
GL20	17.1	15.8	15.4	8.2	4.3	7.1	20.5	0.0	7.4	18.6	37.2
GL21	17.1	15.9	15.6	8.6	4.3	7.1	22.1	0.0	7.5	18.8	37.6
GL24	15.5	15.3	15.4	10.6	4.3	7.1	27.3	0.0	10.8	26.9	53.8
GR01	13.0	10.1	10.7	4.2	4.3	7.1	10.8	0.0	14.6	36.6	73.2
GR02	11.7	10.1	11.4	9.3	4.3	7.1	23.9	0.0	14.8	37.1	74.2
GR03	13.3	10.1	10.7	2.6	4.3	7.1	6.6	0.0	14.3	35.8	71.7
GR06	13.6	10.4	11.0	4.6	4.3	7.1	12.0	0.0	13.8	34.5	69.0
GR07	13.1	9.8	10.2	1.8	4.3	7.1	4.6	0.0	16.8	42.1	84.2
GR08	12.8	9.8	10.2	0.7	4.3	7.1	1.9	0.0	15.5	38.7	77.4
GR09	12.2	9.6	10.3	0.1	4.3	7.1	0.2	0.0	15.4	38.6	77.1
GY04	12.4	12.6	12.9	10.7	4.3	7.1	27.2	0.0	15.8	39.4	78.9
GY05	13.0	13.7	13.6	10.4	4.3	7.1	23.0	0.0	15.1	37.7	75.3
GY06	12.8	13.7	13.5	10.4	4.3	7.1	22.4	0.0	15.8	39.4	78.8
GY07	12.8	13.6	13.3	4.7	4.3	7.1	11.4	0.0	12.3	30.7	61.4
GY08	13.9	13.5	13.4	10.8	4.3	7.1	27.8	0.0	12.4	31.0	62.1
GY09	14.4	13.3	13.2	10.8	4.3	7.1	27.8	0.0	12.4	31.0	62.1
GY10	14.7	14.1	13.6	5.7	4.3	7.1	12.8	0.0	17.3	43.2	86.4
GY11	16.0	15.3	14.1	0.0	4.3	7.1	0.0	0.0	17.3	43.2	86.4
GY13	14.6	13.4	13.1	10.7	4.3	7.1	27.2	0.0	13.6	33.9	67.9
GY14	13.2	12.9	13.1	10.4	4.3	7.1	21.7	0.0	16.5	41.3	82.7
GY16	13.9	13.8	13.8	11.1	4.3	7.1	27.2	0.0	8.5	21.3	42.6
HI01	18.5	14.4	13.4	10.3	4.3	7.1	20.4	0.0	12.2	30.6	61.2
HI02	18.7	14.5	13.5	4.3	4.3	7.1	8.2	0.0	12.2	30.4	60.8
HI05	18.9	14.5	13.3	10.2	4.3	7.1	21.3	0.0	12.2	30.6	61.2
HI06	18.7	14.5	13.4	7.5	4.3	7.1	16.1	0.0	10.9	27.3	54.5
HI07	19.4	15.0	13.9	1.1	4.3	7.1	2.2	0.0	10.9	27.2	54.3
HI08	19.2	14.7	13.5	2.1	4.3	7.1	5.0	0.0	10.9	27.2	54.3
HI09	18.8	14.5	13.5	6.6	4.3	7.1	14.4	0.0	10.0	25.0	50.1
HI10	18.7	14.4	13.4	10.5	4.3	7.1	23.1	0.0	13.2	33.1	66.2

ID	BC_{dep}[1]			N Terms			BC_{up}	ANC_{limit}			
	1995	2000	2001	Uptake	Immob.	Denitr.		0	20	50	100
HI11	18.3	14.3	13.3	10.3	4.3	7.1	20.7	0.0	13.1	32.8	65.7
HI12	13.8	10.6	10.1	10.8	4.3	7.1	27.7	0.0	11.0	27.5	54.9
HI13	13.3	10.4	10.0	10.8	4.3	7.1	27.8	0.0	11.8	29.5	58.9
HI14	14.3	10.8	10.2	10.8	4.3	7.1	27.7	0.0	11.8	29.4	58.8
M002	13.1	13.9	14.0	10.4	4.3	7.1	26.7	0.0	15.7	39.2	78.3
M034	12.1	10.9	12.1	3.6	4.3	7.1	9.2	0.0	8.9	22.3	44.6
M036	14.1	11.5	11.4	0.0	4.3	7.1	0.0	0.0	14.3	35.8	71.6
MA04	13.2	10.7	11.2	0.0	4.3	7.1	0.0	0.0	11.8	29.6	59.2
MA05	12.2	10.3	11.2	0.0	4.3	7.1	0.0	0.0	12.8	32.1	64.1
MA06	13.8	10.5	11.1	0.0	4.3	7.1	0.0	0.0	12.8	32.1	64.1
MA07	14.3	10.9	11.4	0.0	4.3	7.1	0.0	0.0	12.1	30.3	60.7
MA10	11.6	10.2	11.2	0.0	4.3	7.1	0.0	0.0	13.7	34.2	68.5
MA12	14.0	10.4	10.9	0.0	4.3	7.1	0.0	0.0	15.7	39.2	78.3
MA13	13.9	10.4	10.9	0.4	4.3	7.1	1.0	0.0	15.3	38.2	76.4
MA14	12.3	10.1	11.0	8.8	4.3	7.1	22.6	0.0	13.2	33.0	65.9
MA18	10.4	10.0	11.6	10.8	4.3	7.1	27.7	0.0	10.6	26.6	53.2
MAD2	11.7	9.1	9.7	0.0	4.3	7.1	0.0	0.0	11.3	28.3	56.6
MAIA98-167	12.0	9.9	10.2	10.8	4.3	7.1	27.8	0.0	6.5	16.3	32.6
MNF101	22.2	15.8	14.5	10.1	4.3	7.1	19.0	0.0	14.4	36.0	71.9
MNF102	18.2	13.7	13.1	10.8	4.3	7.1	27.7	0.0	6.0	15.0	30.0
MNF103	19.4	16.7	16.2	10.5	4.3	7.1	23.2	0.0	14.6	36.4	72.8
MNF104	21.4	17.4	16.7	10.7	4.3	7.1	26.5	0.0	13.8	34.4	68.8
MNF105	20.6	15.1	14.2	10.2	4.3	7.1	19.3	0.0	14.7	36.7	73.4
MNF108	14.9	14.8	14.9	10.8	4.3	7.1	27.3	0.0	8.0	20.1	40.2
MNF109	18.1	17.8	16.9	0.0	4.3	7.1	0.0	0.0	19.2	48.0	96.1
MNF110	17.8	17.3	16.7	0.0	4.3	7.1	0.0	0.0	18.4	46.1	92.1
MNF111	18.0	17.7	16.9	10.2	4.3	7.1	19.1	0.0	17.8	44.5	89.1
MNF112	18.8	18.7	17.8	10.3	4.3	7.1	20.2	0.0	17.4	43.6	87.2
MNF113	17.3	17.8	17.2	10.7	4.3	7.1	26.1	0.0	16.4	41.0	82.1
MNF114	18.8	18.6	17.7	10.3	4.3	7.1	21.3	0.0	17.4	43.4	86.9
MNF115	18.6	18.7	17.6	10.5	4.3	7.1	24.2	0.0	17.4	43.4	86.9
MNF116	17.0	18.0	17.7	10.6	4.3	7.1	25.0	0.0	16.0	40.1	80.1
MNF117	16.8	17.7	17.2	10.7	4.3	7.1	27.1	0.0	15.4	38.6	77.1
MNF118	16.7	17.9	17.4	10.7	4.3	7.1	26.8	0.0	15.1	37.9	75.7

ID	BC_{dep}[1]			N Terms			BC_{up}	ANC_{limit}			
	1995	2000	2001	Uptake	Immob.	Denitr.		0	20	50	100
MNF119	16.2	18.1	18.0	10.6	4.3	7.1	25.4	0.0	14.9	37.2	74.4
MNF120	17.9	18.0	17.2	10.2	4.3	7.1	19.1	0.0	18.2	45.5	90.9
MNF121	16.3	18.0	17.7	10.4	4.3	7.1	26.3	0.0	14.6	36.5	73.0
MNF122	16.2	17.8	17.5	10.6	4.3	7.1	26.7	0.0	14.4	35.9	71.8
MNF123	16.3	18.0	17.8	10.7	4.3	7.1	27.1	0.0	14.8	37.1	74.2
MNF124	15.3	17.7	17.8	10.8	4.3	7.1	27.5	0.0	14.4	35.9	71.9
MNF125	15.4	18.3	18.6	10.6	4.3	7.1	25.4	0.0	14.5	36.2	72.4
MNF126	23.9	18.8	18.4	0.0	4.3	7.1	0.0	0.0	15.5	38.6	77.3
MNF13	17.9	16.8	16.5	9.5	4.3	7.1	17.7	0.0	15.8	39.5	79.0
MNF15	21.0	16.5	16.0	10.5	4.3	7.1	23.9	0.0	13.5	33.8	67.5
MNF16	20.1	17.9	17.0	10.0	4.3	7.1	18.8	0.0	19.6	49.0	98.1
MNF18	19.6	17.5	16.9	9.9	4.3	7.1	18.5	0.0	19.3	48.3	96.6
MNF19	20.8	17.7	16.7	10.0	4.3	7.1	18.7	0.0	19.7	49.1	98.3
MNF2	19.7	14.9	13.8	10.2	4.3	7.1	20.2	0.0	13.1	32.7	65.4
MNF20	21.0	18.0	17.3	9.9	4.3	7.1	18.3	0.0	18.5	46.4	92.7
MNF22	21.0	17.6	17.0	10.2	4.3	7.1	19.1	0.0	18.2	45.5	91.1
MNF24	23.5	17.7	16.7	10.2	4.3	7.1	19.1	0.0	18.1	45.4	90.7
MNF26	21.8	17.6	16.9	10.2	4.3	7.1	19.1	0.0	17.7	44.4	88.7
MNF29	21.3	16.5	15.9	10.1	4.3	7.1	19.8	0.0	12.7	31.7	63.4
MNF3	21.2	15.3	14.2	9.9	4.3	7.1	19.1	0.0	14.3	35.6	71.3
MNF30	20.9	17.1	16.6	10.7	4.3	7.1	26.7	0.0	13.6	34.1	68.1
MNF35	21.1	15.2	14.2	10.2	4.3	7.1	19.2	0.0	15.8	39.6	79.2
MNF37	21.4	16.4	15.4	3.1	4.3	7.1	5.9	0.0	16.1	40.3	80.5
MNF38	21.1	16.3	15.4	2.0	4.3	7.1	4.0	0.0	15.4	38.5	77.0
MNF40	21.2	16.9	16.2	10.0	4.3	7.1	19.0	0.0	15.2	38.1	76.2
MNF41	21.4	16.9	16.2	10.0	4.3	7.1	18.9	0.0	13.9	34.9	69.7
MNF42	19.5	16.6	16.5	10.2	4.3	7.1	20.1	0.0	14.0	35.0	70.1
MNF45	21.4	16.9	17.1	9.7	4.3	7.1	18.2	0.0	16.9	42.3	84.6
MNF5	24.2	17.1	16.0	10.2	4.3	7.1	19.9	0.0	9.4	23.6	47.2
MNF50	22.0	16.8	16.7	10.1	4.3	7.1	18.9	0.0	17.9	44.7	89.4
MNF51	22.4	16.0	15.1	0.2	4.3	7.1	0.4	0.0	17.9	44.6	89.3
MNF56	19.5	16.4	16.9	10.2	4.3	7.1	21.8	0.0	12.6	31.5	63.0
MNF57	19.3	16.7	17.1	10.5	4.3	7.1	23.4	0.0	12.8	31.9	63.9
MNF59	23.6	18.4	17.4	10.7	4.3	7.1	26.4	0.0	13.6	34.0	68.0

ID	BC_{dep}[1]			N Terms			BC_{up}	ANC_{limit}			
	1995	2000	2001	Uptake	Immob.	Denitr.		0	20	50	100
MNF6	20.7	16.3	15.8	10.5	4.3	7.1	24.7	0.0	6.0	15.0	30.0
MNF60	18.5	18.2	17.9	10.0	4.3	7.1	19.2	0.0	15.2	37.9	75.8
MNF62	20.1	19.0	18.7	10.2	4.3	7.1	19.1	0.0	15.2	38.1	76.2
MNF63	20.2	18.7	18.1	10.2	4.3	7.1	19.1	0.0	15.5	38.7	77.4
MNF64	17.5	17.6	17.6	9.9	4.3	7.1	19.8	0.0	15.6	39.1	78.2
MNF66	20.5	16.9	16.5	10.1	4.3	7.1	18.8	0.0	15.1	37.7	75.5
MNF67	19.8	16.1	15.5	10.2	4.3	7.1	19.9	0.0	15.1	37.7	75.4
MNF68	20.5	16.9	16.4	10.1	4.3	7.1	19.2	0.0	13.3	33.3	66.5
MNF69	20.2	15.6	14.7	9.3	4.3	7.1	18.0	0.0	14.8	37.0	73.9
MNF70	20.1	15.5	14.6	9.6	4.3	7.1	18.1	0.0	13.7	34.4	68.7
MNF71	18.1	14.7	14.1	10.1	4.3	7.1	19.7	0.0	13.3	33.2	66.5
MNF72	17.9	14.3	13.4	10.6	4.3	7.1	26.0	0.0	13.4	33.4	66.8
MNF73	19.2	16.2	15.7	10.0	4.3	7.1	20.0	0.0	10.2	25.6	51.1
MNF74	16.0	14.1	13.7	10.6	4.3	7.1	26.0	0.0	11.5	28.7	57.4
MNF75	14.8	14.6	14.4	10.8	4.3	7.1	27.5	0.0	9.1	22.9	45.7
MNF76	18.7	18.2	17.8	10.1	4.3	7.1	18.9	0.0	17.4	43.5	87.1
MNF77	17.4	17.5	17.4	10.1	4.3	7.1	19.4	0.0	16.8	42.0	84.0
MNF78	19.3	18.3	17.7	10.2	4.3	7.1	19.1	0.0	20.4	50.9	101.8
MNF8	18.1	14.1	13.3	9.0	4.3	7.1	21.4	0.0	6.0	15.0	30.0
MNF80	19.1	18.1	17.5	9.9	4.3	7.1	18.6	0.0	19.9	49.8	99.6
MNF81	18.0	17.6	17.0	0.0	4.3	7.1	0.0	0.0	18.3	45.9	91.7
MNF82	17.9	17.8	17.4	0.1	4.3	7.1	0.1	0.0	16.7	41.8	83.6
MNF83	17.1	17.9	17.7	9.8	4.3	7.1	18.5	0.0	16.7	41.8	83.6
MNF84	17.2	17.6	17.4	5.4	4.3	7.1	10.1	0.0	17.8	44.5	89.0
MNF85	18.3	17.7	17.2	0.2	4.3	7.1	0.4	0.0	20.3	50.7	101.3
MNF87	18.1	17.3	16.4	9.1	4.3	7.1	16.6	0.0	20.2	50.5	101.0
MNF88	17.6	17.9	17.3	7.3	4.3	7.1	14.9	0.0	15.1	37.7	75.4
MNF89	16.6	17.8	17.4	10.5	4.3	7.1	26.3	0.0	15.0	37.6	75.1
MNF91	17.4	17.7	17.1	10.2	4.3	7.1	19.2	0.0	18.7	46.7	93.4
MNF92	16.9	17.7	17.3	10.2	4.3	7.1	19.6	0.0	18.2	45.6	91.1
MNF93	17.8	17.8	16.8	10.2	4.3	7.1	19.1	0.0	18.6	46.6	93.2
MNF95	17.5	17.8	17.3	10.2	4.3	7.1	19.1	0.0	19.0	47.5	95.0
MNF98	18.0	18.2	17.3	10.6	4.3	7.1	24.6	0.0	16.7	41.7	83.4
MNF99	16.1	18.2	18.1	10.6	4.3	7.1	24.7	0.0	14.6	36.5	73.1

ID	BC_{dep}[1]			N Terms			BC_{up}	ANC_{limit}			
	1995	2000	2001	Uptake	Immob.	Denitr.		0	20	50	100
NE01	12.2	10.3	10.9	10.8	4.3	7.1	27.8	0.0	9.1	22.9	45.7
NE02	13.5	11.0	11.4	10.8	4.3	7.1	27.8	0.0	9.9	24.6	49.3
NE03	12.8	10.8	11.1	10.8	4.3	7.1	27.8	0.0	12.5	31.3	62.7
NE05	13.2	10.9	11.2	10.7	4.3	7.1	27.6	0.0	14.5	36.1	72.3
NE06	13.5	11.0	11.2	10.7	4.3	7.1	27.6	0.0	14.2	35.6	71.2
NE07	13.5	11.1	11.3	10.7	4.3	7.1	27.1	0.0	14.4	35.9	71.9
NE08	13.9	11.2	11.4	10.8	4.3	7.1	27.7	0.0	15.9	39.8	79.6
NE10	14.3	11.3	11.4	10.8	4.3	7.1	27.8	0.0	16.5	41.2	82.4
NE11	13.9	11.2	11.4	10.8	4.3	7.1	27.8	0.0	16.5	41.2	82.4
NE15	13.9	11.2	11.4	10.8	4.3	7.1	27.8	0.0	14.6	36.5	72.9
NE16	13.4	10.9	11.1	3.3	4.3	7.1	8.5	0.0	11.6	28.9	57.8
NE18	13.2	11.0	11.4	0.0	4.3	7.1	0.1	0.0	13.8	34.6	69.2
NE22	11.9	10.4	10.7	2.0	4.3	7.1	5.1	0.0	13.8	34.4	68.9
NE23	13.1	11.0	11.4	10.7	4.3	7.1	27.4	0.0	11.0	27.5	55.0
NE25	13.6	11.1	11.4	10.8	4.3	7.1	26.6	0.0	13.6	34.1	68.1
OC05	23.5	17.6	16.5	1.2	4.3	7.1	2.2	0.0	16.4	41.0	81.9
OC09	25.2	18.1	16.7	0.0	4.3	7.1	0.0	0.0	16.7	41.8	83.6
OC31	23.1	17.4	16.6	0.0	4.3	7.1	0.1	0.0	16.2	40.6	81.1
OC32	23.6	17.2	16.1	0.1	4.3	7.1	0.1	0.0	16.4	41.0	82.1
PG03	10.7	8.2	8.5	11.0	4.3	7.1	27.6	0.0	7.5	18.8	37.5
PG04	12.4	9.0	9.1	10.7	4.3	7.1	27.5	0.0	8.1	20.3	40.7
PG05	10.8	8.9	9.4	0.3	4.3	7.1	0.9	0.0	7.5	18.9	37.7
PG08	11.8	9.5	10.2	0.1	4.3	7.1	0.3	0.0	12.0	30.0	60.0
PG09	11.1	9.4	10.4	0.0	4.3	7.1	0.0	0.0	11.6	29.1	58.2
PT01	16.8	15.2	15.8	10.1	4.3	7.1	25.9	0.0	19.1	47.7	95.4
PT02	17.0	15.0	15.3	10.7	4.3	7.1	27.7	0.0	12.5	31.2	62.4
PT03	16.5	14.9	15.5	10.8	4.3	7.1	27.8	0.0	19.1	47.7	95.4
PT04	18.0	16.4	16.4	10.8	4.3	7.1	27.8	0.0	14.2	35.5	70.9
PT05	17.5	15.9	15.8	10.8	4.3	7.1	27.8	0.0	13.3	33.2	66.3
PT07	17.7	16.0	15.9	10.8	4.3	7.1	27.8	0.0	13.7	34.3	68.6
PT08	17.6	15.9	16.0	10.6	4.3	7.1	27.4	0.0	14.1	35.1	70.3
PT09	17.3	15.7	15.8	10.8	4.3	7.1	27.8	0.0	13.7	34.3	68.5
PT11	16.8	15.7	16.0	10.8	4.3	7.1	27.8	0.0	13.3	33.3	66.7
PT12	15.5	14.1	14.6	10.8	4.3	7.1	27.8	0.0	13.8	34.6	69.2

ID	BC_{dep}[1]			N Terms			BC_{up}	ANC_{limit}			
	1995	2000	2001	Uptake	Immob.	Denitr.		0	20	50	100
PU01	15.4	14.9	14.9	10.3	4.3	7.1	24.7	0.0	6.9	17.2	34.5
PU02	15.6	14.0	14.2	10.8	4.3	7.1	27.8	0.0	7.9	19.8	39.6
PU03	16.3	14.3	14.5	10.8	4.3	7.1	27.7	0.0	10.8	26.9	53.8
PU06	16.5	14.3	14.3	10.8	4.3	7.1	27.8	0.0	7.1	17.8	35.6
RA06	12.1	10.0	10.4	0.0	4.3	7.1	0.0	0.0	13.9	34.8	69.7
RA07	12.1	10.1	10.5	0.0	4.3	7.1	0.0	0.0	12.3	30.6	61.3
RA09	10.9	9.0	9.7	1.3	4.3	7.1	3.4	0.0	13.7	34.1	68.3
RA10	12.7	10.2	10.8	0.0	4.3	7.1	0.0	0.0	12.4	30.9	61.9
RA12	12.1	9.5	10.0	3.2	4.3	7.1	8.3	0.0	9.4	23.4	46.8
RB01	11.8	10.6	11.1	10.9	4.3	7.1	27.6	0.0	12.8	31.9	63.9
RB02	12.0	10.6	11.1	10.8	4.3	7.1	27.7	0.0	11.8	29.6	59.2
RB03	12.3	10.8	11.2	11.2	4.3	7.1	27.2	0.0	10.9	27.4	54.7
RB04	12.4	10.7	11.0	10.9	4.3	7.1	27.7	0.0	11.5	28.9	57.7
RB05	11.9	10.4	10.5	10.8	4.3	7.1	27.8	0.0	8.2	20.4	40.8
RB07	12.2	11.1	11.0	10.8	4.3	7.1	27.8	0.0	9.9	24.8	49.6
RB08	12.6	11.1	11.1	10.9	4.3	7.1	27.6	0.0	10.6	26.5	53.0
RB09	13.3	11.5	11.3	11.0	4.3	7.1	27.6	0.0	10.7	26.7	53.4
RB11	14.3	12.2	12.2	10.8	4.3	7.1	27.7	0.0	10.9	27.3	54.6
RB12	12.7	11.3	11.7	10.9	4.3	7.1	27.7	0.0	10.2	25.5	50.9
RB13	11.7	10.3	10.5	10.8	4.3	7.1	27.8	0.0	9.9	24.7	49.4
RB14	11.6	10.2	10.5	10.8	4.3	7.1	27.8	0.0	9.8	24.5	49.0
RB15	11.3	10.2	10.7	10.8	4.3	7.1	27.8	0.0	6.2	15.4	30.8
RB16	11.1	10.2	10.8	10.8	4.3	7.1	27.8	0.0	6.2	15.4	30.8
RB18	11.4	10.2	10.6	10.8	4.3	7.1	27.7	0.0	8.3	20.8	41.6
RB19	13.3	11.2	11.2	0.0	4.3	7.1	0.0	0.0	13.0	32.4	64.8
RB26	11.7	10.6	11.1	10.9	4.3	7.1	27.7	0.0	9.6	24.0	48.0
RB28	11.5	10.3	10.6	10.9	4.3	7.1	27.7	0.0	8.8	22.1	44.2
RB29	13.0	11.4	10.8	0.6	4.3	7.1	1.4	0.0	10.1	25.2	50.3
RB30	13.5	11.7	11.4	7.8	4.3	7.1	20.0	0.0	9.5	23.8	47.7
RH02	16.2	12.0	11.5	2.2	4.3	7.1	5.6	0.0	9.3	23.2	46.4
RH03	15.8	11.8	11.4	5.1	4.3	7.1	13.2	0.0	7.7	19.2	38.4
RH06	12.2	10.4	10.6	10.8	4.3	7.1	27.8	0.0	6.0	15.0	30.0
RH07	12.3	10.1	10.4	10.8	4.3	7.1	27.8	0.0	6.0	15.1	30.1
RH08	10.1	9.0	9.8	10.8	4.3	7.1	27.8	0.0	6.7	16.7	33.5

ID	BC_{dep}[1]			N Terms			BC_{up}	ANC_{limit}			
	1995	2000	2001	Uptake	Immob.	Denitr.		0	20	50	100
RH09	10.2	9.1	9.8	10.8	4.3	7.1	27.8	0.0	6.7	16.7	33.3
RH12	14.5	10.5	10.3	0.1	4.3	7.1	0.2	0.0	9.7	24.2	48.4
RH13	16.1	11.5	11.1	0.0	4.3	7.1	0.1	0.0	9.7	24.3	48.6
RH14	14.8	11.1	10.9	1.0	4.3	7.1	2.5	0.0	9.3	23.3	46.6
RH15	12.4	9.9	9.5	8.3	4.3	7.1	21.3	0.0	6.3	15.9	31.7
RH16	14.6	11.4	11.1	5.3	4.3	7.1	13.5	0.0	8.8	21.9	43.9
RH17	14.1	11.2	10.9	6.3	4.3	7.1	16.4	0.0	8.3	20.7	41.4
RH18	14.3	11.4	11.2	5.7	4.3	7.1	14.6	0.0	8.1	20.4	40.7
RH20	15.1	11.3	11.1	0.0	4.3	7.1	0.1	0.0	9.9	24.7	49.4
RH21	14.3	11.2	11.0	2.0	4.3	7.1	5.1	0.0	9.9	24.8	49.5
RH22	14.0	11.0	10.8	2.2	4.3	7.1	5.5	0.0	9.9	24.7	49.4
RH23	13.5	10.7	10.5	5.8	4.3	7.1	14.9	0.0	7.7	19.3	38.5
RH24	12.6	10.1	10.0	7.0	4.3	7.1	18.2	0.0	7.4	18.5	36.9
RH25	13.4	10.7	10.4	6.6	4.3	7.1	17.0	0.0	7.9	19.7	39.4
RH26	13.9	10.8	10.5	6.3	4.3	7.1	16.2	0.0	7.9	19.9	39.7
RH27	11.6	9.3	9.3	8.4	4.3	7.1	21.6	0.0	6.9	17.2	34.4
RH28	13.9	10.7	10.6	6.5	4.3	7.1	16.8	0.0	7.4	18.5	36.9
RH30	14.0	10.9	10.5	6.8	4.3	7.1	17.6	0.0	8.2	20.4	40.9
RH33	12.1	10.2	10.2	9.4	4.3	7.1	24.3	0.0	6.4	16.1	32.1
RH34	11.9	10.2	10.2	10.1	4.3	7.1	26.0	0.0	6.1	15.2	30.5
RH36	13.4	10.8	10.6	6.5	4.3	7.1	16.6	0.0	8.2	20.4	40.8
RH40	12.7	8.8	8.6	10.8	4.3	7.1	27.8	0.0	9.1	22.6	45.3
RH42	11.4	9.1	9.9	0.1	4.3	7.1	0.3	0.0	10.4	26.0	52.0
RH49	12.4	9.6	10.1	0.0	4.3	7.1	0.0	0.0	10.1	25.2	50.5
RH50	11.7	9.2	9.8	0.0	4.3	7.1	0.0	0.0	10.4	26.1	52.2
RH51	11.3	8.9	9.4	0.0	4.3	7.1	0.0	0.0	7.5	18.7	37.4
RN01	15.8	14.6	14.5	10.8	4.3	7.1	26.5	0.0	12.3	30.8	61.6
SC01	19.1	18.4	17.6	10.6	4.3	7.1	27.4	0.0	19.6	49.0	98.1
SC02	18.1	17.7	17.2	10.3	4.3	7.1	26.6	0.0	19.6	49.0	98.1
SC04	20.5	19.9	18.1	10.7	4.3	7.1	27.7	0.0	12.9	32.3	64.7
SC05	20.6	20.1	18.2	8.7	4.3	7.1	22.4	0.0	13.1	32.8	65.6
SC08	19.9	19.8	17.6	10.6	4.3	7.1	27.4	0.0	17.7	44.3	88.6
SH02	10.4	9.7	10.4	10.8	4.3	7.1	27.8	0.0	6.2	15.5	30.9
SH03	12.1	10.3	10.9	10.8	4.3	7.1	27.8	0.0	6.0	15.0	30.0

ID	BC_{dep} [1] 1995	BC_{dep} [1] 2000	BC_{dep} [1] 2001	N Terms Uptake	N Terms Immob.	N Terms Denitr.	BC_{up}	ANC_{limit} 0	ANC_{limit} 20	ANC_{limit} 50	ANC_{limit} 100
SH04	12.0	10.5	11.1	10.8	4.3	7.1	27.8	0.0	8.6	21.6	43.2
SH06	11.6	9.4	9.7	10.8	4.3	7.1	27.8	0.0	6.0	15.0	30.0
SY01	12.9	12.8	13.0	10.8	4.3	7.1	27.8	0.0	10.7	26.8	53.7
SY02	12.9	12.9	13.0	10.8	4.3	7.1	27.8	0.0	11.5	28.7	57.4
SY03	13.9	13.4	13.4	10.8	4.3	7.1	27.8	0.0	12.5	31.3	62.6
SY04	13.7	13.4	13.3	10.8	4.3	7.1	27.8	0.0	12.0	30.0	60.1
SY05	13.3	13.5	13.6	10.8	4.3	7.1	27.8	0.0	11.6	28.9	57.9
SY06	13.3	13.5	13.5	10.9	4.3	7.1	27.7	0.0	12.0	30.0	59.9
SY07	13.8	13.4	13.4	10.8	4.3	7.1	27.8	0.0	12.5	31.2	62.4
SY08	14.2	13.4	13.3	10.8	4.3	7.1	27.6	0.0	12.4	31.1	62.2
SY09	13.1	13.4	13.4	10.7	4.3	7.1	26.6	0.0	12.2	30.6	61.2
SY10	12.8	13.5	13.4	10.7	4.3	7.1	27.3	0.0	9.2	23.0	46.0
SY11	12.7	13.2	13.3	10.7	4.3	7.1	27.2	0.0	10.1	25.3	50.6
SY13	14.8	13.9	13.6	10.8	4.3	7.1	27.8	0.0	11.5	28.7	57.4
SY14	12.5	12.4	13.0	10.7	4.3	7.1	27.0	0.0	12.0	30.1	60.2
SY15	12.1	12.5	13.0	10.8	4.3	7.1	27.8	0.0	12.0	30.1	60.2
SY16	12.0	12.6	13.1	10.8	4.3	7.1	27.8	0.0	11.1	27.7	55.4
SY17	11.9	12.7	13.2	10.8	4.3	7.1	27.8	0.0	11.3	28.4	56.7
SY18	12.3	12.5	13.0	10.4	4.3	7.1	23.6	0.0	13.9	34.7	69.5
SY19	12.5	12.4	12.9	10.5	4.3	7.1	23.3	0.0	14.0	34.9	69.8
SY20	13.0	12.5	13.0	10.2	4.3	7.1	25.4	0.0	13.4	33.4	66.8
SY22	14.4	13.3	13.5	10.7	4.3	7.1	26.6	0.0	14.3	35.8	71.7
SY23	14.5	13.7	13.7	0.0	4.3	7.1	0.0	0.0	16.2	40.5	81.0
SY25	12.7	13.0	13.1	10.8	4.3	7.1	27.8	0.0	13.4	33.6	67.1
SY27	13.3	13.5	13.5	10.8	4.3	7.1	27.8	0.0	12.4	30.9	61.8
TA01	14.7	14.2	13.9	10.8	4.3	7.1	27.6	0.0	13.7	34.4	68.7
TA06	16.2	15.3	14.6	10.5	4.3	7.1	27.2	0.0	8.8	22.0	43.9
TA07	14.1	14.4	14.3	10.8	4.3	7.1	27.8	0.0	9.7	24.3	48.5
TA13	16.2	15.0	14.4	4.5	4.3	7.1	11.7	0.0	10.2	25.4	50.9
VA538S	14.2	10.9	10.5	4.4	4.3	7.1	11.2	0.0	8.4	21.0	41.9
VA546S	9.8	9.0	9.8	10.8	4.3	7.1	27.7	0.0	6.0	15.0	30.0
VA550S	16.1	14.3	14.3	10.8	4.3	7.1	27.8	0.0	7.1	17.9	35.7
VA567S	13.7	13.5	13.5	10.8	4.3	7.1	27.8	0.0	8.3	20.9	41.7
VA756S	13.6	11.2	10.9	11.1	4.3	7.1	27.5	0.0	8.1	20.3	40.7

ID	BC_{dep}[1]			N Terms			BC_{up}	ANC_{limit}			
	1995	2000	2001	Uptake	Immob.	Denitr.		0	20	50	100
VA769S	15.2	15.1	15.2	0.4	4.3	7.1	1.0	0.0	7.3	18.2	36.3
VA772S	12.7	10.8	10.6	11.6	4.3	7.1	27.1	0.0	8.5	21.1	42.3
VA774S	11.7	10.1	11.0	10.8	4.3	7.1	27.8	0.0	6.0	15.0	30.0
VA788S	16.4	15.2	15.6	8.0	4.3	7.1	20.6	0.0	7.1	17.9	35.7
VA789S	16.5	14.8	14.9	1.9	4.3	7.1	4.8	0.0	7.0	17.5	35.1
VA793S	12.4	10.3	10.6	10.8	4.3	7.1	27.8	0.0	19.7	49.3	98.6
VA794S	11.9	10.5	10.7	10.8	4.3	7.1	27.8	0.0	9.9	24.8	49.6
VA822S	13.2	13.3	13.4	10.3	4.3	7.1	24.5	0.0	14.1	35.3	70.6
VT01	15.2	13.3	13.5	2.4	4.3	7.1	6.1	0.0	19.3	48.2	96.4
VT03	13.2	12.8	13.0	8.8	4.3	7.1	20.2	0.0	15.7	39.3	78.7
VT04	14.6	14.2	13.5	3.1	4.3	7.1	7.9	0.0	17.3	43.1	86.3
VT13	14.2	12.1	11.8	10.8	4.3	7.1	27.8	0.0	7.9	19.8	39.6
VT16	12.4	11.3	10.6	0.2	4.3	7.1	0.4	0.0	8.1	20.2	40.4
VT17	12.6	11.7	11.6	11.2	4.3	7.1	27.5	0.0	7.0	17.5	35.0
VT22	13.4	11.7	11.7	10.8	4.3	7.1	27.8	0.0	12.9	32.3	64.7
VT23	12.5	11.4	11.4	10.8	4.3	7.1	27.8	0.0	14.1	35.3	70.7
VT29	17.6	15.5	15.3	0.2	4.3	7.1	0.6	0.0	9.2	22.9	45.8
VT40	13.6	11.1	11.3	0.3	4.3	7.1	0.9	0.0	15.9	39.7	79.4
VT42	13.5	11.4	11.5	10.1	4.3	7.1	26.2	0.0	17.3	43.3	86.5
VT43	13.8	11.1	11.2	10.8	4.3	7.1	27.8	0.0	18.4	46.0	92.0
VT44	13.6	10.9	11.4	10.8	4.3	7.1	27.8	0.0	15.2	37.9	75.8
VT45	12.5	10.6	10.7	10.8	4.3	7.1	27.8	0.0	9.7	24.2	48.5
VT51	11.4	9.4	10.2	0.0	4.3	7.1	0.0	0.0	6.6	16.4	32.9
VT52	10.8	8.1	8.2	11.1	4.3	7.1	27.5	0.0	9.3	23.2	46.4
VT60	12.6	10.0	10.7	0.2	4.3	7.1	0.4	0.0	12.1	30.2	60.4
VT61	12.0	9.8	10.6	0.1	4.3	7.1	0.3	0.0	12.0	30.0	60.0
VT63	13.2	11.0	11.3	8.4	4.3	7.1	21.7	0.0	14.9	37.1	74.3
VT64	13.0	11.0	11.7	10.1	4.3	7.1	26.0	0.0	13.2	32.9	65.8
VT65	13.0	11.2	12.1	10.8	4.3	7.1	27.8	0.0	13.3	33.2	66.3
VT68	14.0	11.3	11.3	0.0	4.3	7.1	0.0	0.0	14.5	36.3	72.6
VT69	13.1	11.0	11.3	0.0	4.3	7.1	0.0	0.0	14.5	36.2	72.4
VT71	13.1	11.1	11.6	0.3	4.3	7.1	0.7	0.0	13.6	34.1	68.1
VT76	11.9	10.7	11.1	1.7	4.3	7.1	4.3	0.0	10.5	26.3	52.6
WA01	12.4	12.6	13.1	10.8	4.3	7.1	27.8	0.0	11.2	28.0	56.0

ID	BC_{dep}[1] 1995	2000	2001	N Terms Uptake	Immob.	Denitr.	BC_{up}	ANC_{limit} 0	20	50	100
WA02	12.6	12.6	13.1	10.8	4.3	7.1	27.8	0.0	11.2	27.9	55.8
WA04	12.2	12.7	12.9	11.0	4.3	7.1	27.6	0.0	9.3	23.3	46.5
WE01	20.0	17.7	17.4	10.1	4.3	7.1	26.1	0.0	21.3	53.2	106.4
WE02	19.6	17.6	17.2	10.0	4.3	7.1	25.9	0.0	22.0	55.0	110.0
WE03	17.6	17.8	16.9	10.1	4.3	7.1	25.9	0.0	14.2	35.4	70.8
WN01	10.8	9.1	9.9	0.0	4.3	7.1	0.0	0.0	6.0	15.0	30.0
WV525S	12.1	10.3	11.4	10.8	4.3	7.1	27.8	0.0	6.0	15.0	30.0
WV543S	19.8	15.2	14.2	10.2	4.3	7.1	19.6	0.0	14.8	36.9	73.8
WV545S	15.0	16.9	16.9	10.6	4.3	7.1	27.2	0.0	10.1	25.3	50.6
WY01	14.8	13.8	13.7	10.8	4.3	7.1	27.7	0.0	8.2	20.4	40.8
WY02	13.3	13.5	13.4	10.7	4.3	7.1	27.6	0.0	7.8	19.6	39.2
WY03	14.0	13.5	13.2	9.0	4.3	7.1	23.2	0.0	8.9	22.2	44.5
WY04	14.1	13.1	13.0	10.8	4.3	7.1	27.8	0.0	8.9	22.4	44.7
WY05	13.5	13.4	13.3	5.4	4.3	7.1	14.0	0.0	7.9	19.8	39.5

[1] Data are given in this table for all SSWC model input parameters except BC_w. There are multiple estimates of BC_w for each site, and these are given in Table F-3.

[2] BC_{dep} is given for three years, 1995 (earliest year for which data were available), 2000, and 2001.

Table F-3. Estimates of BC_w ($meq/m^2/yr$) for study streams.

ID	MAGIC Estimate Of BC_w[1]	BC_w Estimated from Regression Relationship	
		With Water Chemistry	Without Water Chemistry
2B047032	136	99	91
2C041039	137	151	139
2C041040	159	141	128
2C041045	231	189	138
2C041051	39	62	58
2C046033	55	82	115
2C046034	70	84	75
2C046043L	214	180	107
2C046043U	177	164	103
2C046050	249	272	184
2C047007	172	161	129
2C047010L	68	71	89
2C047010U	69	72	87
2C057004	117	93	135
AU28	25	33	30
BLFC	34	36	39
BO02	104	108	74
DR	34	29	38
DS04	23	19	46
DS09	21	14	20
DS19	27	29	12
DS50	12	8	1
FN1	139	122	127
FN2	126	101	131
FN3	112	107	126
LEWF	77	75	71
M037	52	46	41
M038	49	46	39
M039	31	42	39
NFD	99	91	81
OC02	38	40	59
OC08	15	16	84
OC35	54	34	49
OC79	69	60	56
PAIN	47	33	43
RA05	98	95	92
RH53	36	38	45
STAN	74	83	90

ID	MAGIC Estimate Of BC_w[1]	BC_w Estimated from Regression Relationship	
		With Water Chemistry	Without Water Chemistry
VA524S	30	69	37
VA526S	150	130	117
VA531S	78	81	94
VA548S	63	115	131
VA555S	58	64	55
VA821S	129	163	100
VT05	86	75	58
VT07	49	37	18
VT08	58	50	29
VT09	38	46	41
VT10	44	47	39
VT11	46	43	46
VT12	94	87	50
VT15	41	47	64
VT18	56	80	59
VT19	56	78	84
VT24	31	54	58
VT25	38	44	39
VT26	28	50	51
VT28	37	39	33
VT31	27	42	32
VT32	63	66	28
VT34	72	65	70
VT36	36	28	34
VT37	32	47	76
VT38	65	82	90
VT46	113	81	90
VT48	70	62	72
VT49	80	84	87
VT50	45	76	66
VT54	58	97	103
VT55	98	126	124
VT56	31	46	65
VT57	47	75	94
VT58	74	87	96
VT66	129	137	127
VT70	24	38	46
VT72	19	26	17
VT73	44	41	38
VT74	21	30	30

ID	MAGIC Estimate Of BC_w[1]	BC_w Estimated from Regression Relationship: With Water Chemistry	Without Water Chemistry
VT75	127	133	128
VT77	43	59	53
VT78	44	25	28
WOR	65	61	55
WV523S	55	46	55
WV531S	29	86	106
WV547S	281	275	293
WV548S	82	82	100
WV769S	122	124	81
WV770S	178	158	132
WV771S	210	173	210
WV785S	61	68	104
WV788S	75	58	101
WV796S	44	50	19
2A068015U	NA	58	51
2B041020L	NA	296	189
2B041032U	NA	922	171
2B041049U	NA	96	81
2B047044U	NA	106	77
2B047076U	NA	39	10
2B058015U	NA	35	60
2C040006U	NA	247	210
2C041033U	NA	158	172
2C041043U	NA	183	78
2C046013L	NA	184	198
2C046041	NA	330	148
2C046048U	NA	342	193
2C046053L	NA	147	96
2C046062L	NA	237	29
AB01	NA	115	110
AB02	NA	43	67
AB04	NA	43	122
AB05	NA	63	69
AB06	NA	136	134
AB07	NA	147	118
AB08	NA	138	119
AB09	NA	80	85
AG03	NA	73	52
AG04	NA	89	59
AG05	NA	81	69

ID	MAGIC Estimate Of BC_w[1]	BC_w Estimated from Regression Relationship	
		With Water Chemistry	Without Water Chemistry
AG06	NA	143	76
AG07	NA	123	123
AG10	NA	86	101
AM02	NA	207	92
AM03	NA	164	90
AM05	NA	69	89
AM06	NA	78	89
AM10	NA	158	93
AM11	NA	132	91
AM12	NA	101	90
AM13	NA	152	82
AM15	NA	159	81
AM18	NA	64	91
AM19	NA	77	90
AM24	NA	87	88
AU04	NA	72	83
AU05	NA	30	22
AU07	NA	76	92
AU08	NA	106	111
AU09	NA	79	115
AU10	NA	101	129
AU13	NA	146	126
AU14	NA	32	17
AU16	NA	19	18
AU17	NA	23	17
AU19	NA	58	73
AU20	NA	127	134
AU29	NA	55	40
AU30	NA	74	111
AU31	NA	74	113
AU32	NA	77	110
AU33	NA	136	133
AU34	NA	199	114
AU35	NA	30	25
BA01	NA	120	122
BA02	NA	130	120
BA09	NA	23	44
BA11	NA	233	53
BA12	NA	100	46
BA14	NA	46	57

ID	MAGIC Estimate Of BC_w[1]	BC_w Estimated from Regression Relationship With Water Chemistry	Without Water Chemistry
BA16	NA	72	61
BA17	NA	98	65
BA21	NA	96	94
BA22	NA	121	112
BA25	NA	279	57
BA26	NA	249	49
BA27	NA	125	126
BA28	NA	176	116
BD01	NA	32	41
BD02	NA	38	23
BD04	NA	75	88
BE01	NA	110	72
BE02	NA	66	72
BO01	NA	475	83
BO04	NA	63	82
BO07	NA	120	78
BO08	NA	92	72
BO11	NA	126	71
BO12	NA	89	71
BO13	NA	103	72
CA01	NA	72	42
CA02	NA	98	41
CR02	NA	81	98
CR03	NA	62	74
CR05	NA	207	93
CR08	NA	118	69
CR09	NA	62	66
CR10	NA	90	80
CR11	NA	98	79
CR12	NA	52	62
CR13	NA	40	1032
CR14	NA	48	73
DS06	NA	10	28
FL01	NA	198	95
FL02	NA	101	88
FR01	NA	316	85
FR02	NA	350	102
FR03	NA	366	94
GL02	NA	59	32
GL03	NA	93	83

ID	MAGIC Estimate Of BC_w[1]	BC_w Estimated from Regression Relationship: With Water Chemistry	BC_w Estimated from Regression Relationship: Without Water Chemistry
GL06	NA	58	43
GL08	NA	41	33
GL10	NA	44	44
GL12	NA	53	44
GL13	NA	25	21
GL14	NA	37	33
GL16	NA	101	38
GL18	NA	47	81
GL19	NA	125	65
GL20	NA	119	55
GL21	NA	72	68
GL24	NA	34	29
GR01	NA	87	98
GR02	NA	66	90
GR03	NA	71	95
GR06	NA	121	110
GR07	NA	155	134
GR08	NA	112	114
GR09	NA	152	127
GY04	NA	67	39
GY05	NA	53	71
GY06	NA	58	71
GY07	NA	69	71
GY08	NA	87	51
GY09	NA	104	88
GY10	NA	52	70
GY11	NA	60	67
GY13	NA	67	66
GY14	NA	60	62
GY16	NA	127	54
HI01	NA	68	87
HI02	NA	76	74
HI05	NA	98	83
HI06	NA	81	83
HI07	NA	76	61
HI08	NA	66	88
HI09	NA	83	83
HI10	NA	63	83
HI11	NA	65	84
HI12	NA	87	99

ID	MAGIC Estimate Of BC_w[1]	BC_w Estimated from Regression Relationship With Water Chemistry	Without Water Chemistry
HI13	NA	80	95
HI14	NA	89	99
M002	NA	41	14
M034	NA	56	53
M036	NA	59	40
MA04	NA	58	96
MA05	NA	88	92
MA06	NA	93	96
MA07	NA	117	133
MA10	NA	66	90
MA12	NA	119	132
MA13	NA	82	109
MA14	NA	84	89
MA18	NA	130	87
MAD2	NA	89	81
MAIA98-167	NA	102	66
MNF101	NA	119	593
MNF102	NA	450	1438
MNF103	NA	407	681
MNF104	NA	99	141
MNF105	NA	118	85
MNF108	NA	158	565
MNF109	NA	12	82
MNF110	NA	53	31
MNF111	NA	12	83
MNF112	NA	73	93
MNF113	NA	68	116
MNF114	NA	33	89
MNF115	NA	57	98
MNF116	NA	68	99
MNF117	NA	72	140
MNF118	NA	66	151
MNF119	NA	124	148
MNF120	NA	23	83
MNF121	NA	83	148
MNF122	NA	60	150
MNF123	NA	65	139
MNF124	NA	67	165
MNF125	NA	43	167
MNF126	NA	54	96

ID	MAGIC Estimate Of BC_w[1]	BC_w Estimated from Regression Relationship With Water Chemistry	Without Water Chemistry
MNF13	NA	968	1
MNF15	NA	203	602
MNF16	NA	292	1
MNF18	NA	106	13
MNF19	NA	141	1
MNF2	NA	58	88
MNF20	NA	76	25
MNF22	NA	63	1
MNF24	NA	54	1
MNF26	NA	117	1
MNF29	NA	315	53
MNF3	NA	113	734
MNF30	NA	95	142
MNF35	NA	79	82
MNF37	NA	80	90
MNF38	NA	269	497
MNF40	NA	80	101
MNF41	NA	131	361
MNF42	NA	94	115
MNF45	NA	1	64
MNF5	NA	171	59
MNF50	NA	15	18
MNF51	NA	9	33
MNF56	NA	182	475
MNF57	NA	146	141
MNF59	NA	168	592
MNF6	NA	295	1006
MNF60	NA	171	1
MNF62	NA	169	1
MNF63	NA	112	1
MNF64	NA	561	87
MNF66	NA	74	100
MNF67	NA	63	90
MNF68	NA	126	346
MNF69	NA	119	279
MNF70	NA	96	236
MNF71	NA	78	94
MNF72	NA	71	74
MNF73	NA	145	259
MNF74	NA	119	100

ID	MAGIC Estimate Of BC_w[1]	BC_w Estimated from Regression Relationship	
		With Water Chemistry	Without Water Chemistry
MNF75	NA	153	1463
MNF76	NA	202	1
MNF77	NA	199	1
MNF78	NA	23	15
MNF8	NA	554	796
MNF80	NA	81	28
MNF81	NA	49	87
MNF82	NA	91	131
MNF83	NA	20	101
MNF84	NA	162	3
MNF85	NA	58	52
MNF87	NA	29	35
MNF88	NA	225	284
MNF89	NA	38	124
MNF91	NA	134	68
MNF92	NA	99	73
MNF93	NA	25	70
MNF95	NA	10	65
MNF98	NA	48	95
MNF99	NA	48	131
NE01	NA	188	135
NE02	NA	106	126
NE03	NA	134	122
NE05	NA	65	103
NE06	NA	78	89
NE07	NA	105	93
NE08	NA	61	88
NE10	NA	63	87
NE11	NA	73	85
NE15	NA	82	89
NE16	NA	68	90
NE18	NA	70	91
NE22	NA	82	93
NE23	NA	112	96
NE25	NA	115	87
OC05	NA	1	69
OC09	NA	1	51
OC31	NA	1	52
OC32	NA	5	46
PG03	NA	339	81

ID	MAGIC Estimate Of BC_w[1]	BC_w Estimated from Regression Relationship With Water Chemistry	Without Water Chemistry
PG04	NA	120	91
PG05	NA	54	79
PG08	NA	139	122
PG09	NA	130	114
PT01	NA	165	66
PT02	NA	341	67
PT03	NA	167	101
PT04	NA	224	61
PT05	NA	196	93
PT07	NA	173	73
PT08	NA	217	71
PT09	NA	362	65
PT11	NA	129	75
PT12	NA	72	110
PU01	NA	94	72
PU02	NA	71	69
PU03	NA	49	73
PU06	NA	66	70
RA06	NA	83	93
RA07	NA	73	95
RA09	NA	160	133
RA10	NA	131	94
RA12	NA	218	108
RB01	NA	141	94
RB02	NA	74	96
RB03	NA	162	94
RB04	NA	96	72
RB05	NA	62	122
RB07	NA	122	66
RB08	NA	37	71
RB09	NA	128	81
RB11	NA	169	2388
RB12	NA	182	87
RB13	NA	86	65
RB14	NA	68	66
RB15	NA	95	63
RB16	NA	93	67
RB18	NA	150	77
RB19	NA	69	43
RB26	NA	222	73

ID	MAGIC Estimate Of BC_w[1]	BC_w Estimated from Regression Relationship	
		With Water Chemistry	Without Water Chemistry
RB28	NA	42	59
RB29	NA	99	114
RB30	NA	320	87
RH02	NA	103	105
RH03	NA	131	113
RH06	NA	145	142
RH07	NA	138	138
RH08	NA	325	97
RH09	NA	416	109
RH12	NA	58	55
RH13	NA	66	55
RH14	NA	56	72
RH15	NA	87	117
RH16	NA	78	111
RH17	NA	103	116
RH18	NA	99	111
RH20	NA	51	65
RH21	NA	72	76
RH22	NA	60	99
RH23	NA	75	110
RH24	NA	80	106
RH25	NA	64	107
RH26	NA	66	88
RH27	NA	62	51
RH28	NA	80	118
RH30	NA	79	110
RH33	NA	61	57
RH34	NA	72	63
RH36	NA	78	106
RH40	NA	199	97
RH42	NA	151	133
RH49	NA	81	81
RH50	NA	40	58
RH51	NA	27	12
RN01	NA	41	56
SC01	NA	86	59
SC02	NA	104	57
SC04	NA	32	84
SC05	NA	60	71
SC08	NA	307	46

ID	MAGIC Estimate Of BC_w[1]	BC_w Estimated from Regression Relationship With Water Chemistry	Without Water Chemistry
SH02	NA	423	81
SH03	NA	92	76
SH04	NA	105	75
SH06	NA	86	70
SY01	NA	526	61
SY02	NA	408	62
SY03	NA	90	53
SY04	NA	71	53
SY05	NA	58	56
SY06	NA	58	52
SY07	NA	99	47
SY08	NA	63	54
SY09	NA	67	53
SY10	NA	86	50
SY11	NA	78	59
SY13	NA	51	63
SY14	NA	53	54
SY15	NA	33	54
SY16	NA	41	54
SY17	NA	67	50
SY18	NA	67	44
SY19	NA	59	54
SY20	NA	85	54
SY22	NA	65	73
SY23	NA	86	77
SY25	NA	67	62
SY27	NA	55	57
TA01	NA	68	54
TA06	NA	59	83
TA07	NA	34	29
TA13	NA	31	59
VA538S	NA	82	86
VA546S	NA	210	99
VA550S	NA	90	80
VA567S	NA	74	53
VA756S	NA	142	134
VA769S	NA	87	117
VA772S	NA	110	126
VA774S	NA	208	158
VA788S	NA	121	156

ID	MAGIC Estimate Of BC_w[1]	BC_w Estimated from Regression Relationship	
		With Water Chemistry	Without Water Chemistry
VA789S	NA	153	83
VA793S	NA	67	86
VA794S	NA	97	58
VA822S	NA	88	89
VT01	NA	100	62
VT03	NA	76	51
VT04	NA	48	71
VT13	NA	94	43
VT16	NA	55	119
VT17	NA	132	130
VT22	NA	89	72
VT23	NA	111	72
VT29	NA	33	31
VT40	NA	36	37
VT42	NA	78	72
VT43	NA	63	89
VT44	NA	67	90
VT45	NA	51	69
VT51	NA	142	103
VT52	NA	99	61
VT60	NA	165	115
VT61	NA	205	117
VT63	NA	79	88
VT64	NA	66	88
VT65	NA	71	86
VT68	NA	23	30
VT69	NA	46	49
VT71	NA	51	40
VT76	NA	34	39
WA01	NA	63	60
WA02	NA	59	43
WA04	NA	48	52
WE01	NA	29	22
WE02	NA	96	17
WE03	NA	80	58
WN01	NA	231	117
WV525S	NA	65	55
WV543S	NA	101	87
WV545S	NA	146	183
WY01	NA	112	50

ID	MAGIC Estimate Of BC_w[1]	BC_w Estimated from Regression Relationship With Water Chemistry	Without Water Chemistry
WY02	NA	68	50
WY03	NA	86	46
WY04	NA	99	53
WY05	NA	74	51

[1] NA = not applicable; no MAGIC calibration was done

Table F-4. Critical load estimates (meq/m^2/yr) for stream study sites, based on an ANC threshold value of 0 μeq/L.

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
2B047032	158	120	112
2C041039	157	171	159
2C041040	178	159	147
2C041045	250	207	157
2C041051	73	96	92
2C046033	73	100	133
2C046034	102	115	107
2C046043L	234	200	127
2C046043U	197	184	123
2C046050	261	284	196
2C047007	186	175	143
2C047010L	89	92	110
2C047010U	91	93	109
2C057004	128	104	147
AU28	50	57	54
BLFC	57	60	63
BO02	113	118	83
DR	56	51	60
DS04	57	52	80
DS09	54	48	54
DS19	59	61	45
DS50	47	44	36
FN1	160	143	148
FN2	141	116	146
FN3	126	121	140
LEWF	102	100	96
M037	76	71	65
M038	73	70	63
M039	55	65	62
NFD	123	115	105
OC02	72	74	93
OC08	50	51	118
OC35	88	68	83
OC79	103	94	90
PAIN	70	55	65
RA05	122	119	117
RH53	59	61	68

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
STAN	96	105	113
VA524S	56	95	63
VA526S	164	144	131
VA531S	100	103	116
VA548S	68	119	136
VA555S	65	71	62
VA821S	141	175	112
VT05	94	82	66
VT07	77	65	46
VT08	86	78	57
VT09	64	71	67
VT10	53	57	48
VT11	56	52	55
VT12	104	97	59
VT15	51	57	74
VT18	86	110	89
VT19	86	109	115
VT24	55	78	83
VT25	53	59	54
VT26	55	76	78
VT28	48	51	44
VT31	38	52	42
VT32	75	77	39
VT34	79	73	77
VT36	59	50	57
VT37	56	71	100
VT38	90	107	115
VT46	120	88	98
VT48	81	73	83
VT49	86	90	94
VT50	52	83	73
VT54	82	122	128
VT55	105	133	131
VT56	44	59	78
VT57	59	87	107
VT58	99	111	120
VT66	154	161	151
VT70	48	62	70
VT72	44	51	42
VT73	67	65	61

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
VT74	45	55	55
VT75	153	159	154
VT77	67	83	78
VT78	53	34	38
WOR	88	84	79
WV523S	72	63	72
WV531S	64	121	141
WV547S	297	292	310
WV548S	96	96	115
WV769S	137	140	97
WV770S	194	175	148
WV771S	228	192	229
WV785S	73	80	116
WV788S	91	74	116
WV796S	76	82	51
2A068015U	NA[4]	66	58
2B041020L	NA	302	195
2B041032U	NA	938	187
2B041049U	NA	102	87
2B047044U	NA	123	93
2B047076U	NA	63	33
2B058015U	NA	41	66
2C040006U	NA	265	228
2C041033U	NA	177	191
2C041043U	NA	198	93
2C046013L	NA	198	212
2C046041	NA	349	166
2C046048U	NA	349	201
2C046053L	NA	161	110
2C046062L	NA	249	42
AB01	NA	131	126
AB02	NA	64	88
AB04	NA	56	134
AB05	NA	84	90
AB06	NA	157	155
AB07	NA	167	139
AB08	NA	153	133
AB09	NA	101	106
AG03	NA	82	61
AG04	NA	97	67

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
AG05	NA	90	78
AG06	NA	151	85
AG07	NA	131	132
AG10	NA	92	108
AM02	NA	212	97
AM03	NA	169	95
AM05	NA	74	94
AM06	NA	84	95
AM10	NA	163	98
AM11	NA	137	97
AM12	NA	106	95
AM13	NA	157	87
AM15	NA	164	86
AM18	NA	69	97
AM19	NA	82	95
AM24	NA	92	93
AU04	NA	93	105
AU05	NA	52	44
AU07	NA	97	113
AU08	NA	111	116
AU09	NA	85	120
AU10	NA	106	134
AU13	NA	151	130
AU14	NA	54	39
AU16	NA	42	41
AU17	NA	48	42
AU19	NA	64	79
AU20	NA	133	139
AU29	NA	74	59
AU30	NA	89	125
AU31	NA	88	127
AU32	NA	90	123
AU33	NA	141	138
AU34	NA	204	119
AU35	NA	40	35
BA01	NA	129	130
BA02	NA	138	128
BA09	NA	30	50
BA11	NA	240	61
BA12	NA	107	53

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
BA14	NA	54	64
BA16	NA	80	69
BA17	NA	107	74
BA21	NA	113	111
BA22	NA	129	120
BA25	NA	287	64
BA26	NA	256	56
BA27	NA	132	134
BA28	NA	185	125
BD01	NA	41	50
BD02	NA	47	32
BD04	NA	85	98
BE01	NA	116	78
BE02	NA	72	78
BO01	NA	483	91
BO04	NA	71	91
BO07	NA	127	85
BO08	NA	99	80
BO11	NA	132	77
BO12	NA	95	77
BO13	NA	109	78
CA01	NA	81	51
CA02	NA	107	50
CR02	NA	102	119
CR03	NA	86	98
CR05	NA	227	113
CR08	NA	132	83
CR09	NA	73	77
CR10	NA	115	106
CR11	NA	113	94
CR12	NA	61	71
CR13	NA	52	1045
CR14	NA	73	98
DS06	NA	41	59
FL01	NA	208	106
FL02	NA	111	98
FR01	NA	327	96
FR02	NA	359	111
FR03	NA	375	104
GL02	NA	84	57

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
GL03	NA	115	104
GL06	NA	69	54
GL08	NA	52	44
GL10	NA	67	67
GL12	NA	63	55
GL13	NA	50	47
GL14	NA	59	54
GL16	NA	113	50
GL18	NA	57	92
GL19	NA	140	80
GL20	NA	134	70
GL21	NA	86	81
GL24	NA	44	39
GR01	NA	102	113
GR02	NA	73	97
GR03	NA	89	113
GR06	NA	136	124
GR07	NA	174	153
GR08	NA	132	134
GR09	NA	173	148
GY04	NA	75	47
GY05	NA	65	83
GY06	NA	71	84
GY07	NA	88	90
GY08	NA	95	59
GY09	NA	112	96
GY10	NA	70	88
GY11	NA	87	94
GY13	NA	75	74
GY14	NA	73	75
GY16	NA	136	63
HI01	NA	83	103
HI02	NA	98	96
HI05	NA	113	97
HI06	NA	98	101
HI07	NA	101	87
HI08	NA	89	111
HI09	NA	102	102
HI10	NA	76	96
HI11	NA	80	100

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
HI12	NA	92	104
HI13	NA	85	100
HI14	NA	95	105
M002	NA	50	23
M034	NA	73	69
M036	NA	82	63
MA04	NA	80	118
MA05	NA	110	114
MA06	NA	115	118
MA07	NA	139	156
MA10	NA	88	112
MA12	NA	141	154
MA13	NA	103	130
MA14	NA	92	97
MA18	NA	134	92
MAD2	NA	110	102
MAIA98-167	NA	108	72
MNF101	NA	136	611
MNF102	NA	457	1446
MNF103	NA	422	696
MNF104	NA	111	153
MNF105	NA	134	102
MNF108	NA	168	574
MNF109	NA	40	111
MNF110	NA	81	59
MNF111	NA	31	103
MNF112	NA	92	112
MNF113	NA	82	129
MNF114	NA	51	107
MNF115	NA	72	114
MNF116	NA	82	113
MNF117	NA	85	152
MNF118	NA	79	164
MNF119	NA	138	163
MNF120	NA	43	103
MNF121	NA	97	161
MNF122	NA	73	163
MNF123	NA	78	151
MNF124	NA	80	178
MNF125	NA	58	182

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
MNF126	NA	83	126
MNF13	NA	988	21
MNF15	NA	217	616
MNF16	NA	312	21
MNF18	NA	126	33
MNF19	NA	160	20
MNF2	NA	74	103
MNF20	NA	96	45
MNF22	NA	82	21
MNF24	NA	73	20
MNF26	NA	136	20
MNF29	NA	332	71
MNF3	NA	129	750
MNF30	NA	107	154
MNF35	NA	96	99
MNF37	NA	104	114
MNF38	NA	293	522
MNF40	NA	98	119
MNF41	NA	150	380
MNF42	NA	112	134
MNF45	NA	21	84
MNF5	NA	189	77
MNF50	NA	34	37
MNF51	NA	36	59
MNF56	NA	199	492
MNF57	NA	162	157
MNF59	NA	182	605
MNF6	NA	308	1019
MNF60	NA	191	21
MNF62	NA	190	22
MNF63	NA	133	22
MNF64	NA	580	107
MNF66	NA	93	120
MNF67	NA	80	107
MNF68	NA	144	364
MNF69	NA	136	296
MNF70	NA	113	253
MNF71	NA	94	110
MNF72	NA	81	83
MNF73	NA	162	276

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
MNF74	NA	128	110
MNF75	NA	163	1472
MNF76	NA	222	21
MNF77	NA	219	21
MNF78	NA	43	36
MNF8	NA	566	808
MNF80	NA	101	49
MNF81	NA	78	116
MNF82	NA	119	160
MNF83	NA	40	121
MNF84	NA	186	27
MNF85	NA	87	81
MNF87	NA	50	55
MNF88	NA	246	305
MNF89	NA	51	137
MNF91	NA	153	88
MNF92	NA	118	93
MNF93	NA	44	89
MNF95	NA	29	85
MNF98	NA	63	110
MNF99	NA	63	147
NE01	NA	193	140
NE02	NA	111	131
NE03	NA	139	127
NE05	NA	71	108
NE06	NA	84	94
NE07	NA	111	99
NE08	NA	67	94
NE10	NA	69	93
NE11	NA	78	91
NE15	NA	88	95
NE16	NA	85	107
NE18	NA	92	113
NE22	NA	101	112
NE23	NA	118	102
NE25	NA	122	94
OC05	NA	35	103
OC09	NA	38	87
OC31	NA	35	87
OC32	NA	40	81

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
PG03	NA	342	84
PG04	NA	123	95
PG05	NA	74	99
PG08	NA	160	143
PG09	NA	151	135
PT01	NA	176	77
PT02	NA	350	77
PT03	NA	176	110
PT04	NA	234	71
PT05	NA	206	103
PT07	NA	183	83
PT08	NA	228	82
PT09	NA	372	76
PT11	NA	139	85
PT12	NA	81	119
PU01	NA	106	84
PU02	NA	79	78
PU03	NA	58	82
PU06	NA	75	79
RA06	NA	104	114
RA07	NA	95	117
RA09	NA	178	151
RA10	NA	153	116
RA12	NA	234	124
RB01	NA	146	99
RB02	NA	79	101
RB03	NA	168	100
RB04	NA	101	78
RB05	NA	67	127
RB07	NA	127	72
RB08	NA	43	77
RB09	NA	134	88
RB11	NA	176	2395
RB12	NA	188	93
RB13	NA	91	70
RB14	NA	72	70
RB15	NA	99	67
RB16	NA	98	71
RB18	NA	155	82
RB19	NA	92	66

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
RB26	NA	228	79
RB28	NA	47	64
RB29	NA	121	136
RB30	NA	331	98
RH02	NA	123	125
RH03	NA	146	128
RH06	NA	150	147
RH07	NA	142	143
RH08	NA	329	100
RH09	NA	420	112
RH12	NA	80	77
RH13	NA	89	78
RH14	NA	77	93
RH15	NA	95	125
RH16	NA	92	126
RH17	NA	116	129
RH18	NA	113	125
RH20	NA	73	88
RH21	NA	92	96
RH22	NA	79	118
RH23	NA	88	124
RH24	NA	90	117
RH25	NA	76	119
RH26	NA	78	100
RH27	NA	70	58
RH28	NA	92	130
RH30	NA	90	122
RH33	NA	68	64
RH34	NA	78	69
RH36	NA	90	118
RH40	NA	202	100
RH42	NA	172	153
RH49	NA	102	102
RH50	NA	61	79
RH51	NA	47	32
RN01	NA	51	66
SC01	NA	99	73
SC02	NA	117	70
SC04	NA	47	98
SC05	NA	78	89

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
SC08	NA	322	60
SH02	NA	427	85
SH03	NA	97	81
SH04	NA	110	80
SH06	NA	90	74
SY01	NA	533	68
SY02	NA	415	70
SY03	NA	98	61
SY04	NA	79	61
SY05	NA	66	64
SY06	NA	66	60
SY07	NA	107	55
SY08	NA	71	62
SY09	NA	76	62
SY10	NA	95	58
SY11	NA	86	67
SY13	NA	59	71
SY14	NA	61	62
SY15	NA	39	61
SY16	NA	48	61
SY17	NA	74	57
SY18	NA	78	55
SY19	NA	70	65
SY20	NA	94	63
SY22	NA	73	82
SY23	NA	111	103
SY25	NA	74	70
SY27	NA	63	65
TA01	NA	77	63
TA06	NA	69	93
TA07	NA	43	38
TA13	NA	50	78
VA538S	NA	101	105
VA546S	NA	214	103
VA550S	NA	101	90
VA567S	NA	83	61
VA756S	NA	151	142
VA769S	NA	113	143
VA772S	NA	119	134
VA774S	NA	214	164

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
VA788S	NA	137	171
VA789S	NA	178	108
VA793S	NA	74	93
VA794S	NA	103	64
VA822S	NA	98	99
VT01	NA	121	83
VT03	NA	90	64
VT04	NA	69	92
VT13	NA	100	50
VT16	NA	77	141
VT17	NA	139	137
VT22	NA	95	78
VT23	NA	118	79
VT29	NA	62	60
VT40	NA	58	59
VT42	NA	85	79
VT43	NA	69	94
VT44	NA	73	96
VT45	NA	56	74
VT51	NA	163	124
VT52	NA	102	64
VT60	NA	186	136
VT61	NA	226	138
VT63	NA	88	97
VT64	NA	72	94
VT65	NA	76	92
VT68	NA	48	56
VT69	NA	68	72
VT71	NA	73	62
VT76	NA	54	59
WA01	NA	70	67
WA02	NA	66	50
WA04	NA	56	60
WE01	NA	42	36
WE02	NA	109	31
WE03	NA	93	71
WN01	NA	251	137
WV525S	NA	71	62
WV543S	NA	123	109
WV545S	NA	156	193

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
WY01	NA	121	58
WY02	NA	76	58
WY03	NA	96	57
WY04	NA	107	61
WY05	NA	90	68

1 BC_w taken from MAGIC calibrations
2 BC_w estimated using regression equations based on water chemistry plus landscape variables
3 BC_w estimated using regression equations based on landscape variables
4 NA = not applicable; no MAGIC calibration was done

Table F-5. Critical load estimates (meq/m^2/yr) for stream study sites, based on an ANC threshold value of 20 μeq/L.

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
2B047032	148	110	102
2C041039	143	156	145
2C041040	163	145	132
2C041045	237	194	144
2C041051	58	82	77
2C046033	56	83	116
2C046034	81	95	86
2C046043L	216	181	109
2C046043U	179	166	105
2C046050	251	274	186
2C047007	175	164	132
2C047010L	75	79	96
2C047010U	76	79	94
2C057004	115	91	134
AU28	40	47	44
BLFC	43	46	49
BO02	107	112	77
DR	48	43	52
DS04	41	37	64
DS09	38	32	38
DS19	45	48	31
DS50	32	28	20
FN1	145	128	133
FN2	126	101	131
FN3	110	105	125
LEWF	83	81	77
M037	62	57	52
M038	62	59	52
M039	44	55	52
NFD	111	103	93
OC02	56	58	77
OC08	33	34	102
OC35	72	52	67
OC79	86	78	74
PAIN	59	45	55
RA05	108	105	103
RH53	52	54	60

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
STAN	86	94	102
VA524S	45	85	53
VA526S	153	134	120
VA531S	88	91	104
VA548S	61	112	129
VA555S	54	60	51
VA821S	135	169	106
VT05	81	70	53
VT07	65	53	34
VT08	74	66	45
VT09	55	62	58
VT10	45	48	39
VT11	47	44	47
VT12	96	89	51
VT15	43	49	66
VT18	74	98	77
VT19	75	97	103
VT24	49	72	76
VT25	43	49	44
VT26	45	67	68
VT28	38	40	34
VT31	30	44	35
VT32	63	65	27
VT34	70	63	68
VT36	48	40	46
VT37	45	61	89
VT38	80	98	105
VT46	106	74	83
VT48	71	64	73
VT49	78	82	86
VT50	45	76	66
VT54	73	113	118
VT55	97	125	123
VT56	37	52	71
VT57	53	81	100
VT58	87	99	108
VT66	143	150	140
VT70	34	48	56
VT72	30	36	28
VT73	55	52	48

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
VT74	33	43	42
VT75	141	147	143
VT77	58	74	68
VT78	40	20	24
WOR	77	73	67
WV523S	56	47	56
WV531S	48	105	125
WV547S	282	277	295
WV548S	80	80	98
WV769S	123	125	82
WV770S	182	163	136
WV771S	215	179	216
WV785S	63	70	106
WV788S	73	56	98
WV796S	60	66	36
2A068015U	NA[4]	51	44
2B041020L	NA	296	189
2B041032U	NA	932	181
2B041049U	NA	96	81
2B047044U	NA	112	83
2B047076U	NA	51	22
2B058015U	NA	30	55
2C040006U	NA	252	216
2C041033U	NA	161	176
2C041043U	NA	190	84
2C046013L	NA	183	197
2C046041	NA	335	152
2C046048U	NA	340	191
2C046053L	NA	144	94
2C046062L	NA	232	25
AB01	NA	117	112
AB02	NA	48	72
AB04	NA	40	118
AB05	NA	68	74
AB06	NA	141	139
AB07	NA	151	123
AB08	NA	138	119
AB09	NA	87	92
AG03	NA	73	51
AG04	NA	88	58

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL: Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
AG05	NA	84	72
AG06	NA	145	79
AG07	NA	124	124
AG10	NA	85	100
AM02	NA	201	86
AM03	NA	158	84
AM05	NA	55	75
AM06	NA	67	78
AM10	NA	152	86
AM11	NA	126	86
AM12	NA	96	85
AM13	NA	147	78
AM15	NA	155	77
AM18	NA	53	81
AM19	NA	66	79
AM24	NA	79	80
AU04	NA	82	94
AU05	NA	41	33
AU07	NA	88	104
AU08	NA	102	107
AU09	NA	74	109
AU10	NA	98	126
AU13	NA	138	118
AU14	NA	44	30
AU16	NA	32	31
AU17	NA	38	32
AU19	NA	48	63
AU20	NA	116	123
AU29	NA	64	49
AU30	NA	81	117
AU31	NA	80	119
AU32	NA	82	115
AU33	NA	133	130
AU34	NA	195	111
AU35	NA	29	24
BA01	NA	121	122
BA02	NA	130	120
BA09	NA	21	42
BA11	NA	233	54
BA12	NA	98	44

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
BA14	NA	46	56
BA16	NA	72	61
BA17	NA	99	66
BA21	NA	102	100
BA22	NA	120	111
BA25	NA	279	56
BA26	NA	248	48
BA27	NA	125	127
BA28	NA	179	119
BD01	NA	32	41
BD02	NA	39	24
BD04	NA	76	89
BE01	NA	99	61
BE02	NA	55	60
BO01	NA	477	85
BO04	NA	65	85
BO07	NA	117	75
BO08	NA	86	67
BO11	NA	121	66
BO12	NA	81	63
BO13	NA	94	63
CA01	NA	67	37
CA02	NA	93	36
CR02	NA	95	112
CR03	NA	78	90
CR05	NA	219	105
CR08	NA	122	72
CR09	NA	62	66
CR10	NA	105	96
CR11	NA	105	86
CR12	NA	51	61
CR13	NA	45	1037
CR14	NA	66	91
DS06	NA	24	42
FL01	NA	195	92
FL02	NA	92	79
FR01	NA	319	88
FR02	NA	351	103
FR03	NA	367	95
GL02	NA	75	47

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
GL03	NA	104	93
GL06	NA	57	42
GL08	NA	41	34
GL10	NA	57	57
GL12	NA	53	45
GL13	NA	40	36
GL14	NA	49	45
GL16	NA	103	40
GL18	NA	50	84
GL19	NA	133	72
GL20	NA	126	63
GL21	NA	79	74
GL24	NA	33	29
GR01	NA	87	98
GR02	NA	58	82
GR03	NA	74	99
GR06	NA	122	110
GR07	NA	157	136
GR08	NA	116	118
GR09	NA	158	133
GY04	NA	59	31
GY05	NA	50	68
GY06	NA	55	68
GY07	NA	75	77
GY08	NA	82	47
GY09	NA	99	83
GY10	NA	53	71
GY11	NA	69	77
GY13	NA	62	61
GY14	NA	56	58
GY16	NA	127	55
HI01	NA	71	90
HI02	NA	86	83
HI05	NA	101	85
HI06	NA	87	90
HI07	NA	90	76
HI08	NA	78	100
HI09	NA	92	92
HI10	NA	63	83
HI11	NA	67	87

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
HI12	NA	81	93
HI13	NA	73	88
HI14	NA	83	93
M002	NA	34	7
M034	NA	64	60
M036	NA	68	49
MA04	NA	68	106
MA05	NA	97	101
MA06	NA	102	105
MA07	NA	127	143
MA10	NA	74	98
MA12	NA	125	138
MA13	NA	88	114
MA14	NA	78	84
MA18	NA	123	81
MAD2	NA	99	90
MAIA98-167	NA	102	66
MNF101	NA	121	596
MNF102	NA	451	1440
MNF103	NA	407	682
MNF104	NA	98	139
MNF105	NA	119	87
MNF108	NA	160	566
MNF109	NA	21	91
MNF110	NA	62	41
MNF111	NA	13	85
MNF112	NA	75	95
MNF113	NA	65	112
MNF114	NA	34	90
MNF115	NA	55	96
MNF116	NA	66	97
MNF117	NA	69	137
MNF118	NA	64	149
MNF119	NA	123	148
MNF120	NA	25	85
MNF121	NA	82	147
MNF122	NA	58	148
MNF123	NA	63	137
MNF124	NA	65	164
MNF125	NA	44	168

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
MNF126	NA	68	110
MNF13	NA	972	5
MNF15	NA	203	602
MNF16	NA	292	1
MNF18	NA	106	14
MNF19	NA	141	1
MNF2	NA	61	90
MNF20	NA	78	26
MNF22	NA	64	2
MNF24	NA	55	2
MNF26	NA	119	3
MNF29	NA	320	58
MNF3	NA	115	736
MNF30	NA	93	140
MNF35	NA	80	83
MNF37	NA	88	98
MNF38	NA	278	506
MNF40	NA	83	104
MNF41	NA	136	366
MNF42	NA	98	119
MNF45	NA	4	67
MNF5	NA	179	68
MNF50	NA	16	20
MNF51	NA	18	41
MNF56	NA	186	479
MNF57	NA	149	144
MNF59	NA	168	591
MNF6	NA	302	1013
MNF60	NA	176	6
MNF62	NA	175	7
MNF63	NA	118	6
MNF64	NA	564	91
MNF66	NA	78	104
MNF67	NA	65	92
MNF68	NA	131	351
MNF69	NA	121	281
MNF70	NA	99	239
MNF71	NA	80	96
MNF72	NA	67	70
MNF73	NA	152	266

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
MNF74	NA	117	99
MNF75	NA	153	1463
MNF76	NA	205	4
MNF77	NA	202	4
MNF78	NA	22	15
MNF8	NA	560	802
MNF80	NA	81	29
MNF81	NA	59	98
MNF82	NA	103	143
MNF83	NA	23	104
MNF84	NA	169	9
MNF85	NA	66	60
MNF87	NA	29	35
MNF88	NA	231	290
MNF89	NA	36	122
MNF91	NA	135	69
MNF92	NA	100	74
MNF93	NA	26	71
MNF95	NA	10	66
MNF98	NA	46	93
MNF99	NA	49	132
NE01	NA	183	131
NE02	NA	101	122
NE03	NA	127	115
NE05	NA	56	94
NE06	NA	70	80
NE07	NA	97	84
NE08	NA	51	78
NE10	NA	52	77
NE11	NA	62	74
NE15	NA	73	80
NE16	NA	73	95
NE18	NA	79	99
NE22	NA	87	98
NE23	NA	107	91
NE25	NA	108	81
OC05	NA	19	87
OC09	NA	21	71
OC31	NA	19	70
OC32	NA	24	65

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
PG03	NA	334	77
PG04	NA	115	87
PG05	NA	66	92
PG08	NA	148	131
PG09	NA	139	123
PT01	NA	157	58
PT02	NA	338	64
PT03	NA	157	91
PT04	NA	220	57
PT05	NA	193	90
PT07	NA	170	70
PT08	NA	214	68
PT09	NA	358	62
PT11	NA	126	72
PT12	NA	67	105
PU01	NA	99	77
PU02	NA	71	70
PU03	NA	47	71
PU06	NA	67	72
RA06	NA	91	100
RA07	NA	83	104
RA09	NA	164	137
RA10	NA	141	103
RA12	NA	225	115
RB01	NA	133	87
RB02	NA	67	89
RB03	NA	158	89
RB04	NA	90	66
RB05	NA	59	119
RB07	NA	117	62
RB08	NA	32	66
RB09	NA	123	77
RB11	NA	165	2384
RB12	NA	178	83
RB13	NA	81	60
RB14	NA	63	60
RB15	NA	93	61
RB16	NA	92	65
RB18	NA	147	74
RB19	NA	79	53

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
RB26	NA	218	69
RB28	NA	38	55
RB29	NA	111	126
RB30	NA	321	88
RH02	NA	113	115
RH03	NA	138	120
RH06	NA	144	141
RH07	NA	136	137
RH08	NA	322	93
RH09	NA	413	106
RH12	NA	70	67
RH13	NA	79	68
RH14	NA	68	84
RH15	NA	89	119
RH16	NA	84	117
RH17	NA	108	121
RH18	NA	105	117
RH20	NA	63	78
RH21	NA	82	86
RH22	NA	70	108
RH23	NA	80	116
RH24	NA	83	109
RH25	NA	68	111
RH26	NA	70	92
RH27	NA	63	51
RH28	NA	84	123
RH30	NA	82	114
RH33	NA	62	58
RH34	NA	72	63
RH36	NA	81	110
RH40	NA	193	91
RH42	NA	161	143
RH49	NA	91	92
RH50	NA	50	68
RH51	NA	40	25
RN01	NA	38	54
SC01	NA	79	53
SC02	NA	97	50
SC04	NA	34	85
SC05	NA	65	76

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
SC08	NA	304	42
SH02	NA	421	78
SH03	NA	91	75
SH04	NA	102	71
SH06	NA	84	68
SY01	NA	522	58
SY02	NA	404	58
SY03	NA	86	49
SY04	NA	67	49
SY05	NA	54	52
SY06	NA	54	48
SY07	NA	94	43
SY08	NA	58	50
SY09	NA	63	50
SY10	NA	85	49
SY11	NA	76	57
SY13	NA	48	59
SY14	NA	49	50
SY15	NA	27	49
SY16	NA	37	50
SY17	NA	62	46
SY18	NA	64	41
SY19	NA	56	51
SY20	NA	80	49
SY22	NA	59	67
SY23	NA	95	86
SY25	NA	61	56
SY27	NA	51	53
TA01	NA	63	50
TA06	NA	60	84
TA07	NA	33	28
TA13	NA	40	68
VA538S	NA	93	97
VA546S	NA	208	97
VA550S	NA	94	83
VA567S	NA	74	53
VA756S	NA	143	134
VA769S	NA	105	135
VA772S	NA	111	126
VA774S	NA	208	158

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
VA788S	NA	129	164
VA789S	NA	171	101
VA793S	NA	54	73
VA794S	NA	93	54
VA822S	NA	84	85
VT01	NA	102	64
VT03	NA	74	49
VT04	NA	52	75
VT13	NA	93	42
VT16	NA	69	133
VT17	NA	132	130
VT22	NA	82	65
VT23	NA	104	65
VT29	NA	52	51
VT40	NA	42	43
VT42	NA	68	61
VT43	NA	50	76
VT44	NA	58	81
VT45	NA	46	64
VT51	NA	156	118
VT52	NA	93	55
VT60	NA	174	124
VT61	NA	214	126
VT63	NA	73	83
VT64	NA	59	81
VT65	NA	63	79
VT68	NA	34	41
VT69	NA	54	57
VT71	NA	59	48
VT76	NA	43	48
WA01	NA	59	56
WA02	NA	55	39
WA04	NA	46	50
WE01	NA	21	14
WE02	NA	87	9
WE03	NA	79	57
WN01	NA	245	131
WV525S	NA	65	56
WV543S	NA	108	94
WV545S	NA	146	183

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
WY01	NA	112	50
WY02	NA	68	50
WY03	NA	88	48
WY04	NA	98	52
WY05	NA	82	60

[1] BC_w taken from MAGIC calibrations
[2] BC_w estimated using regression equations based on water chemistry plus landscape variables
[3] BC_w estimated using regression equations based on landscape variables
[4] NA = not applicable; no MAGIC calibration was done

Table F-6. Critical load estimates (meq/m^2/yr) for stream study sites, based on an ANC threshold value of 50 μeq/L.

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
2B047032	132	94	87
2C041039	122	135	124
2C041040	141	122	110
2C041045	217	175	125
2C041051	37	60	56
2C046033	31	58	90
2C046034	51	65	56
2C046043L	188	154	82
2C046043U	151	139	78
2C046050	235	259	171
2C047007	157	146	114
2C047010L	54	58	76
2C047010U	55	57	72
2C057004	96	72	115
AU28	24	32	28
BLFC	22	24	28
BO02	98	103	68
DR	37	32	41
DS04	18	14	41
DS09	14	8	14
DS19	25	27	10
DS50	8	4	0
FN1	122	105	110
FN2	103	79	108
FN3	87	82	102
LEWF	55	53	49
M037	42	37	31
M038	47	43	36
M039	29	40	37
NFD	93	86	76
OC02	31	33	52
OC08	7	8	76
OC35	49	29	44
OC79	62	53	49
PAIN	44	29	39
RA05	88	85	82
RH53	41	43	49

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
STAN	69	78	86
VA524S	29	69	37
VA526S	138	118	105
VA531S	69	72	85
VA548S	51	103	119
VA555S	37	43	34
VA821S	125	159	96
VT05	63	51	35
VT07	47	35	16
VT08	57	48	27
VT09	40	48	44
VT10	32	35	26
VT11	35	31	34
VT12	83	76	38
VT15	31	37	54
VT18	57	81	60
VT19	57	80	85
VT24	39	62	66
VT25	29	35	30
VT26	30	52	53
VT28	22	25	18
VT31	18	33	23
VT32	45	47	9
VT34	56	50	54
VT36	32	24	30
VT37	29	45	74
VT38	66	84	91
VT46	84	52	61
VT48	57	50	60
VT49	66	70	74
VT50	34	65	55
VT54	58	98	104
VT55	86	114	111
VT56	27	41	60
VT57	43	71	90
VT58	69	82	91
VT66	127	134	124
VT70	13	28	35
VT72	8	15	6
VT73	36	34	30

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
VT74	15	25	24
VT75	124	130	126
VT77	44	60	54
VT78	19	0	3
WOR	60	56	50
WV523S	31	23	32
WV531S	23	80	101
WV547S	259	254	272
WV548S	56	56	74
WV769S	102	104	61
WV770S	164	145	118
WV771S	196	160	197
WV785S	47	55	91
WV788S	47	29	72
WV796S	37	42	12
2A068015U	NA[4]	30	23
2B041020L	NA	287	180
2B041032U	NA	923	172
2B041049U	NA	87	72
2B047044U	NA	96	67
2B047076U	NA	34	5
2B058015U	NA	15	40
2C040006U	NA	234	197
2C041033U	NA	138	153
2C041043U	NA	177	72
2C046013L	NA	161	175
2C046041	NA	314	132
2C046048U	NA	326	177
2C046053L	NA	119	69
2C046062L	NA	208	0
AB01	NA	96	91
AB02	NA	24	48
AB04	NA	16	94
AB05	NA	45	51
AB06	NA	116	114
AB07	NA	126	98
AB08	NA	117	97
AB09	NA	66	71
AG03	NA	59	37
AG04	NA	74	44

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
AG05	NA	75	63
AG06	NA	136	70
AG07	NA	113	113
AG10	NA	73	89
AM02	NA	185	70
AM03	NA	142	68
AM05	NA	27	47
AM06	NA	43	54
AM10	NA	134	69
AM11	NA	110	70
AM12	NA	80	69
AM13	NA	133	64
AM15	NA	141	63
AM18	NA	29	56
AM19	NA	42	55
AM24	NA	60	61
AU04	NA	66	77
AU05	NA	24	17
AU07	NA	74	90
AU08	NA	88	93
AU09	NA	57	92
AU10	NA	85	113
AU13	NA	119	98
AU14	NA	29	15
AU16	NA	17	17
AU17	NA	22	17
AU19	NA	23	38
AU20	NA	92	99
AU29	NA	49	35
AU30	NA	69	105
AU31	NA	67	107
AU32	NA	71	104
AU33	NA	122	119
AU34	NA	182	98
AU35	NA	12	7
BA01	NA	108	110
BA02	NA	117	107
BA09	NA	8	29
BA11	NA	223	43
BA12	NA	85	30

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
BA14	NA	34	44
BA16	NA	60	48
BA17	NA	86	53
BA21	NA	87	85
BA22	NA	106	97
BA25	NA	267	44
BA26	NA	236	36
BA27	NA	114	116
BA28	NA	169	109
BD01	NA	18	27
BD02	NA	27	12
BD04	NA	63	75
BE01	NA	74	36
BE02	NA	28	34
BO01	NA	468	76
BO04	NA	56	76
BO07	NA	103	61
BO08	NA	67	47
BO11	NA	104	49
BO12	NA	60	42
BO13	NA	73	42
CA01	NA	46	16
CA02	NA	73	16
CR02	NA	85	102
CR03	NA	66	78
CR05	NA	208	93
CR08	NA	107	57
CR09	NA	45	49
CR10	NA	91	82
CR11	NA	92	73
CR12	NA	37	47
CR13	NA	33	1025
CR14	NA	55	81
DS06	NA	0	17
FL01	NA	175	72
FL02	NA	64	51
FR01	NA	307	76
FR02	NA	339	90
FR03	NA	353	82
GL02	NA	61	34

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
GL03	NA	88	77
GL06	NA	39	24
GL08	NA	25	17
GL10	NA	43	42
GL12	NA	39	30
GL13	NA	24	20
GL14	NA	35	30
GL16	NA	88	25
GL18	NA	39	73
GL19	NA	122	62
GL20	NA	115	51
GL21	NA	67	63
GL24	NA	17	13
GR01	NA	65	76
GR02	NA	36	60
GR03	NA	53	77
GR06	NA	101	90
GR07	NA	132	111
GR08	NA	93	95
GR09	NA	135	110
GY04	NA	35	7
GY05	NA	28	45
GY06	NA	32	44
GY07	NA	57	59
GY08	NA	64	28
GY09	NA	81	65
GY10	NA	27	45
GY11	NA	43	51
GY13	NA	41	40
GY14	NA	32	33
GY16	NA	115	42
HI01	NA	53	72
HI02	NA	68	65
HI05	NA	83	67
HI06	NA	71	73
HI07	NA	74	59
HI08	NA	62	84
HI09	NA	77	77
HI10	NA	43	63
HI11	NA	47	67

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
HI12	NA	65	77
HI13	NA	56	71
HI14	NA	65	75
M002	NA	11	0
M034	NA	51	47
M036	NA	46	28
MA04	NA	50	88
MA05	NA	78	82
MA06	NA	83	86
MA07	NA	109	125
MA10	NA	54	77
MA12	NA	102	115
MA13	NA	65	92
MA14	NA	59	64
MA18	NA	108	65
MAD2	NA	82	73
MAIA98-167	NA	92	56
MNF101	NA	100	575
MNF102	NA	442	1431
MNF103	NA	386	660
MNF104	NA	77	119
MNF105	NA	97	65
MNF108	NA	148	554
MNF109	NA	0	63
MNF110	NA	35	13
MNF111	NA	0	58
MNF112	NA	49	68
MNF113	NA	41	88
MNF114	NA	8	64
MNF115	NA	29	70
MNF116	NA	42	73
MNF117	NA	46	114
MNF118	NA	41	126
MNF119	NA	101	126
MNF120	NA	0	58
MNF121	NA	60	125
MNF122	NA	37	127
MNF123	NA	41	114
MNF124	NA	44	142
MNF125	NA	22	146

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
MNF126	NA	45	87
MNF13	NA	948	0
MNF15	NA	183	582
MNF16	NA	263	0
MNF18	NA	77	0
MNF19	NA	111	0
MNF2	NA	41	71
MNF20	NA	50	0
MNF22	NA	37	0
MNF24	NA	28	0
MNF26	NA	92	0
MNF29	NA	300	39
MNF3	NA	93	715
MNF30	NA	73	120
MNF35	NA	56	59
MNF37	NA	64	74
MNF38	NA	255	483
MNF40	NA	60	81
MNF41	NA	115	345
MNF42	NA	77	98
MNF45	NA	0	42
MNF5	NA	165	53
MNF50	NA	0	0
MNF51	NA	0	14
MNF56	NA	167	460
MNF57	NA	130	125
MNF59	NA	148	571
MNF6	NA	293	1004
MNF60	NA	153	0
MNF62	NA	152	0
MNF63	NA	94	0
MNF64	NA	541	67
MNF66	NA	55	82
MNF67	NA	42	69
MNF68	NA	111	331
MNF69	NA	99	259
MNF70	NA	79	219
MNF71	NA	60	76
MNF72	NA	47	50
MNF73	NA	136	250

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
MNF74	NA	100	81
MNF75	NA	140	1449
MNF76	NA	179	0
MNF77	NA	177	0
MNF78	NA	0	0
MNF8	NA	551	793
MNF80	NA	51	0
MNF81	NA	32	70
MNF82	NA	78	118
MNF83	NA	0	79
MNF84	NA	142	0
MNF85	NA	36	30
MNF87	NA	0	5
MNF88	NA	209	267
MNF89	NA	13	99
MNF91	NA	107	41
MNF92	NA	73	47
MNF93	NA	0	43
MNF95	NA	0	38
MNF98	NA	21	68
MNF99	NA	27	110
NE01	NA	170	117
NE02	NA	87	107
NE03	NA	108	96
NE05	NA	35	72
NE06	NA	48	59
NE07	NA	75	63
NE08	NA	27	54
NE10	NA	28	52
NE11	NA	37	49
NE15	NA	51	58
NE16	NA	56	78
NE18	NA	58	78
NE22	NA	67	77
NE23	NA	90	74
NE25	NA	88	60
OC05	NA	0	62
OC09	NA	0	45
OC31	NA	0	46
OC32	NA	0	40

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
PG03	NA	323	66
PG04	NA	103	74
PG05	NA	55	80
PG08	NA	130	113
PG09	NA	121	105
PT01	NA	129	29
PT02	NA	319	46
PT03	NA	129	63
PT04	NA	199	36
PT05	NA	173	70
PT07	NA	149	49
PT08	NA	193	47
PT09	NA	337	41
PT11	NA	106	52
PT12	NA	46	84
PU01	NA	89	66
PU02	NA	59	58
PU03	NA	31	55
PU06	NA	57	61
RA06	NA	70	79
RA07	NA	64	86
RA09	NA	144	117
RA10	NA	122	85
RA12	NA	211	101
RB01	NA	114	68
RB02	NA	49	71
RB03	NA	141	73
RB04	NA	72	49
RB05	NA	47	106
RB07	NA	102	47
RB08	NA	16	51
RB09	NA	107	61
RB11	NA	149	2368
RB12	NA	163	67
RB13	NA	66	45
RB14	NA	48	46
RB15	NA	84	52
RB16	NA	82	56
RB18	NA	134	61
RB19	NA	59	34

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
RB26	NA	204	55
RB28	NA	25	42
RB29	NA	96	111
RB30	NA	307	74
RH02	NA	99	101
RH03	NA	126	109
RH06	NA	135	132
RH07	NA	127	128
RH08	NA	312	83
RH09	NA	403	96
RH12	NA	56	53
RH13	NA	65	53
RH14	NA	54	70
RH15	NA	79	109
RH16	NA	70	104
RH17	NA	95	108
RH18	NA	93	105
RH20	NA	49	63
RH21	NA	67	71
RH22	NA	55	93
RH23	NA	69	104
RH24	NA	72	98
RH25	NA	56	99
RH26	NA	58	80
RH27	NA	53	41
RH28	NA	73	112
RH30	NA	70	101
RH33	NA	52	48
RH34	NA	63	54
RH36	NA	69	97
RH40	NA	179	78
RH42	NA	146	127
RH49	NA	76	77
RH50	NA	35	53
RH51	NA	29	14
RN01	NA	20	36
SC01	NA	50	23
SC02	NA	68	21
SC04	NA	14	66
SC05	NA	45	56

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
SC08	NA	278	16
SH02	NA	412	69
SH03	NA	82	66
SH04	NA	89	58
SH06	NA	75	59
SY01	NA	506	41
SY02	NA	386	41
SY03	NA	67	30
SY04	NA	49	31
SY05	NA	37	35
SY06	NA	36	30
SY07	NA	75	24
SY08	NA	40	31
SY09	NA	45	31
SY10	NA	72	35
SY11	NA	61	42
SY13	NA	30	42
SY14	NA	31	32
SY15	NA	9	31
SY16	NA	21	33
SY17	NA	45	29
SY18	NA	43	20
SY19	NA	35	30
SY20	NA	60	29
SY22	NA	38	46
SY23	NA	71	62
SY25	NA	41	36
SY27	NA	32	34
TA01	NA	43	29
TA06	NA	47	71
TA07	NA	18	14
TA13	NA	25	52
VA538S	NA	80	84
VA546S	NA	199	88
VA550S	NA	83	73
VA567S	NA	62	41
VA756S	NA	131	122
VA769S	NA	95	124
VA772S	NA	98	113
VA774S	NA	199	149

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
VA788S	NA	119	153
VA789S	NA	160	90
VA793S	NA	25	43
VA794S	NA	78	39
VA822S	NA	63	64
VT01	NA	73	35
VT03	NA	50	25
VT04	NA	26	49
VT13	NA	81	30
VT16	NA	57	121
VT17	NA	122	119
VT22	NA	63	46
VT23	NA	82	44
VT29	NA	39	37
VT40	NA	18	19
VT42	NA	42	35
VT43	NA	23	48
VT44	NA	35	58
VT45	NA	31	49
VT51	NA	146	108
VT52	NA	79	41
VT60	NA	156	106
VT61	NA	196	108
VT63	NA	51	60
VT64	NA	39	61
VT65	NA	43	59
VT68	NA	12	19
VT69	NA	32	36
VT71	NA	39	28
VT76	NA	27	32
WA01	NA	42	39
WA02	NA	38	22
WA04	NA	32	36
WE01	NA	0	0
WE02	NA	54	0
WE03	NA	58	36
WN01	NA	236	122
WV525S	NA	56	47
WV543S	NA	86	72
WV545S	NA	131	167

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
WY01	NA	100	38
WY02	NA	56	38
WY03	NA	74	35
WY04	NA	85	38
WY05	NA	70	48

1 BC_w taken from MAGIC calibrations
2 BC_w estimated using regression equations based on water chemistry plus landscape variables
3 BC_w estimated using regression equations based on landscape variables
4 NA = not applicable; no MAGIC calibration was done

Table F-7 Critical load estimates (meq/m^2/yr) for stream study sites, based on an ANC threshold value of 100 μeq/L.

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
2B047032	106	69	61
2C041039	86	100	88
2C041040	104	85	73
2C041045	185	143	93
2C041051	1	25	20
2C046033	0	16	48
2C046034	1	14	6
2C046043L	143	108	36
2C046043U	105	93	32
2C046050	210	233	145
2C047007	128	117	85
2C047010L	19	23	41
2C047010U	18	21	36
2C057004	64	40	83
AU28	0	6	3
BLFC	0	0	0
BO02	83	88	53
DR	18	13	22
DS04	0	0	2
DS09	0	0	0
DS19	0	0	0
DS50	0	0	0
FN1	84	67	72
FN2	65	41	70
FN3	49	44	63
LEWF	8	6	2
M037	7	2	0
M038	20	17	10
M039	3	14	11
NFD	64	56	46
OC02	0	0	11
OC08	0	0	34
OC35	10	0	5
OC79	21	12	8
PAIN	17	3	13
RA05	53	50	47
RH53	22	24	31

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
STAN	42	51	58
VA524S	3	42	10
VA526S	112	93	79
VA531S	39	42	55
VA548S	35	86	103
VA555S	9	15	6
VA821S	108	142	79
VT05	32	21	4
VT07	17	5	0
VT08	27	18	0
VT09	16	24	20
VT10	10	13	5
VT11	14	10	13
VT12	62	55	17
VT15	10	17	33
VT18	28	52	31
VT19	28	50	56
VT24	23	46	50
VT25	5	11	6
VT26	6	27	28
VT28	0	0	0
VT31	0	13	4
VT32	14	17	0
VT34	33	27	31
VT36	5	0	3
VT37	3	18	47
VT38	43	61	68
VT46	47	15	24
VT48	34	27	36
VT49	45	50	53
VT50	16	47	37
VT54	34	74	80
VT55	67	94	92
VT56	9	23	42
VT57	26	54	73
VT58	40	52	61
VT66	100	107	97
VT70	0	0	1
VT72	0	0	0
VT73	5	2	0

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
VT74	0	0	0
VT75	96	102	97
VT77	20	36	31
VT78	0	0	0
WOR	32	28	22
WV523S	0	0	0
WV531S	0	40	60
WV547S	222	216	234
WV548S	16	16	34
WV769S	66	68	25
WV770S	133	114	88
WV771S	164	127	165
WV785S	22	30	65
WV788S	2	0	27
WV796S	0	3	0
2A068015U	NA[4]	0	0
2B041020L	NA	272	165
2B041032U	NA	908	157
2B041049U	NA	72	57
2B047044U	NA	70	41
2B047076U	NA	6	0
2B058015U	NA	0	14
2C040006U	NA	203	166
2C041033U	NA	100	114
2C041043U	NA	156	51
2C046013L	NA	124	138
2C046041	NA	279	97
2C046048U	NA	302	154
2C046053L	NA	78	28
2C046062L	NA	166	0
AB01	NA	61	56
AB02	NA	0	8
AB04	NA	0	54
AB05	NA	5	11
AB06	NA	74	72
AB07	NA	85	57
AB08	NA	81	62
AB09	NA	31	36
AG03	NA	36	14
AG04	NA	52	21

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
AG05	NA	60	48
AG06	NA	121	55
AG07	NA	94	95
AG10	NA	54	70
AM02	NA	158	42
AM03	NA	115	41
AM05	NA	0	0
AM06	NA	1	12
AM10	NA	105	39
AM11	NA	83	43
AM12	NA	54	43
AM13	NA	110	41
AM15	NA	118	40
AM18	NA	0	16
AM19	NA	2	15
AM24	NA	27	28
AU04	NA	38	50
AU05	NA	0	0
AU07	NA	50	66
AU08	NA	65	70
AU09	NA	29	64
AU10	NA	64	92
AU13	NA	86	66
AU14	NA	4	0
AU16	NA	0	0
AU17	NA	0	0
AU19	NA	0	0
AU20	NA	52	58
AU29	NA	24	10
AU30	NA	48	84
AU31	NA	47	86
AU32	NA	52	85
AU33	NA	103	100
AU34	NA	160	76
AU35	NA	0	0
BA01	NA	88	89
BA02	NA	96	86
BA09	NA	0	8
BA11	NA	205	26
BA12	NA	62	8

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
BA14	NA	14	24
BA16	NA	39	28
BA17	NA	66	33
BA21	NA	61	59
BA22	NA	83	74
BA25	NA	247	24
BA26	NA	215	15
BA27	NA	96	97
BA28	NA	152	92
BD01	NA	0	4
BD02	NA	6	0
BD04	NA	40	52
BE01	NA	32	0
BE02	NA	0	0
BO01	NA	452	60
BO04	NA	41	61
BO07	NA	80	37
BO08	NA	34	14
BO11	NA	76	21
BO12	NA	25	7
BO13	NA	38	7
CA01	NA	11	0
CA02	NA	39	0
CR02	NA	67	84
CR03	NA	47	59
CR05	NA	188	74
CR08	NA	82	32
CR09	NA	17	22
CR10	NA	68	58
CR11	NA	70	52
CR12	NA	14	24
CR13	NA	13	1005
CR14	NA	38	63
DS06	NA	0	0
FL01	NA	142	39
FL02	NA	18	5
FR01	NA	286	55
FR02	NA	318	70
FR03	NA	331	60
GL02	NA	39	11

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
GL03	NA	60	50
GL06	NA	9	0
GL08	NA	0	0
GL10	NA	18	18
GL12	NA	15	6
GL13	NA	0	0
GL14	NA	11	7
GL16	NA	63	0
GL18	NA	21	55
GL19	NA	104	44
GL20	NA	97	33
GL21	NA	48	44
GL24	NA	0	0
GR01	NA	28	40
GR02	NA	0	23
GR03	NA	17	41
GR06	NA	67	55
GR07	NA	90	69
GR08	NA	54	57
GR09	NA	96	71
GY04	NA	0	0
GY05	NA	0	8
GY06	NA	0	5
GY07	NA	26	28
GY08	NA	33	0
GY09	NA	50	34
GY10	NA	0	2
GY11	NA	0	7
GY13	NA	7	6
GY14	NA	0	0
GY16	NA	93	20
HI01	NA	22	41
HI02	NA	37	35
HI05	NA	52	36
HI06	NA	43	46
HI07	NA	47	32
HI08	NA	34	57
HI09	NA	52	52
HI10	NA	10	30
HI11	NA	14	34

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
HI12	NA	37	49
HI13	NA	26	41
HI14	NA	36	46
M002	NA	0	0
M034	NA	29	25
M036	NA	11	0
MA04	NA	21	59
MA05	NA	46	50
MA06	NA	51	54
MA07	NA	79	95
MA10	NA	19	43
MA12	NA	63	76
MA13	NA	27	53
MA14	NA	26	31
MA18	NA	81	38
MAD2	NA	53	45
MAIA98-167	NA	76	40
MNF101	NA	64	539
MNF102	NA	427	1416
MNF103	NA	349	624
MNF104	NA	43	84
MNF105	NA	61	28
MNF108	NA	128	534
MNF109	NA	0	15
MNF110	NA	0	0
MNF111	NA	0	14
MNF112	NA	5	25
MNF113	NA	0	47
MNF114	NA	0	20
MNF115	NA	0	27
MNF116	NA	2	33
MNF117	NA	8	75
MNF118	NA	3	88
MNF119	NA	64	89
MNF120	NA	0	12
MNF121	NA	24	88
MNF122	NA	1	91
MNF123	NA	4	77
MNF124	NA	8	106
MNF125	NA	0	110

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
MNF126	NA	6	49
MNF13	NA	908	0
MNF15	NA	149	548
MNF16	NA	214	0
MNF18	NA	29	0
MNF19	NA	62	0
MNF2	NA	8	38
MNF20	NA	4	0
MNF22	NA	0	0
MNF24	NA	0	0
MNF26	NA	48	0
MNF29	NA	269	7
MNF3	NA	58	679
MNF30	NA	39	86
MNF35	NA	16	20
MNF37	NA	24	33
MNF38	NA	216	445
MNF40	NA	22	43
MNF41	NA	80	310
MNF42	NA	42	63
MNF45	NA	0	0
MNF5	NA	142	30
MNF50	NA	0	0
MNF51	NA	0	0
MNF56	NA	136	428
MNF57	NA	98	93
MNF59	NA	114	537
MNF6	NA	278	989
MNF60	NA	115	0
MNF62	NA	114	0
MNF63	NA	56	0
MNF64	NA	502	28
MNF66	NA	17	44
MNF67	NA	5	31
MNF68	NA	78	298
MNF69	NA	62	222
MNF70	NA	44	184
MNF71	NA	27	43
MNF72	NA	14	16
MNF73	NA	111	225

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
MNF74	NA	71	53
MNF75	NA	117	1426
MNF76	NA	135	0
MNF77	NA	135	0
MNF78	NA	0	0
MNF8	NA	536	778
MNF80	NA	1	0
MNF81	NA	0	24
MNF82	NA	36	76
MNF83	NA	0	37
MNF84	NA	98	0
MNF85	NA	0	0
MNF87	NA	0	0
MNF88	NA	171	230
MNF89	NA	0	62
MNF91	NA	60	0
MNF92	NA	27	1
MNF93	NA	0	0
MNF95	NA	0	0
MNF98	NA	0	26
MNF99	NA	0	74
NE01	NA	147	94
NE02	NA	62	82
NE03	NA	77	64
NE05	NA	0	36
NE06	NA	13	23
NE07	NA	39	27
NE08	NA	0	14
NE10	NA	0	11
NE11	NA	0	8
NE15	NA	15	22
NE16	NA	27	49
NE18	NA	23	44
NE22	NA	32	43
NE23	NA	63	47
NE25	NA	54	26
OC05	NA	0	21
OC09	NA	0	4
OC31	NA	0	6
OC32	NA	0	0

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
PG03	NA	304	47
PG04	NA	83	54
PG05	NA	36	61
PG08	NA	100	83
PG09	NA	92	76
PT01	NA	81	0
PT02	NA	288	15
PT03	NA	81	15
PT04	NA	163	0
PT05	NA	140	37
PT07	NA	115	15
PT08	NA	158	11
PT09	NA	303	7
PT11	NA	73	19
PT12	NA	11	49
PU01	NA	71	49
PU02	NA	40	38
PU03	NA	4	28
PU06	NA	39	43
RA06	NA	35	44
RA07	NA	34	55
RA09	NA	110	83
RA10	NA	91	54
RA12	NA	188	78
RB01	NA	82	36
RB02	NA	20	42
RB03	NA	114	45
RB04	NA	43	20
RB05	NA	26	86
RB07	NA	78	22
RB08	NA	0	24
RB09	NA	81	34
RB11	NA	122	2340
RB12	NA	137	42
RB13	NA	42	21
RB14	NA	23	21
RB15	NA	68	36
RB16	NA	67	41
RB18	NA	113	40
RB19	NA	27	1

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
RB26	NA	180	31
RB28	NA	3	20
RB29	NA	71	86
RB30	NA	283	50
RH02	NA	76	78
RH03	NA	107	89
RH06	NA	120	117
RH07	NA	112	113
RH08	NA	295	66
RH09	NA	386	79
RH12	NA	32	29
RH13	NA	40	29
RH14	NA	30	47
RH15	NA	63	94
RH16	NA	48	82
RH17	NA	75	87
RH18	NA	72	84
RH20	NA	24	38
RH21	NA	42	46
RH22	NA	30	69
RH23	NA	49	85
RH24	NA	53	80
RH25	NA	36	79
RH26	NA	38	60
RH27	NA	35	24
RH28	NA	55	93
RH30	NA	49	81
RH33	NA	36	32
RH34	NA	47	39
RH36	NA	49	77
RH40	NA	157	55
RH42	NA	120	101
RH49	NA	51	52
RH50	NA	8	27
RH51	NA	10	0
RN01	NA	0	5
SC01	NA	1	0
SC02	NA	19	0
SC04	NA	0	34
SC05	NA	12	23

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
SC08	NA	233	0
SH02	NA	396	54
SH03	NA	67	51
SH04	NA	67	36
SH06	NA	60	44
SY01	NA	479	15
SY02	NA	358	12
SY03	NA	36	0
SY04	NA	19	1
SY05	NA	8	6
SY06	NA	6	0
SY07	NA	44	0
SY08	NA	9	0
SY09	NA	14	1
SY10	NA	49	12
SY11	NA	36	17
SY13	NA	2	13
SY14	NA	1	2
SY15	NA	0	1
SY16	NA	0	6
SY17	NA	17	0
SY18	NA	8	0
SY19	NA	0	0
SY20	NA	27	0
SY22	NA	2	10
SY23	NA	30	22
SY25	NA	7	2
SY27	NA	1	3
TA01	NA	8	0
TA06	NA	25	49
TA07	NA	0	0
TA13	NA	0	27
VA538S	NA	59	63
VA546S	NA	184	73
VA550S	NA	65	55
VA567S	NA	41	20
VA756S	NA	110	102
VA769S	NA	76	106
VA772S	NA	77	92
VA774S	NA	184	134

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
VA788S	NA	101	135
VA789S	NA	143	72
VA793S	NA	0	0
VA794S	NA	54	14
VA822S	NA	28	28
VT01	NA	25	0
VT03	NA	11	0
VT04	NA	0	6
VT13	NA	61	10
VT16	NA	37	101
VT17	NA	104	102
VT22	NA	31	13
VT23	NA	47	8
VT29	NA	16	14
VT40	NA	0	0
VT42	NA	0	0
VT43	NA	0	2
VT44	NA	0	20
VT45	NA	7	25
VT51	NA	130	91
VT52	NA	56	18
VT60	NA	125	75
VT61	NA	166	78
VT63	NA	14	23
VT64	NA	7	28
VT65	NA	10	26
VT68	NA	0	0
VT69	NA	0	0
VT71	NA	5	0
VT76	NA	1	6
WA01	NA	14	11
WA02	NA	10	0
WA04	NA	9	13
WE01	NA	0	0
WE02	NA	0	0
WE03	NA	23	1
WN01	NA	221	107
WV525S	NA	41	32
WV543S	NA	49	35
WV545S	NA	105	142

Site ID	Method of Estimating BC_w for Inclusion in the SSWC Equation to Estimate CL		
	Primary Site Specific[1]	Secondary Site Specific[2]	Mapped Regional[3]
WY01	NA	80	17
WY02	NA	36	19
WY03	NA	52	13
WY04	NA	62	16
WY05	NA	50	28

1 BC_w taken from MAGIC calibrations
2 BC_w estimated using regression equations based on water chemistry plus landscape variables
3 BC_w estimated using regression equations based on landscape variables
4 NA = not applicable; no MAGIC calibration was done