Assessment of Effects of Acidic Deposition on Forested Ecosystems in Great Smoky Mountains National Park using Critical Loads for Sulfur and Nitrogen

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Photo credit: View from Clingmans Dome towards Elkmont (Jim Renfro, NPS)

Executive Summary

Impacts of acidic deposition

The eastern U.S. has been severely impacted by elevated atmospheric deposition of sulfur (S) and nitrogen (N), which contribute to acidification of soils and surface waters, with detrimental effects on forest vegetation and aquatic biota. The decrease in emissions of sulfur dioxide in the U.S. since 1973, as a result of the Clean Air Act (CAA), has not coincided with widespread recovery of soil and surface waters from acidic deposition. Indeed, S and N deposition remain serious threats to forest health in the region. Excess acidic deposition may lead to depletion of nutrient base cations, while excess N deposition may lead to N saturation. Ultimately, both N and S deposition may lead to plant nutrient imbalances, increased susceptibility to pests and disease and other secondary stresses, and declines in forest productivity and health.

Scope of report

The purpose of this assessment was to calculate critical loads of S and N deposition to forests in Great Smoky Mountains National Park (GSMNP) based on available data. Four sites within the park were selected for this assessment to represent the range of forest ecosystems within the Park.

This final report includes a summary of data available for these sites; a description of the methods for making critical loads calculations; the range of calculated critical loads and exceedances using various critical thresholds, and the time to damage/recovery for multiple deposition scenarios. In this summary, we identify the lowest critical load that was calculated for each site, because it is the lowest amount of deposition the ecosystem can receive before causing damage and one that will be the most protective of the forest ecosystem.

Approach used for assessing impacts of Sulfur and N deposition at GSMNP

Critical load calculations of acidity (N+S) and nutrient N were calculated using a simple mass-balance model and the Very Simple Dynamic model (VSD).The simple mass-balance model compares ecosystem inputs (including N or S deposition) to ecosystem outputs (including leaching) and uptake. The dynamic model introduces a time element to predict at what point in the future an effect may occur, or when ecosystem recovery may occur. In the dynamic modeling, we evaluated various deposition scenarios in order to evaluate emission control strategies (planned or potential) including VISTAS and EPA-CAIR.

A **critical load** is the deposition below which harmful effects to the ecosystem do not occur. **Exceedance** is amount by which current deposition exceeds the critical load.

In order to make this assessment, we assembled a database including S and N deposition inputs; vegetation nutrient uptake and dynamics; soil properties, including the ability to buffer against acidification and re-supply nutrients lost because of acidification of soils; and soil solution chemistry.

Impacts

Current deposition exceeded the critical load at all four sites evaluated (2 high elevation spruce-fir sites, a mid-high elevation beech site, and a lower elevation mixed hardwood site). The exceedance for S + N deposition ranged from 150 eq ha^{-1} y^{-1} for the low elevation mixed hardwood site to 2300 eq ha^{-1} y^{-1} at the upper spruce-fir site. The maximum acceptable deposition of N (the critical load for N nutrient) ranged from 200 eq ha^{-1} y^{-1} (3 kg ha^{-1} y^{-1}) for the low elevation mixed hardwood site to 500 eq ha^{-1} y^{-1} (7 kg ha^{-1} y^{-1}) at the upper spruce-fir site.

The consequences of exceeding acidification, based on the literature, are expected to be elevated streamwater nitrate concentration and acid neutralizing capacity (ANC) below 0 μeq L^{-1}. At GSMNP, we currently observe both of these conditions, which indicate that the system has become acidified at the current level of deposition. The consequences of exceeding N saturation, based on the literature, are expected to be elevated streamwater nitrate concentration, increased nitrification, and ultimately plant nutrient imbalances and declines in forest health. At GSMNP, studies have shown elevated streamwater nitrate losses and relatively low N retention at the Lower Spruce-Fir site (van Miegroet et al., 2001) which suggests that the site is at N saturation. These field observations confirm our estimation that current deposition is in excess of the critical load for nutrient N.

Deposition reductions

Current deposition ranges from 10-31 kg ha^{-1} y^{-1} for S and 8.5-32 ha^{-1} y^{-1} for N. Deposition reductions of 53% of S+N (from current inputs of 4271 eq ha^{-1} y^{-1}) would be necessary to protect the upper spruce-fir site for concerns of acidification, deposition reductions of 89% (from current inputs of 32 kg N ha^{-1} y^{-1}; 2313 eq ha^{-1} y^{-1}) would be required to protect the lower spruce-fir site for concerns of N saturation. Under both VISTAS and EPA-CAIR deposition reductions, the lower spruce-fir, the beech and the mixed hardwood site would be protected from detrimental effects of acidification (S+N), but not from N saturation. The upper spruce-fir site would not be protected for either acidification or N saturation using either deposition reduction scenario.

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1. Introduction

The eastern U.S. has been severely impacted by elevated atmospheric deposition of sulfur (S) and nitrogen (N; Driscoll et al., 2001). Atmospheric S and N deposition have contributed to acidification of soils and surface waters, with potential effects on forest vegetation and aquatic biota. Emissions of sulfur dioxide peaked in the U.S. in 1973 and, as a result of the Clean Air Act (CAA), have since declined ~45%. However, this pattern has not coincided with widespread recovery of soil and surface waters from acidic deposition (Stoddard et al., 2003). Nitrogen deposition represents a threat to forest health beyond the impacts of acidification; elevated N deposition can lead to plant nutrient imbalances and declines in forest health, in addition to elevated stream water nitrate concentrations (Aber et al., 1989). In the eastern U.S., widespread elevated streamwater nitrate concentrations have been observed (Aber et al. 2003) and, with total N inputs of only 20 kg N ha^{-1} y^{-1}, forest decline was induced at an experimental N addition in southern Vermont (McNulty et al., 1996; 2005). In the western U.S., detrimental effects of N deposition including increased N mineralization and N losses in streamwater and changes in species composition have been observed (Fenn et al., 2003a, b).

Great Smoky Mountains National Park (GSMNP) receives high levels of N and S deposition. Soils in the park have low levels of base cations (e.g., calcium and magnesium) and therefore little capacity for buffering acidic inputs from N and S (Johnson and Lindberg, 1992). Acidification can mobilize aluminum (Al) in soils (Reuss 1983; Reuss and Johnson, 1985), resulting in toxicity to plants and other biota. Some tree species in the park are sensitive to acid and elevated N inputs (Southern Forest Resource Assessment, 2002). Therefore, GSMNP is susceptible to detrimental impacts from N and S deposition.

Critical Loads (CL) were introduced more than a decade ago in Europe as an air pollution control strategy to protect sensitive ecosystems (Posch et al., 2001). A critical load is "the estimate of exposure to pollutants below which harmful effects on sensitive elements of the environment do not occur according to present knowledge" (UBA, 2005). Critical loads have been calculated for a variety of pollutants including N, S, and heavy metals (DeVries et al., 1998; UBA, 2005; http://www.oekodata.com/icpmapping/index.html). Critical loads for acidity (N+S) are used to estimate the level of deposition that will lead to soil acidification and the subsequent detrimental effects. Critical loads for nutrient N describe the level of N deposition in excess of what the ecosystem can assimilate through biological activity. Ecosystems susceptible to effects of atmospheric deposition can be characterized by quantifying the extent to which current deposition exceeds the critical load (Exceedance = Current deposition – Critical Load).

1.1 Objective

The purpose of this assessment was to calculate critical loads for S and N deposition to forested ecosystems in Great Smoky Mountains National Park (GSMNP) based on existing data.
While many areas in the eastern and western U.S. receive high levels of N and/or S deposition, this modeling study focused on GSMNP, because the park receives some of the highest levels of atmospheric deposition in the eastern U.S. and has sufficient data available for the analysis. The methods described here may be applied to other areas where there are adequate data available.
Critical loads of acidity (N+S) and nutrient N were calculated for 2 high elevation spruce-fir sites (near Clingmans Dome; one is adjacent to Noland Divide Watershed), a mid-to-high elevation site (Beech Gap), and a lower elevation mixed hardwood site (near Elkmont) in Great Smoky Mountains National Park using a simple mass-balance model and the Very Simple Dynamic model (Version 2.4, Alterra, MNP/CCE, 2006; http://www.mnp.nl/cce/methmod).The simple mass-balance model compares ecosystem inputs (including N or S deposition) to ecosystem outputs and uptake. The dynamic model introduces a time element to predict at what point in the future an effect may occur, or when ecosystem recovery may occur. In the dynamic modeling, we evaluated various deposition scenarios in order to evaluate emission control strategies (planned or potential).

It is important to note that the critical loads presented in this report are specifically for the forest ecosystem. Critical loads for surface waters are not assessed in this analysis.

1.2 Approach

The steps involved in this assessment were to: (1) identify site data available; (2) identify sensitive indicators and critical thresholds; (3) identify deposition scenarios; (4) assemble data and assess data quality; (5) make simple mass balance method CL calculations for the four individual sites; (6) apply the Very Simple Dynamic model to these sites.

This final report includes a summary of data available for these sites; a description of the methods for making critical loads calculations; the range of calculated critical loads and exceedances using various critical thresholds, including identifying the lowest (most protective) critical load; and the time to damage/recovery for multiple deposition scenarios. The report includes several appendices: (1) a description of the database table; (2) the Microsoft ACCESS database of all data assembled; (3) input and output data from VSD model runs; (4) a summary of data relevant for determining critical thresholds at this site; (5) historical deposition data used in the VSD model; (6) a summary of publications at this site. The report also identifies missing data that could be used to improve CL estimates at this site; these may prove helpful for setting inventory and monitoring priorities in the future.

2 Site description

Four sites were used for the critical loads assessment in GSMNP (Table 2.1; Figure 2.1). These four sites were chosen to represent three forest types at different elevations. They were also chosen because we had available observational data (e.g. deposition, etc) associated with these landscapes. The forest types were: (1) high elevation spruce-fir, (2) mid-to-high elevation American beech, and (3) lower elevation hardwood. The high elevation spruce-fir and the mid-to-high elevation American beech sites were chosen so that data gathered in GSMNP for the Integrated Forest Study (IFS; Johnson and Lindberg, 1992) could be used. The lower elevation hardwood site selected was near the National Atmospheric Deposition Program (NADP) station in Elkmont.

The high elevation spruce-fir forest type is represented by two IFS sites, the Upper Spruce-Fir site (called the Becking site in the IFS), located at an elevation of 1800 m on a southwesterly slope west of Noland Divide near Clingmans Done, and the Lower Spruce-Fir site (called the Tower site in the IFS), located at an elevation of 1740 m on a southerly slope near Noland Divide near a spur road off of the main road to Clingmans Dome. The vegetation at the two sites are described in the IFS (Lindberg et al. 1992) as being dominated by old-growth red spruce (*Picea rubens*) with occasional Fraser fir (*Abies fraseri*) at the Upper Spruce-Fir site and occasional yellow birch (*Betula alleghaniensis*) at the Lower Spruce-Fir site (Lindberg et al., 1992). Both sites have Fraser fir as a component of the understory. The soils at both sites are classified as Umbric Dystrochrepts derived from Thunderhead sandstone. Soils have a silt loam to sandy loam texture, are acidic, characterized by high organic matter content and low base saturation, as well as high nitrogen (N) mineralization and nitrification capacity (Johnson et al., 1991; Garten and Van Miegroet, 1994).The Upper Spruce-Fir site is characterized by frequent large sandstone boulders on top of and within the soil profile. Both sites have a long-term mean annual precipitation volume of 200 cm. The forest condition at the Upper Spruce-Fir site was severely impacted by the balsam woolly adelgid (*Adelges picea* Ratz.), which caused dieback of mature Fraser fir. This major disturbance first led to changes in the forest structure by creating gaps of standing dead and fallen fir (Pauley et al., 1996). The function of the fir stand was subsequently altered by increased productivity of understory trees as a result of the gaps (Van Miegroet et al., 2007). Prior to the introduction of the balsam wooly adelgid, this site and the others within GSMNP had no history of logging or fire.

Table 2.1 Site Description

Site	Elevation (m)	Forest Type	Additional Site Information	IFS Study Site[1]
Upper Spruce-Fir	1800	Spruce-Fir	Red Spruce Becking site	IFS (SS)
Lower Spruce-Fir	1740	Spruce-Fir	Red Spruce Noland Divide Tower site	IFS (ST)
Beech Gap	1600	American Beech	American Beech site	IFS (SB)
Mixed Hardwood	635	Mixed Hardwood	NADP/NTN[2] Elkmont Site (TN11)	

[1]Sites included in the Integrated Forest Study (IFS; Johnson and Lindberg, 1992) are identified.
[2]National Atmospheric Deposition Program/National Trends Network

The mid-to-high elevation American beech site is represented by the IFS Beech Gap site, located at an elevation of 1600 m on a southerly slope 1 km west of Newfound Gap on the road to Clingmans Dome. The vegetation at the Beech Gap site is described by IFS as consisting primarily of beech (*Fagus grandifolia*) with occasional Buckeye (*Aesculus flava*) and red spruce (*Picea rubens*; Lindberg et al., 1992). The soils are classified as Umbric Dystrochrepts derived from the Anakeesta formation (shale parent material). (Note that Anakeesta formation is S-bearing, and thus leads to release of sulfate in soil solution/streamwater that is not anthropogenic). The Beech Gap site also has a long-term mean annual precipitation volume of 200 cm.

The low elevation hardwood site was chosen near the NADP station in Elkmont (elevation 635 m). An order 2 US Forest Soil Survey is available for GSMNP through NRCS (Khiel and Thomas, 2007). The Mixed Hardwood site is mapped as the Ditney-Unicoi soil complex. Typically, this soil complex consists of 40-50% moderately deep Ditney soils, 25-36% shallow Unicoi soils, and about 5% rock outcrop. These soils are well-drained and are weathered from metasedimentary rock such as arkose, metagraywacke, metasandstone, or quartzite. The dominant vegetation is listed as oak, hickory, and yellow pine. The Mixed Hardwood site has a long-term mean annual precipitation volume of 162 cm.

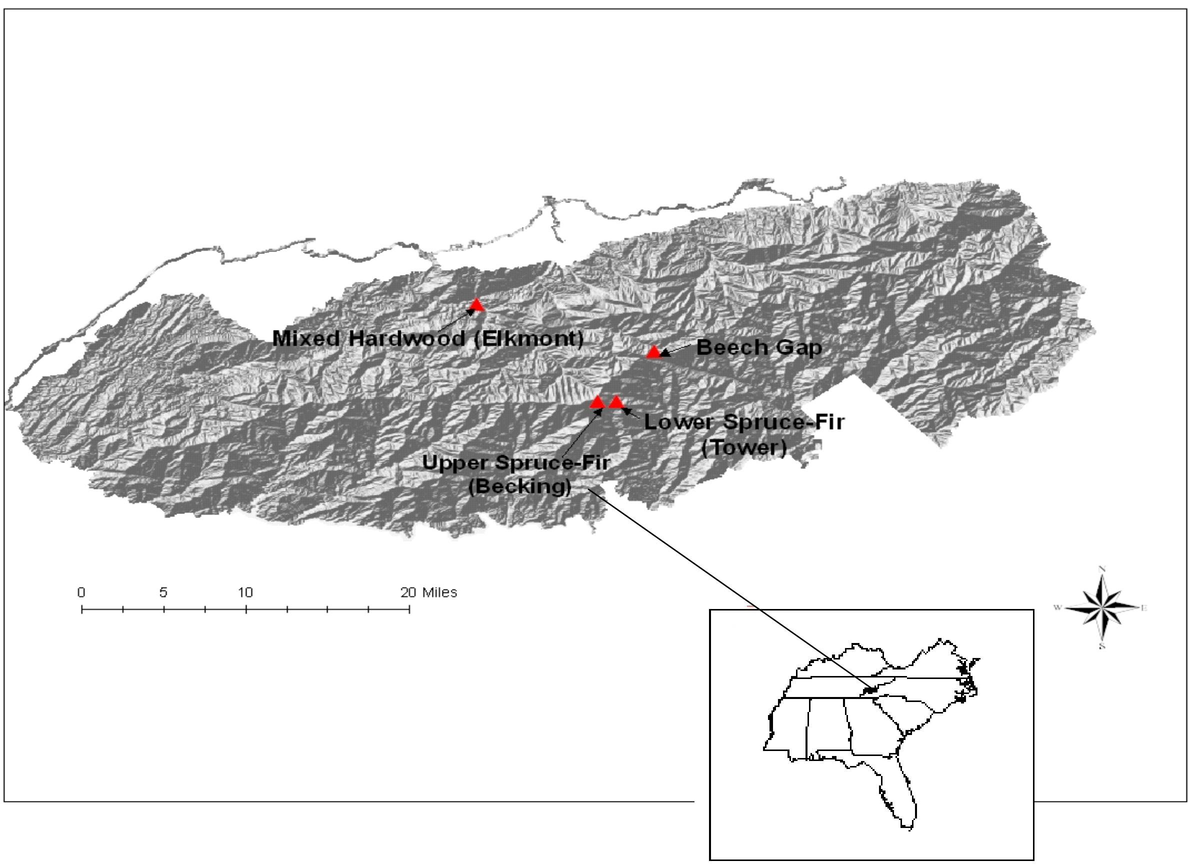
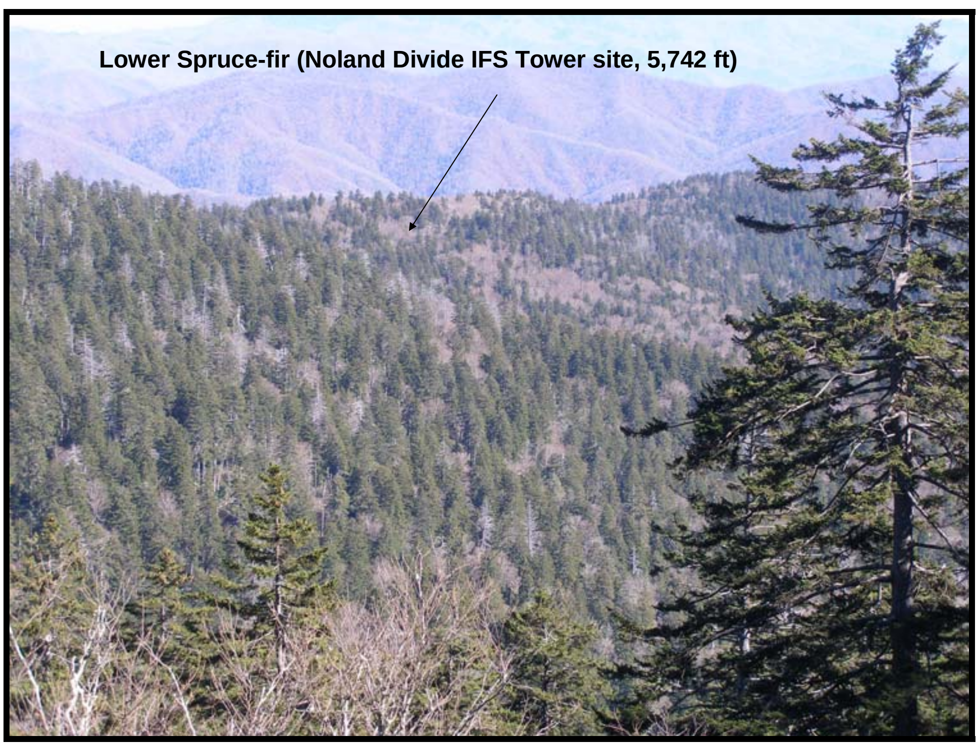
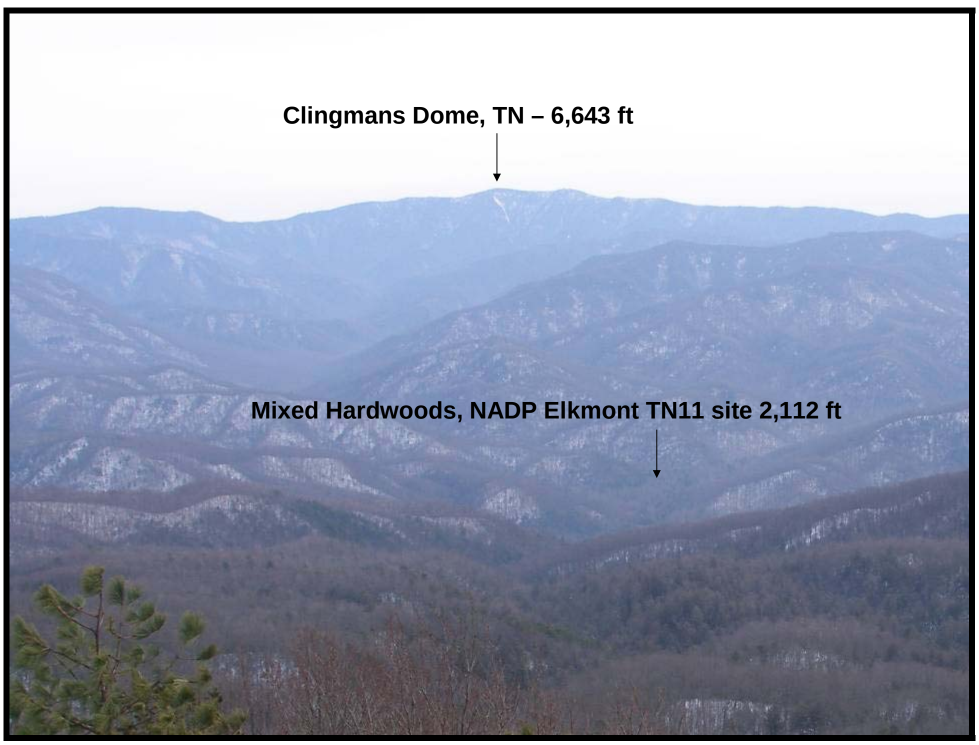


Figure 2.1 Map of site locations within Great Smoky Mountains National Park


Upper Spruce-fir (Clingmans Dome, IFS Becking site, 5940 ft)


Lower Spruce-fir (Noland Divide IFS Tower site, 5,742 ft)


Beech Gap (IFS American Beech site, 5,280 ft)


Clingmans Dome, TN – 6,643 ft
Mixed Hardwoods, NADP Elkmont TN11 site 2,112 ft

3 Methods for calculating critical loads

3.1 Background

The critical load is essentially a mass balance equation—the total amount of acid deposition that the ecosystem can tolerate must be balanced by the net input of neutralizing base cations (BC) in the ecosystem. Therefore, we calculate the sum of the BC inputs (from atmospheric deposition and mineral weathering) and outputs (from removal of biomass and leaching losses) for an ecosystem to determine, first the net input of BC base cations per year and then, by extension, the CL for acidity for that site.

Critical loads for acidity are calculated using a process that involves several steps. Sulfur and nitrogen are processed very differently by forest ecosystems and therefore must be handled differently in calculating critical loads. Because all the S deposition to a site could contribute to acidifying that site, we calculate a term called CLS_{max} (we use the terminology of the ICP Mapping and Modelling Group for clarity and consistency). This term is the CL for acidity *in the absence of N deposition.* That is because, some of the N deposition will *not* contribute to acidifying the forest ecosystem, because it is taken up and stored in or released from the ecosystem. This non-acidifying portion of the N deposition is called CL N_{min}. In order to calculate the maximum CL for N, CLN_{max}, we add this amount of N (CLN_{min}) to the CLS_{max}. Thus the sum of CLS_{max} and CLN_{min} is also equivalent to the CL S+N or the critical load for acidity. Because the maximum CL for S and for N are different, we plot a function that describes all the possible combinations of S and N deposition that are equal to the critical load for acidity. In the sections that follow, we describe the equations that are used to calculate critical loads. Further description of the method can be found in Pardo (in review) and of the equations can be found in the ICP Mapping Manual (UBA, 2005).

3.1.1 Maximum critical load for sulfur ($CL_{max}(S)$)

The maximum CL for sulfur is given by:

$$CL_{max}(S) = BC_{dep} + BC_w - BC_u - ANC_{le} \quad [1]$$

where:

BC_{dep} = sum of Ca + Mg + Na + K deposition rate (eq ha^{-1} y^{-1})

BC_w = soil weathering rate of Ca + Mg + K + Na (eq ha^{-1} y^{-1})

BC_u = net Ca + Mg + K uptake rate (eq ha^{-1} y^{-1}) ultimately removed by harvest or disturbance

ANC_{le} = acceptable acid neutralizing capacity (ANC) leaching rate (eq ha^{-1} y^{-1}).

The acceptable ANC leaching rate is a measure of the loss of acid neutralizing capacity from the ecosystem. The acceptable ANC leaching rate is not a measured value, but is set based on a critical threshold which is intended to prevent certain detrimental conditions from occurring in the forest ecosystem. Critical thresholds and acceptable flux rates are described in more detail in section 3.3; the values used for critical thresholds in this analysis are also given. ANC leaching (ANC_{le}) can be calculated from the BC fluxes into and out of the ecosystem and from the critical threshold. Below we give the method for calculating ANC_{le} for the critical threshold using BC:Al ratio. This threshold is set based on projected detrimental effects on plant roots and ultimately on forest health when Al becomes more available to plants (relative to BC). The reasoning behind the use of the BC:Al ratio is described in detail elsewhere (Sverdrup and Warfvinge, 1993; Cronan and Grigal, 1995; UBA, 2005).The relationship between soil acidity and base cation status is based on the ion exchange equilibrium. In particular, the maintenance of the soil base saturation is closely linked with what constitutes an acceptable base cation leaching rate. This rate can be calculated from:

$$ANC_{le} = -1.5 \left(\frac{BC_{dep} + BC_w - BC_u}{(BC/Al)_{crit}} \right) - Q^{2/3} \left(1.5 \frac{BC_{dep} + BC_w - BC_u}{(BC/Al)_{crit} K_{gibb}} \right)^{1/3} \quad [2]$$

where:

ANC_{le} =	acceptable leaching rate of acid neutralizing capacity (ANC; eq ha^{-1} y^{-1})
BC_{dep} =	atmospheric base cation deposition rate (eq ha^{-1} y^{-1})
BC_w =	soil mineral weathering of base cations rate (eq ha^{-1} y^{-1})
BC_u =	net base cation removed via biomass removal; eq ha^{-1} y^{-1})
$(BC/Al)_{crit}$ =	critical threshold for BC/Al, set prior to calculating
Q =	rate of soil percolation, assumed equal to streamwater flux (m y^{-1})
K_{Gibb} =	Gibbsite dissolution constant that controls Al solubility (m^6 eq^{-2}), the multiplication factor 1.5 covert moles to equivalents

When critical thresholds other than the BC/Al ratio were used, the above equation was modified using the relationship between aluminum and hydrogen ion concentration described in the following equation. These modifications of the equations are described in detail in the ICP Mapping Manual (UBA, 2005).

$$K_{Gibb} = [Al] / [H^+]^3 \quad [3]$$

where:

K_{Gibb} = Gibbsite dissolution constant (m^6 mol^{-2})

$[H^+]$ = Hydrogen ion concentration in soil solution (mol m^{-3}),

[Al] = Aluminum concentration in soil solution (mol m^{-3}),

3.1.2 Minimum critical load for nitrogen ($CL_{min}(N)$)

The minimum critical load for N deposition is defined as the amount of N the forest ecosystem can retain. When all deposited N is consumed by N sinks within the ecosystem (acceptable N accumulation in soil, N uptake by the vegetation) or lost via denitrification, the deposition of N is below the minimum critical load of nitrogen, i.e.,

$$N_{dep} \leq N_a + N_u + N_{de} = CL_{min}(N) \qquad [4]$$

where:

N_{dep} = atmospheric N deposition rate (eq ha^{-1} y^{-1})

N_a = acceptable net N accumulation rate in the soil (eq ha^{-1} y^{-1})

N_u = net N removed via biomass removal; eq ha^{-1} y^{-1})

N_{de} = soil denitrification rate (eq ha^{-1} y^{-1})

When N deposition remains below $CL_{min}(N)$, $CL_{max}(S)$ alone determines the critical load of acidity ((S+N); Figure 3.1). All of the above fluxes of N are expressed as net annual quantities. Although net soil accumulation of N may vary among sites (due to differences in long-term site history), this parameter is not a measured value, but an acceptable threshold that is set prior to making critical loads calculations. Values for rates of acceptable fluxes are given in Tables 3.6-3.8 and are described in more detail in section 3.3. For well-drained, upland forest soils, denitrification rates are typically low (Binkley et al., 1995). Assuming denitrification to be negligible gives a conservative estimate of CL (i.e., the CL would be higher if denitrification were assumed to be greater).

3.1.3 Maximum critical load for nitrogen ($CL_{max}(N)$)

The maximum critical load for N deposition, $CL_{max}(N)$ is the sum of the N retained in the ecosystem ($CL_{min}N$) plus the maximum acid deposition rate for S (CL S_{max}), and is given by:

$$CL_{max}N = CL_{min}(N) + CL_{max}(S) \qquad [5]$$

3.1.4 Critical load of nutrient nitrogen ($CL_{nut}(N)$)

Upland forests initially respond to the fertilizing effect of additional N deposition by increasing productivity, until they reach N saturation (Aber et al., 1989). Once a forest reaches N saturation, acidification from N deposition increases, nitrate leaching increases, and plant nutrient imbalances may occur. When there is excess available nitrogen, other nutrient elements such as calcium (Ca), magnesium (Mg), potassium (K), and phosphorus (P) become growth limiting (Schulze, 1989). The resulting nutrient imbalances can lead to increased susceptibility to insect infestation and to disease and may ultimately lead to changes in plant species composition. More discussion on the concept of a critical load for nutrient N can be found in the ICP Mapping Manual (UBA, 2005) and Pardo (In review).

The critical load for nutrient N is defined as the sum of the net N accumulation in the soil, net N removed via biomass removal, soil denitrification, and acceptable N leaching. (Note that the first three terms represent the CL_{min}(N)). The acceptable nitrogen leaching rate, N_{le}, is the maximum acceptable leaching rate for an ecosystem that is not at N saturation. This leaching rate is given by

$$N_{le(acc)} = Q[N]_{crit} \quad [6]$$

where:

$N_{le(acc)}$ = acceptable leaching of N

$[N]_{crit}$ = the N concentration in the soil solution above which would be considered detrimental to ecosystem or soil

CL_{nut}(N) can then be expressed as

$$CL_{nut}(N) = N_a + N_u + N_{de} + N_{le} \quad [7]$$

In view of both acidification and N saturation issues, the critical load for N deposition was determined by CL_{max}(N) or CL_{nut}(N), whichever had the lowest value.

3.1.5 Critical load for acidity (CL(S+N))

Since both S and N deposition contribute to acidity, they are both included in the calculation of the critical load for acidity:

$$CL(S+N) = CL_{max}(S) + CL_{min}(N) \quad [8]$$

3.1.6 Calculation of exceedance (of the critical load of acidity)

Calculated critical loads were compared with current rates of S+N deposition. When current S+N deposition was greater than the critical load, the critical load was exceeded. Exceedance is defined as:

$$Exceedance = [S_{dep} + N_{dep}] - CL(S+N) \qquad [9]$$

For any forest ecosystem, there are many combinations of S and N deposition that will not exceed this critical load. The various combinations of S and N deposition that add up to the critical load for acidity therefore delineate the **acceptable acidic deposition region within the S and N deposition continuum** (i.e., the shaded area in Figure 3.1 is below *CL(S+N)*).

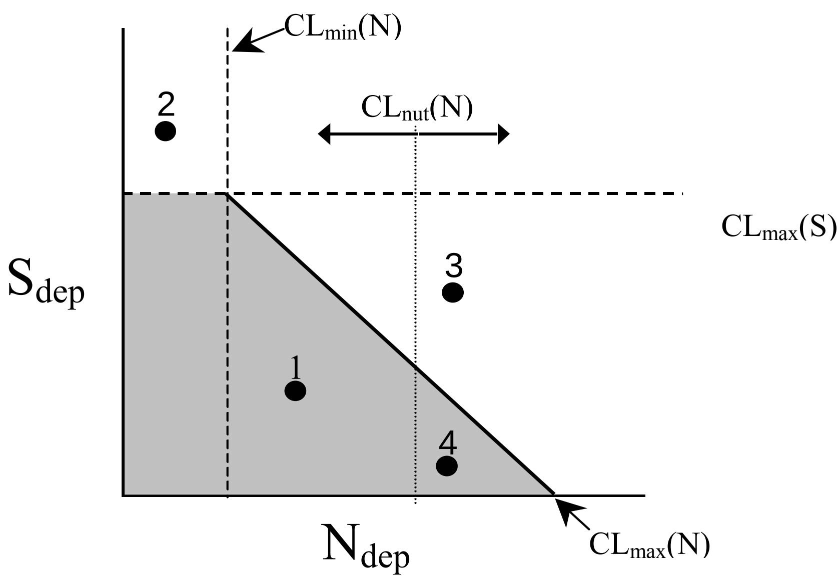


Figure 3.1 Relationship between atmospheric S and N deposition and the critical loads $CL_{max}(S) + CL_{max}(N)$ for upland forest soils For each point lying in the shaded area (e.g., Point 1), there is no exceedance of *CL(S+N)*. Points lying outside the shaded area exceed the critical load. For Point 2, S deposition is larger than $CL_{max}(S)$, and N deposition is less than the amount that the forest ecosystem can retain ($N_{dep} < CL_{min}(N)$). This means that the system would not be saturated with respect to N, and, in this case, only $CL_{max}(S)$ is exceeded. For Point 3, *CL(S+N)* and $CL_{nut}(N)$ are exceeded. For Point 4, even though *CL(S+N)* is not exceeded, $CL_{nut}(N)$ is exceeded (note: the associated vertical line can be moved to the right or the left depending on one's choice about $[N]_{crit}$). The slope of the shaded area is -1 for the case of upland forests, when denitrification is considered negligible.

3.2 Detailed Methodology Used for Calculating Critical Loads

3.2.1 Deposition and Climate Input Parameters

Deposition and climate input parameters for VSD calculations include soil percolation rates (runoff) and atmospheric deposition (S, N, base cations, Cl) rates. The modeled soil percolation rate for the high and mid-to-high elevation sites came from the IFS study (Chapter 3, Table 3.3, p. 32 in Johnson and Lindberg, 1992); the value for the lower elevation Mixed Hardwood site came from a map of mean annual runoff for the northeastern, southeastern, and mid-Atlantic United States (Krug, 1990). Current deposition rates for the high elevation sites are based on mean measured wet deposition data collected using an Aerochemetrics wet-only collector in an open clearing near the Lower Spruce-Fir site from 1999-2004 (B. Robinson, pers. comm.; University of Tennessee). The volume-weighted annual mean wet deposition values were then scaled, as described below, to estimate total (wet + dry + cloud) deposition (Table 3.1).

Table 3.1 Deposition Inputs at GSMNP

Site	Elevation	Total S deposition		Total N deposition		Total base cation deposition
	(m)	eq ha^{-1} y^{-1}	kg ha^{-1} y^{-1}	eq ha^{-1} y^{-1}	kg ha^{-1} y^{-1}	eq ha^{-1} y^{-1}
Upper Spruce-Fir	1800	1958	31	2313	32	1713
Lower Spruce-Fir	1740	1958	31	2313	32	1713
Beech Gap	1600	983	16	1162	16	860
Mixed Hardwood	635	625	10	607	8.5	173

For the high elevation conifer sites (Upper and Lower Spruce-Fir), we used the scaling factor of 4.4:1 for total N: wet N deposition based on the ratios from the IFS as reported by Van Miegroet et al. (2001) to estimate total (wet + dry + cloud) N deposition. For sulfur deposition, we used a scaling factor of 3.7:1 based on the ratio of total:wet deposition reported in the IFS (Johnson and Lindberg, 1992). We estimated current total base cation deposition by using the total BC: throughfall BC ratio from the IFS (0.79:1; Johnson and Lindberg, 1992) to scale the current throughfall BC deposition of 2159 eq ha^{-1} y^{-1} (B. Robinson, pers. comm.; University of Tennessee) to the total BC deposition of 1713 eq ha^{-1} y^{-1} at the spruce-fir sites. Current throughfall rates for the high elevation sites are based on mean measured throughfall data collected under the canopy at the Lower Spruce-Fir site from 1999-2004 (B. Robinson, pers. comm.; University of Tennessee).

There are no current measured deposition data for the Beech Gap site (mid-to-high-elevation). Therefore, we used the ratio of total deposition at the Beech Gap site: total deposition at the Upper Spruce-Fir site, 0.50 as reported by Weathers et al. (2006; and K. Weathers, personal communication), to estimate current deposition of N, S and BC.

For the Mixed Hardwood site (low elevation), we used current measurements of wet deposition data (S, N, base cation, Cl) from the National Atmospheric Deposition Program (NADP) site at Elkmont and current estimates of dry deposition (S and N only) from the CASTNET site at Look Rock. We used the scaling factor of 1.4:1 for total base cation: wet base cation deposition to estimate total (wet + dry) base cation deposition; the factor of 1.4 was calculated using the ratio of wet + dry S deposition: wet S deposition reported at Look Rock. It was not necessary to include cloud/fog contribution in deposition estimates for this site, as cloud/fog inputs at this low elevation are negligible.

Eleven deposition scenarios, based on planned or hypothetical emissions control strategies, were used to run the VSD model (Table 3.2). Scenario 1 holds current deposition rates constant into the future. Scenario 2 incorporates the relative reduction factors (percent changes) for total S (SO_4^{2-}, SO_2) and total N (NO_3^-, NH_4^+) deposition from VISTAS[1] based on 36 km CMAQ[2] modeled runs using 2002 as the base deposition year and 2018 as the target year. Scenario 3 uses the relative reduction factors for total S (SO_4^{2-}, SO_2) and total N (NO_3^-, NH_4^+) deposition from EPA-CAIR[3] based on 36 km CMAQ modeled runs using 2001 as the base deposition year and 2015 as the target year.

The remaining deposition reduction scenarios represent reductions of total S and NO_3^- deposition rates from 70 to 90%, combined with increases of 5-9% or reductions of 20-80% for NH_4^+. Deposition reductions are set to occur over the period 2002 – 2015 and then deposition is

[1] Visibility Improvement States and Tribal Association of the Southeast
[2] Community Multi-scale Air Quality Model
[3] Clean Air Interstate Rule

modeled to remain constant until 2150 (Table 3.2). In order to explore the effects of these relatively rapid reductions in deposition rates versus slower reductions, additional scenarios were implemented for scenarios 4 and 11 (4b and 11b, respectively). For these two additional scenarios, the same reduction as Scenario 3 was used for the period 2002-2015 and then the remaining reduction in deposition rates occurs from 2016-2050, after which deposition remains constant.

Table 3.2 Deposition Scenarios used for Critical Loads Dynamic Modeling in GSMNP

Scenario	Total S	NO_3^-	NH_4^+	Deposition reductions
1	No change	No change	No change	Current deposition (1999-2004 mean)
2	-50%	-48%	+9%	Deposition reductions evenly distributed from 2002 – 2018 (VISTAS)
3	-48%	-56%	+5%	Deposition reductions evenly distributed from 2002 – 2015 (EPA-CAIR)
4a	-70%	-70%	+9%	Deposition reductions evenly distributed from 2002 – 2015
4b	-70%	-70%	+9%	Scenario 3 reductions were used through 2015, the remainder of the deposition reductions are evenly distributed from 2015 – 2050
5	-80%	-80%	+9%	Deposition reductions evenly distributed from 2002 – 2015
6	-90%	-90%	+9%	Deposition reductions evenly distributed from 2002 – 2015
7	-90%	-90%	No change	Deposition reductions evenly distributed from 2002 – 2015
8	-90%	-90%	-20%	Deposition reductions evenly distributed from 2002 – 2015
9	-90%	-90%	-40%	Deposition reductions evenly distributed from 2002 – 2015
10	-90%	-90%	-60%	Deposition reductions evenly distributed from 2002 – 2015
11a	-90%	-90%	-80%	Deposition reductions evenly distributed from 2002 – 2015
11b	-90%	-90%	-80%	Scenario 3 reductions were used through 2015, the remainder of the deposition reductions are evenly distributed from 2015 – 2050

Table 3.3 shows the actual deposition values (scenario 1) and the various deposition reduction scenarios detailed in table 3.2.

Table 3.3 Deposition by Site for Deposition Scenarios used for Critical Loads Modeling

Future Deposition Scenarios (kg ha^{-1} y^{-1})												
	Upper/Lower Spruce-Fir				Beech Gap				Mixed hardwood			
Scenario[1]	Total S	NO3-N	NH4-N	Total N	Total S	NO3-N	NH4-N	Total N	Total S	NO3-N	NH4-N	Total N
1	31.4	19.7	12.7	32.4	15.7	9.8	6.3	16.2	10.0	6.0	2.5	8.5
2	15.7	10.2	13.8	24.0	7.8	5.1	6.9	12.0	5.0	3.1	2.7	5.8
3	16.3	8.7	13.3	22.0	8.1	4.7	6.7	11.4	6.3	2.6	2.6	5.2
4	9.4	5.9	13.8	19.7	4.7	3.0	6.9	9.9	3.0	1.8	2.7	4.5
5	6.3	3.9	13.8	17.7	3.1	2.0	6.9	8.9	2.0	1.2	2.7	3.9
6	3.1	2.0	13.8	15.8	1.6	1.0	6.9	7.9	1.0	0.6	2.7	3.3
7	3.1	2.0	12.7	14.7	1.6	1.0	6.3	7.3	1.0	0.6	2.5	3.1
8	3.1	2.0	10.2	12.2	1.6	1.0	5.1	6.1	1.0	0.6	2.0	2.6
9	3.1	2.0	7.6	9.6	1.6	1.0	3.8	4.8	1.0	0.6	1.5	2.1
10	3.1	2.0	5.1	7.1	1.6	1.0	2.5	3.5	1.0	0.6	1.0	1.6
11	3.1	2.0	2.5	4.5	1.6	1.0	1.3	2.3	1.0	0.6	0.5	1.1
Future Deposition Scenarios (eq ha^{-1} y^{-1})												
	Upper/Lower Spruce-Fir				Beech Gap				Mixed hardwood			
Scenario[1]	Total S	NO3-N	NH4-N	Total N	Total S	NO3-N	NH4-N	Total N	Total S	NO3-N	NH4-N	Total N
1	1962	1406	907	2313	979	703	453	1156	625	428	178	607
2	981	728	985	1713	490	366	494	859	312	221	193	414
3	1019	621	950	1571	509	337	476	813	394	186	186	371
4	587	421	985	1406	294	211	494	705	187	129	193	321
5	394	278	985	1264	196	141	494	634	125	86	193	278
6	194	141	985	1128	98	70	494	564	62	43	193	236
7	194	143	907	1049	98	70	453	523	62	43	178	221
8	194	143	728	871	98	70	362	433	62	43	143	186
9	194	143	543	685	98	70	272	342	62	43	107	150
10	194	143	363	507	98	70	181	252	62	43	71	114
11	194	143	178	321	98	70	91	161	62	43	36	79

[1] Scenarios are described in Table 3.2

3.2.2 Nutrient uptake parameters

In the calculation of critical loads, nutrient uptake and storage by vegetation are only accounted for when vegetation biomass is removed from the ecosystem. Otherwise, at steady state, for the ecosystem as a whole, there is no ***net*** change in standing biomass and therefore no ***net annual*** nutrient requirement. While forest tree species vary in their inherent growth rates and demand for specific nutrients, it is assumed that the foliar requirements are met by nutrients recycled in litter. When forests are harvested, in contrast to the steady-state scenario, all or part of the nutrient pool in the aboveground biomass is removed.

3.2.2.1 Nutrient sequestration

Although there is no harvesting in GSMNP, an unusual situation is found at the higher elevation sites. Due to high mortality of fir from an infestation of the exotic pest, the balsam woolly adelgid, since the 1970s, followed by hurricane- and ice storm- driven blowdown of spruce in the 1980s and 1990s, most of the mature fir trees are no longer present in the overstory and the presence of spruce in the overstory has also been reduced (Van Miegroet et al., 2001). This has radically altered the structure of spruce-fir forest, especially at higher elevations, creating gaps which have allowed high growth rates normally associated with a forest that is growing rapidly and accumulating biomass (aggrading). This growth includes both release of advanced regeneration and increased growth of existing trees. Because of this rapid growth, the assumption of steady state for the above-ground biomass was not correct. Therefore, we estimated what the N uptake would be during this aggrading phase until the stands reached steady state, at which point there would be no further need to account for uptake of N and base cations.

We estimated net N uptake at the sites based on several previous studies over the period 1993-2003 (Barker et al., 2002; Van Miegroet et al., 2007). First, we estimated N increment in wood, by taking the mean of the value reported for 1993-1998 (Barker et al., 2002) and the value for C increment reported for 1998-2003 (Van Miegroet et al., 2007) from which we estimated N uptake using a C:N ratio of 200. In order to calculate **net** N increment, we then subtracted N release calculated from coarse woody debris decomposition reported by Van Miegroet et al. (2007), again, assuming a C:N ratio of 200. Finally, we estimated that the aggrading period might continue for approximately 50 years of the 100 year period for which we were making the critical load calculation; so we divided the current net N increment by 2 in order to have an average annual net increment value over the entire period we modeled. We refer to this value as *N sequestration.* Average N sequestration rates of 321 eq ha^{-1} y^{-1} (4.5 kg ha^{-1} y^{-1}) were used for the Upper Spruce-Fir site and 45 eq ha^{-1} y^{-1} (0.63 kg ha^{-1} y^{-1}) for the Lower Spruce-Fir site

(Table 3.4). This is consistent with greater growth responses at the highest elevation where disturbance was most pronounced. We used the base cation:N ratio of 1.75 for nutrient content in overstory bole wood, based on IFS data (Johnson and Lindberg, 1992), to estimate the net base cation removal rates of 562 eq ha^{-1} y^{-1} for the Upper Spruce-Fir site and 79 eq ha^{-1} y^{-1} for the Lower Spruce-Fir site. There was no long-term nutrient sequestration for the mid or low elevation hardwood sites, which were not affected by the balsam woolly adelgid infestation.

We altered equation 7 to reflect the N sequestration term.

CL_{nut}(N) can then be expressed as

$$CL_{nut}(N) = N_a + N_u + N_{se} + N_{de} + N_{le} \qquad [10]$$

Table 3.4 Nutrient Sequestration Rates used for calculating Critical Loads in GSMNP

Site	**N sequestration rate (eq ha^{-1} y^{-1})**	**Base cation sequestration rate (eq ha^{-1} y^{-1})**
Upper Spruce-Fir	321	562
Lower Spruce-Fir	45	79
Beech Gap	0	0
Mixed Hardwood	0	0

3.2.3 Soil input parameters

The primary soil input parameter used for both steady-state calculations and the VSD model is the soil mineral weathering rate. Soil mineral weathering, the primary means of replenishing base cations lost from the soil due to leaching caused by acidic deposition, is a very important parameter in the critical load model and is difficult to estimate. The soil mineral weathering rate is determined by the types of minerals present in the bedrock or substrate, soil physical properties, and the local climate (temperature and precipitation).

The high and mid elevation sites have mineral weathering rates reported in the IFS. The Mixed Hardwood site is not an IFS site and therefore did not have weathering rates calculated as described above. For this site, we used the substrate type/clay content method for estimating mineral weathering (Sverdrup et al., 1990). The inputs for the substrate type/clay content method include mean annual air temperature, soil depth, clay percent, and soil substrate. The three categories of soil substrate used are: acidic, intermediate, and basic. *Acidic soil substrates* include granites, gneiss, sandstones, and felsic rocks; *intermediate soil substrates* include diorite, granodiorite, conglomerates and most sedimentary rocks other than sand stone; *basic soil substrates* include mafic rocks, sedimentary rocks with low carbonate content, and carbonate rocks. Mineral soil depth was defined as the depth from the top of the mineral soil (A or E horizon) through the bottom of the B horizon (excluding BC and Bx horizons, if present); this depth was selected to represent the rooting zone. Average clay content was calculated as the depth-weighted average of clay content in the mineral soil in the rooting zone (based on horizon-level data).

The following equations are used in the substrate type/clay content method:

$$W_e = 56.7 * Clay - 0.32 * Clay^2 \quad \text{for acidic substrates} \quad [11]$$

$$W_e = 500 + 53.6 * Clay - 0.18 * Clay^2 \quad \text{for intermediate substrates} \quad [12]$$

$$W_e = 500 + 59.2 * Clay \quad \text{for basic substrates} \quad [13]$$

where: W_e = empirical mineral weathering rate for 1 m soil (eq ha^{-1} y^{-1})
Clay = average clay percent in the mineral soil (%)

For this analysis, all the sites fell into the acidic substrate category, so we used equation 11. This empirical mineral weathering rate is then corrected for the air temperature:

$$W_c = W_e * e^{((A/(2.6 + 273))-(A/(273 + T_m)))} \quad [14]$$

where: W_c = weathering rate corrected for air temp. (eq ha^{-1} y^{-1} m^{-1})
A = Arthenius constant (3600º K)
T_m = Mean annual air temperature (ºC)

Lastly, the weathering rate is corrected for the actual depth of the mineral soil, through the B horizon:

$$W = W_c * depth \quad [15]$$

where W = the estimated mineral weathering rate (eq ha^{-1} y^{-1})
Depth = the depth of the mineral soil, through the B horizon (m)

Weathering rates were calculated using depth-weighted data weighted by area for the all of the soil series that make up the components of the NRCS GSMNP order 2 map unit ID (Khiel and Thomas, 2007) for the site. Order 2 soil maps are mapped to the soil series level, the map units in GSMNP map range from 1.6 ha to approximately 405 ha. The Mixed Hardwood site is mapped as the Ditney-Unicoi soil complex. Typically, this soil complex consists of 40-50% moderately deep Ditney soils, 25-36% shallow Unicoi soils, and about 5% rock outcrop. These soils are well-drained and are weathered from metasedimentary rock such as arkose, metagraywacke, metasandstone, or quartzite.

Because the weathering rate reported for the Beech Gap site in the IFS, 289 eq ha^{-1} y^{-1}, was extremely low, we used the substrate type/clay content method to estimate soil mineral weathering at this site as well. The Beech Gap site is mapped as the Luftee-Anakeesta soil complex. Typically, this soil complex consists of 45-55% moderately deep Luftee soils and 25-35% deep Anakeesta soils. These soils are well-drained and are underlain by Anakeesta slate. Approximately 20% of this map unit area is described as small areas of Breakneck and Pullback soils that form over Thunderhead Sandstone bedrock, and boulder trains and rock outcrops.

Table 3.5 Soil Mineral Weathering Rates used for GSMNP Sites

Site	Weathering rates (eq ha^{-1} y^{-1})	Source
Upper Spruce-Fir Site	770	IFS
Lower Spruce-Fir Site	2632	IFS
Beech Gap Site	682	Substrate type – clay %[1]
Mixed Hardwood Site	971	Substrate type – clay %[1]

[1]Sverdrup et al., 1990

Additional soil input parameters for VSD include depth, bulk density, moisture, cation exchange capacity (CEC), base saturation, carbon pool, C:N, and partial pressure of CO_2 (pCO_2) in soil solution. Soil depth, bulk density, cation exchange capacity (CEC), base saturation (BS), C pool, and C:N are depth-weighted means calculated using measured values for each of the sites. For the high and mid elevation sites, these data came from the IFS study (Johnson and Lindberg, 1992). For the low elevation sites, all soil data came from pedon data used in creating the NRCS order 2 soil map for GSMNP (Khiel and Thomas, 2007). Soil bulk density reported in the NRCS order 2 soil map is based only on the <2mm fraction of soil. While this might be expected to lead to an underestimate of bulk density (and, thus, an underestimate of weathering rate), the value reported was nearly the same as that measured at the Beech Gap site. We therefore assumed that the bulk density used for the Mixed Hardwood site was similar to what would have been measured in the field. Soil moisture (field capacity) was estimated based on reported soil texture using the relationships reported by Brady (1990); we did not use the measured data, as these data indicate soil moisture at the time of sampling, and do not necessarily represent typical field capacity. As we did not have measured pCO_2 in soil solution (as a multiple of pCO_2 (atm) in air) for any of the sites, a value of 17 was used as default.

3.3 Sensitive receptors and critical thresholds

An important step in estimating critical loads is trying to relate the ultimate biological or ecosystem effect to some measurable quantity—often a chemical characteristic. This chemical characteristic is referred to as a *chemical criteria*. The value of the chemical criteria, above which a detrimental effect is observed, is called the *critical threshold.* In terrestrial ecosystems, setting critical thresholds is difficult, because of the complexity of nutrient cycling and the spatial heterogeneity of these ecosystems (UBA, 2005). Different critical thresholds will lead to different critical loads. In general, the critical threshold that best addresses the receptor of concern is selected (for example, for some receptors, a decrease in pH would be most problematic, for other receptors, an increase in the Al concentration). A receptor might be a particular organism or it might be an ecosystem compartment. When several critical loads are calculated using different receptors, the lowest value is generally used as the critical load for the ecosystem.

3.3.1 Critical thresholds for calculating CL(S+N)

The VSD model can also be used to calculate steady-state CL(S+N) using various chemical criteria. For this project, we used four different chemical criteria: Al concentration, Al:BC ratio pH in soil solution, and base saturation of soil for the VSD model calculations (Table 3.6). We selected these chemical criteria because they are the most widely used in critical loads assessment in Europe and North America. For steady-state calculations of CL(S+N), the Al:BC ratios of 0.1 and 1.0 mol mol^{-1} were used as the critical thresholds. The values of the critical thresholds we used for these chemical criteria, as well as for the acceptable flux rates, are shown in Tables 3.6 and 3.7.

Table 3.6 Critical Thresholds used to calculate Steady-State Critical Loads for Acidity (S+N) in GSMNP

Chemical Criterion	Critical Threshold	Comments
Aluminum concentration in soil solution	0.2 meq L^{-1}	
Al:BC ratio in soil solution	0.1 mol mol^{-1}	Used in NEG/ECP analysis[1]
	1.0 mol mol^{-1}	Widely used in Europe
pH in soil solution	4.2	
Base saturation of soil	No decrease	

[1]New England Governors' and Eastern Canadian Premiers Forest Sensitivity Mapping Project

Table 3.7 Acceptable Flux Terms used to calculate Steady-State Critical Loads for Acidity (S+N) in GSMNP

Parameter		Acceptable flux rate	Comments
Biomass BC removal	BC_u	0 eq ha^{-1} y^{-1}	No harvesting is permitted in the Park
BC sequestration	BC_{se}	0-560 eq ha^{-1} y^{-1}	

We used a range of values for critical thresholds in order to be able to compare the results of our analysis with previous analyses. Different chemical criteria may protect different parts of an ecosystem; different values for a critical threshold afford different levels of protection. The most broadly used chemical criterion is the Al:BC ratio in soil solution. This criterion is used because of research linking elevated Al availability in soils relative to base cation (especially Ca) availability to root toxicity. Because Al uptake by plants increases when Ca and other BC become scarce, it is typically not the absolute value of Al concentration in soil that is biologically meaningful, rather the ratio (Al:BC) is linked to plant toxicity.

Because of the high variability of ecosystem responses to cation depletion, in the New England Governors' and Eastern Canadian Premiers' assessment of forest sensitivity to S+N deposition in the Eastern Canadian Provinces (Ouimet et al. 2001) and New England states (NEG/ECP Forest Mapping Group, 2003), a lower critical threshold was selected (0.1 mol mol^{-1}). The objective in selecting this lower critical threshold was ultimately to protect against decreases in base saturation. Base saturation is a measure of how much of the maximum potential buffering capacity in base cations remains at a site (the percentage of cation exchange sites in a soil that are actually occupied by various base cations). In order to protect forest ecosystems from the effects of cation depletion (loss of exchangeable base cations, and hence reduction in % base saturation), the critical threshold was to allow no decrease in base saturation. Mathematically, this was achieved by setting the Al:BC=0.1 mol mol^{-1}, since base saturation is not a term in the equation used in the steady-state mass balance method. pH is typically selected in systems with high organic matter, since organic matter may complex with Al making it less available and therefore less toxic to plants for a given deposition level. Aluminum concentration may be selected as the chemical criterion, especially if there is a drinking water standard that can be used a critical threshold for Al concentration. We included critical thresholds for these two criteria for comparison purposes and to demonstrate the range of critical loads that different chemical criteria will produce.

3.3.2 Critical thresholds for calculating $CL_{nutrient}(N)$

The values of the critical thresholds we used for these chemical criteria, as well as for the acceptable flux rates and other sinks for N are shown in Table 3.8.

Table 3.8 Parameters used to calculate Critical Loads for Nutrient N

Parameter		Value	Comments
Acceptable nitrate concentration	$N_{le(acc)}$	0.2 mg N L^{-1}	Up to 0.4 mg N/L
Acceptable soil N accumulation	N_a	0.5 kg N ha^{-1} y^{-1}	A range from 0 to 1 kg N/ha/y can be used
Biomass N removal	N_u	0 kg N ha^{-1} y^{-1}	No harvesting is permitted in the Park
***Net* N sequestration**	N_{se}	0 – 5 kg N ha^{-1} y^{-1}	Varies with elevation
Denitrification	N_{de}	0 kg N ha^{-1} y^{-1}	Denitrification is assumed to be negligible in these upland forest soils

3.4 Data input tables for Very Simple Dynamic model

The input data for the VSD model and the sources of data for these inputs are summarized below (Tables 3.9 and 3.10). A complete listing of the input and output data for the VSD model is given in Appendix 8.3.

Table 3.9 Data Sources for VSD Inputs

		High Elevation: Noland Divide		Mid-to-High Elevation	Lower Elevation
Parameters	**Comments**	**Upper Spruce-Fir**	**Lower Spruce-Fir**	**Beech Gap**	**Mixed Hardwood**
Soil Depth	Measured	IFS	IFS	IFS	NRCS
Bulk density	Measured	IFS	IFS	IFS	NRCS
Soil Moisture	Estimated	based on texture[1]	based on texture	based on texture	based on texture
CEC	Measured	IFS	IFS	IFS	NRCS
Base saturation (obs)	Measured	IFS	IFS	IFS	NRCS
C pool (obs)	Measured	IFS	IFS	IFS	NRCS
C:N (obs)	Measured	IFS	IFS	IFS	NRCS
percolation	Modeled	IFS	IFS	IFS	NRCS
Weathering	Modeled	IFS	IFS	Substrate type-clay% method	Substrate type-clay% method
lgKAlBC[3]	Calibrated	VSD	VSD	VSD	VSD
lgKHBC[4]	Calibrated	VSD	VSD	VSD	VSD
lgKAlox[5]	Constant	Lit. Value[2]	Lit. Value	Lit. Value	Lit. Value
soil solution pCO2	Constant	Lit. Value	Lit. Value	Lit. Value	Lit. Value
Nim_acc[6]	Constant	Lit. Value	Lit. Value	Lit. Value	Lit. Value

[1]Brady, 1990, field capacity soil moisture; [2]Based on values from the literature; [3]Selectivity constant for Al-BC exchange; [4]Selectivity constant for H^+-BC exchange; [5]Gibbsite equilibrium constant, K_{Gibb}; [6]Acceptable N accumulation in soil, N_a

3.4.1.1.1 Cation Exchange

In VSD, two cation exchange models are available: Gaines-Thomas and Gapon. For GSMNP, we used the Gaines-Thomas relationship, which has been broadly used in critical loads calculations in the U.S (Cosby et al. 2001; NEC/ECP 2001; Chen et al. 2004). VSD uses recent measured values for C pool, C:N ratio, and base saturation to estimate their initial values and to calibrate the selectivity constants for Al-base cation exchange (log K Al:BC) and H^+-base cation exchange (log K H^+:BC). Other required parameters include the log10 of the Gibbsite equilibrium constant (logKAlox $(mol^2\ l^{-2})^{1-expAl}$), which was set to 8.77 for all three sites, and the exponent [Al] term (gibbsite equilibrium) which is 3 indicating a +3 charge on the Al ion in solution.

Table 3.10 Input Data for VSD Calculations

Parameters	Units	High Elevation: Noland Divide		Mid-to-High Elevation	Lower Elevation
		Upper Spruce-Fir	**Lower Spruce-Fir**	**Beech Gap**	**Mixed Hardwood**
Elevation	M	1800	1740	1600	635
Forest Type		Fraser fir Red Spruce	Fraser fir Red Spruce	Beech	Mixed Hardwood
Time frame		1945 – 2150	1945 - 2150	1945 - 2150	1945 - 2150
Soil Depth	M	0.46	0.57	0.74	0.83
Bulk density	g cm^{-3}	0.92	0.92	1.13	1.09
Soil Moisture	M m^{-1}	0.12	0.12	0.12	0.15
CEC	meq kg^{-1}	180	293	239	132
Base saturation (obs)	%	7.6	9	21	11
C pool (obs)	g m^{-2}	5500	9500	9250	2409
C:N (obs)		10	12	11	16
Q	M	1.16	1.16	1.16	0.79
Weathering	Eq m^{-3} y^{-1}	0.0770	0.2632	0.0682	0.0971
	Eq ha^{-1} y^{-1}	770	2632	682	971
lgKAlBC		-0.48188	1.245	-0.6579	1.3242
lgKHBC		3.9325	4.7959	3.8444	4.8355
lgKAlox[1]		8.77	8.77	8.77	8.77
soil solution pCO2		17	17	17	17
Nim_acc[2]	Eq m^{-2} y^{-1}	0.0036	0.0036	0.0036	0.0036
	Kg ha^{-1} y^{-1}	0.5	0.5	0.5	0.5

[5]Gibbsite equilibrium constant, K_{Gibb}; [6]Acceptable N accumulation in soil, N_a

In order to run the VSD model, an initial calibration needs to be done using historical deposition beginning in a period before inputs of acid deposition were at their recent high levels. We used modeled historical deposition from the Southern Appalachian Mountain Initiative SAMI project (Sullivan et al., 2001; B.J. Cosby pers. comm.) in order to estimate historical deposition at these sites. Details on the estimation of historical deposition are given in Appendix 8.5.

We used modeled deposition for the site beginning in 1945. The model uses the measured base saturation to estimate the "initial" base saturation (at 1945). The exchange constants are calibrated based on the observed base saturation. The VSD model includes exchange between the solid phase and the soil solution for three ions: Al^{3+}, protons (H^+) and BC=Ca+Mg+K. The Gaines-Thomas exchange equation that is used in this calibration is:

$$\frac{E_{Al}^2}{E_{Bc}^3} = K_{AlBc} \cdot \frac{[Al]^2}{[Bc]^3} \quad \text{and} \quad \frac{E_H^2}{E_{Bc}} = K_{HBc} \cdot \frac{[H]^2}{[Bc]} \qquad [16]$$

where E_X is the equivalent fraction of ion X at the exchange complex, and K_{AlBc} and K_{HBc} are the selectivity constants for the Al:BC and H^+:BC exchange, respectively. Since the exchange complex is assumed to include H^+, Al and BC only, mass balance requires that

$$E_{BC} + E_{Al} + E_H = 1 \qquad [17]$$

3.4.1.1.2 Nitrogen

N cycling in VSD is also limited by minimum and maximum C:N ratios in soil. The idea behind these limits is that when an ecosystem has accumulated a lot of N in soil (when the soil C:N is low), nitrification and nitrate leaching will occur (Dise et al. 1998; Goodale et al. 2001); in contrast, when an ecosystem is very N limited (when the soil C:N is high), N will accumulate in the soil and nitrification will be low and nitrate leaching will be negligible. We used the default values for these parameters (minimum C:N = 15; maximum C:N = 40). Below a C:N ratio of 15, excess N leaches from the system as nitrate; above C:N=40 all excess N is accumulated in the soil. Between C:N=40 and C:N=15, the fraction of excess N that leaches from the soil (versus that which is accumulated) varies linearly from 0-100%.

The VSD model uses measured C:N and the C pool in soil to calibrate N immobilization in soil sub-model. At these sites, however, because the measured C:N ratios were below the VSD minimum of 15, the model used a default value of 15. This means that all excess N was leached. Because the measured C pool is an input parameter, this means that when the model calculates the N pool based on a C:N of 15, it underestimates the N pool. But since the size of N pool actually only affects N leaching rate when C:N>15, this underestimation of the N pool size does not change the model function (all excess N is leached).

Running the model shows the simulated time development for the C pool, C:N, and base saturation. If the model calibration was successful, the simulated parameter values match the observed value in the year of observation. Because the VSD model calibration takes place independent of (and before) running the model, there is no lead time required when running the model. VSD uses a single year time-step.

3.4.1.1.3 Model limitations

Organic acid dissociation is no longer an option within VSD. Sulfate adsorption is not included in the VSD model.

4 Results

4.1 Critical loads (CL)

4.1.1 Acidity (S+N)

In the calculation of critical loads for acidity (S+N), the determination of the ANC leaching is a key part of the equation. When ANC leaching is high, the ecosystem loses acid buffering capacity. Therefore, we calculate the acceptable rate of ANC leaching (ANC_{le}; equation 2). Different chemical criteria can be used to calculate ANC_{le} and will lead to different critical loads. For this project, we used four different chemical criteria: Al concentration, Al:BC ratio, and pH in soil solution, and base saturation of soil for the VSD model calculations (Table 3.6). We selected these chemical criteria because they are the most widely used in critical loads assessment in Europe and North America. (See section 3.3.1 for a detailed description of the different chemical criteria and critical thresholds used.) We assume that our methods have an uncertainty of at least 100-200 eq ha^{-1} y^{-1}, therefore, we consider critical loads that fall within that range to be equivalent. Uncertainty is discussed in section 5.4.

The Al:BC ratio of soil solution is used as an indicator for Al toxicity to plant roots, when the ratio is above a threshold value, roots may be harmed by Al. Using the critical threshold of Al:BC=0.1 yielded the lowest critical load for acidity compared to other critical thresholds for the Upper Spruce-Fir and Beech Gap sites; at the Lower Spruce-Fir and Mixed Hardwood sites the critical load for no decrease in base saturation was slightly, although not significantly, lower (Table 4.1; Figure 4.1). For this critical threshold (Al:BC=0.1), the lowest critical load reported was for the Mixed Hardwood site (1250 eq ha^{-1} y^{-1}); the highest critical load reported was for the Lower Spruce-Fir site (3680 eq ha^{-1} y^{-1}). Using the less conservative critical threshold of Al:BC=1.0 yielded critical loads a little more than twice those for the lower Al:BC threshold (Table 4.1; Figures 4.1 and 4.2).

The critical threshold for the chemical criterion base saturation was “no decrease in base saturation”. Permitting no decrease in base saturation protects an ecosystem from further cation depletion. The critical load that would permit no decrease in base saturation was intermediate to the critical load for the two Al:BC thresholds for the Upper Spruce-Fir site. For the other sites, the critical load for no decrease in base saturation was approximately equivalent to the CL using the lower Al:BC threshold (Table 4.1; Figures 4.1 and 4.2).

The critical load using the Al concentration critical threshold (0.2 meq L^{-1}) was higher than that using the upper Al:BC threshold except at the Lower Spruce-Fir site. The critical load using the critical threshold of pH=4.2 was consistently the highest (Table 4.1; Figures 4.1 and 4.2).
The Mixed Hardwood ecosystem had the lowest critical load of the four ecosystems, using the critical thresholds of no decrease in base saturation and Al:BC=0.1.

Table 4.1 Critical Loads for S+N Deposition at GSMNP

	CL(S+N) (eq ha^{-1} y^{-1})			
	Noland Divide			
Site:	**Upper Spruce-Fir**	**Lower Spruce-Fir**	**Beech Gap**	**Mixed Hardwood**
Base Saturation:	**8%**	**9%**	**21%**	**11%**
Critical Threshold				
Al=0.2 meq/L	4430	5780	4110	2920
Al:BC=0.1 mol/mol	2000	3680	1650	1250
Al:BC=1.0 mol/mol	4370	8320	3810	2800
Base Saturation	3210	3540	1690	1080
pH=4.2	7430	8790	7110	4970
S+N Current Deposition	*4271*	*4271*	*2136*	*1232*

4.1.2 Nutrient N

The critical load for nutrient N is typically a very low number at sites without significant timber harvesting. Indeed, for these four sites within GSMNP, the critical load for nutrient N ranged from 200 to 500 eq ha^{-1} y^{-1} (Table 4.2; Figure 4.3a). For all ecosystems, $CL_{nutrient}N$ was lower than CL (S+N). The critical load for nutrient N was similar for the Lower Spruce-Fir, Beech Gap, and Mixed Hardwood sites; $CL_{nutrient}N$ was slightly higher for the Upper Spruce-Fir site.

Table 4.2 Critical Loads and Exceedance for Nutrient N at GSMNP

Site ID	$CL_{nutrient}(N)$		N deposition		Exceedance of $CL_{nutrient}(N)$	
	eq ha^{-1} y^{-1}	kg ha^{-1} y^{-1}	eq ha^{-1} y^{-1}	kg ha^{-1} y^{-1}	eq ha^{-1} y^{-1}	kg ha^{-1} y^{-1}
Upper Spruce-Fir	522	7.3	2313	32.4	**1791**	**25.1**
Lower Spruce-Fir	246	3.4	2313	32.4	**2067**	**29.0**
Beech Gap	198	2.8	1157	16.2	**959**	**13.4**
Mixed Hardwood	196	2.7	607	8.5	**411**	**5.8**

4.2 Exceedance

4.2.1 Acidity (S+N)

The exceedance of the critical load is the amount of excess deposition at a site (the amount of deposition greater than what the ecosystem can tolerate). The exceedance is calculated by subtracting the critical load from the actual deposition (Exceedance = actual deposition – critical load). When the actual deposition is higher than the critical load, the exceedance is positive. When the actual deposition is lower than the critical load, the exceedance is negative.

Using the most conservative critical threshold (Al:BC=0.1), the critical load for S+N was exceeded for all the sites except Mixed Hardwood, where the deposition is approximately equal to the critical load (Table 4.3). For the criterion of no decrease in base saturation, the critical load for S+N was exceeded for all the sites; this exceedance was low at the Mixed Hardwood site (Table 4.3). Using the critical thresholds for Al concentration and Al:BC=1, at the Upper Spruce-Fir site, the current deposition is approximately equal to the critical load. For the remaining sites, using the critical thresholds for Al concentration and Al:BC=1, the critical load for S+N was not exceeded. At none of the sites was the critical load for S+N exceeded using the critical threshold of pH=4.2.

Table 4.3 Exceedance of S+N Deposition at GSMNP

	Exceedance (S+N) (eq ha^{-1} y^{-1})			
	Noland Divide			
Site:	**Upper Spruce-Fir**	**Lower Spruce-Fir**	**Beech Gap**	**Mixed Hardwood**
S+N Current Deposition (eq/ha/y)	*4271*	*4271*	*2136*	*1232*
VSD CL Criteria				
Al=0.2 meq/L	-159	-1511	-1971	-1686
Al:BC=0.1 mol/mol	**2271**	**589**	**491**	-20
Al:BC=1.0 mol/mol	-98	-4052	-1674	-1567
Base Saturation	**1061**	**734**	**445**	**150**
pH=4.2	-3162	-4514	-4973	-3733

Exceedance = actual deposition – critical load. When the actual deposition is higher than the critical load, the exceedance is positive. Positive exceedances are shown in boldface. When the actual deposition is lower than the critical load, the exceedance is negative.

4.2.2 Nutrient N

In all cases, the critical load for nutrient N was exceeded (Table 4.2; Figure 4.3b). The exceedance ranged from 400 eq ha^{-1} y^{-1} at the Mixed Hardwood site to 2100 eq ha^{-1} y^{-1} at the Lower Spruce-Fir site.

For the Lower Spruce-Fir, Beech Gap, and Mixed Hardwood sites, the exceedance of the critical load for nutrient N was higher than the exceedance of the critical load for acidity (using the critical thresholds of no decrease in base saturation and Al:BC=0.1 mol mol^{-1}). For the Upper Spruce-Fir site, the exceedance of the critical load for nutrient N was lower than the exceedance of the critical load for acidity (Al:BC=0.1 mol mol^{-1}), but was still quite high (greater than 1700 eq ha^{-1} y^{-1}).

4.3 Trends over time

One advantage of the VSD model is that it allows prediction of the response of various ecosystem parameters (soil solution ANC, nitrate concentration, etc.) over time and in response to different deposition scenarios. In this section, we compare the predicted values of the different chemical measures with critical thresholds (where they exist) and with current measured properties at the site (only for the Lower Spruce-Fir site, where these data are available).

4.3.1 Nitrate concentration and flux

At all sites for current deposition, the modeled nitrate concentration in soil solution exceeded the critical NO_3^- concentration of 0.2 mg N L^{-1} (14 μeq L^{-1}; Figure 4.4). For the Lower Spruce-Fir site, none of the deposition scenarios was sufficient to reduce modeled soil solution NO_3^- concentration to below the critical threshold (Figure 4.4b). The current measured soil solution NO_3^- concentration at this site was about 80 μeq L^{-1}, well above the critical threshold. For the Upper Spruce-Fir site, deposition reductions of 90% for S and NO_3^- and reductions of 60-80% for NH_4^+ (scenarios 10 and 11) resulted in modeled soil solution NO_3^- concentration below the critical NO_3^- concentration (Figure 4.4a). The measured soil solution NO_3^- concentration reported in the IFS at this site was about 136 μeq L^{-1}, also well above the critical threshold. For the Beech Gap site, deposition reductions of 90% for S and NO_3^- and 80% for NH_4^+ (scenario 11) resulted in modeled soil solution NO_3^- concentration below the critical NO_3^- concentration (Figure 4.4c). For the Mixed Hardwood site, deposition reductions of 90% for S and NO_3^- and reductions of 40% and greater for NH_4^+ (scenarios 9-11) resulted in modeled soil solution NO_3^- concentration below the critical NO_3^- concentration (Figure 4.4d).

4.3.2 ANC

We identified several different critical thresholds for ANC in soil solution. The most conservative threshold was ANC=100 μeq L^{-1}, which minimizes the risk of any acidification. The least conservative critical threshold was ANC = 0 μeq L^{-1}, which is the minimum value of ANC that would protect against chronic acidification. Because of concerns about episodic acidification, it is generally recognized as prudent to select a higher critical ANC value of 20-50 μeq L^{-1}. For all sites for the current deposition (scenario 1), the modeled ANC in soil solution is lower than the lowest critical threshold for ANC of 0 μeq L^{-1} (Figure 4.5). Under certain deposition reduction scenarios, the modeled ANC is greater than this least conservative critical threshold: for the Mixed Hardwood site for deposition reductions of 70% and greater for S and NO_3^- (and no decrease in NH_4^+; scenarios 4-11), for the Lower Spruce-Fir site for scenarios 7-11, and for the Beech Gap sites for scenario 11. The more conservative critical thresholds of 20-100 μeq L^{-1} are never reached under any of the deposition reduction scenarios (Tables 4.4-4.7). Observed ANC is at least 100 μeq L^{-1} lower than any of the critical thresholds for ANC.

4.3.3 [Al]

At all sites, the modeled Al concentration was lower than the critical threshold of 200 μeq L^{-1} for the current deposition (Figure 4.6). At all sites, modeled Al concentrations increased with time under the current deposition scenario, but only at the Upper Spruce-Fir site did modeled Al concentration approach the critical threshold (under scenario 1). All deposition reduction scenarios resulted in significantly decreases in modeled Al concentration at all sites and at the Mixed Hardwood site resulted in a modeled Al concentration near zero.

4.3.4 Al:BC

At all sites except the Mixed Hardwood site, modeled Al:BC ratio exceeded the critical threshold of 0.1 mol/mol for the current deposition (Figure 4.7). For the Upper Spruce-Fir site, deposition reductions of 90% of S and NO_3^- (scenarios 6-11) were necessary to achieve a modeled Al:BC ratio lower than the critical threshold (Figure 4.7a). For the Lower Spruce-Fir site and the Beech Gap site, all deposition reductions resulted in a modeled Al:BC ratio lower than the critical threshold (Figures 4.7b, c). Deposition reductions at the Mixed Hardwood site result in a modeled Al:BC ratio which approached zero (Figure 4.7d).

4.3.5 pH

The modeled soil solution pH values for all sites at current deposition are higher than the critical pH threshold of 4.2. The modeled soil solution pH increases with deposition reductions (Figure 4.8)

4.3.6 Base saturation

The soil base saturation declined for the current deposition scenario at all the sites. Soil base saturation increased for all deposition reductions at all sites. The modeled base saturation increased to near 30% for the Lower and Upper Spruce-Fir sites for the largest deposition reductions. For the Beech Gap site, which had an unusually high base saturation (21%), the modeled increase was only 3-5%; while for the Mixed Hardwood site, the base saturation increased from 11 to 15-20% as a result of the different deposition scenarios (Figure 4.9).

4.3.7 Summary of modeled response to deposition reductions

The deposition scenarios included reductions that would lead to the critical load for S+N not being exceeded at all sites for at least one of the scenarios. The deposition scenarios also included reductions that lowered the model soil solution concentration to be lower than the critical threshold, except for the acceptable NO_3^- concentration at the Lower Spruce-Fir site. For the Upper Spruce-Fir site, none of the ANC critical thresholds are achievable (Table 4.4). The Al:BC=0.1 is achievable by 2053 for the most stringent reduction scenario (11a) and is achievable by 2134 for scenario 6 (Table 4.4).

For the Lower Spruce-Fir site, both Al:BC thresholds are achievable immediately, although that condition is not maintained for the current deposition scenario, in which case the Al:BC ratio increases with time. The ANC=0 μeq L^{-1} is achieved as early as 2039 for the most stringent reduction scenario (11a; Table 4.4).

At the Beech Gap site, the Al:BC=0.1 threshold is reached by 2066 for all deposition reduction scenarios. The ANC=0 μeq L^{-1} is achieved only for the most stringent reduction scenarios (11a and b; Table 4.4) by 2036.

At the Mixed Hardwood site, the Al:BC thresholds are currently achieved. ANC is modeled to be greater than 0 μeq L^{-1} for scenarios 6-11 by 2058.

Ecosystem endpoints are shown by site in Table 4.5 and by deposition scenario in Table 4.6. The deposition level required to achieve an ecosystem endpoint in a given year is shown in Table 4.7

Table 4.4 Years in which ecosystem critical thresholds are achieved for ANC and Al:BC

Upper Spruce-Fir Site	**ANC 0**	**ANC 20**	**ANC 50**	**ANC 100**	**Al:BC 0.1**	**Al:BC 1**
Scenario 1						*
Scenario 2						**2006**
Scenario 3						**2006**
Scenario 4a						**2006**
Scenario 4b						**2006**
Scenario 5		**NOT ACHIEVABLE[1]**				**2006**
Scenario 6					**2134**	**2006**
Scenario 7					**2122**	**2006**
Scenario 8					**2098**	**2006**
Scenario 9					**2080**	**2006**
Scenario 10					**2064**	**2006**
Scenario 11a					**2053**	**2006**
Scenario 11b					**2071**	**2006**

Lower Spruce-Fir Site	**ANC 0**	**ANC 20**	**ANC 50**	**ANC 100**	**Al:BC 0.1**	**Al:BC 1**
Scenario 1					*	**2006**
Scenario 2					**2006**	**2006**
Scenario 3					**2006**	**2006**
Scenario 4a					**2006**	**2006**
Scenario 4b					**2006**	**2006**
Scenario 5		**NOT ACHIEVABLE**			**2006**	**2006**
Scenario 6					**2006**	**2006**
Scenario 7	**2142**				**2006**	**2006**
Scenario 8	**2111**				**2006**	**2006**
Scenario 9	**2084**				**2006**	**2006**
Scenario 10	**2061**				**2006**	**2006**
Scenario 11a	**2039**				**2006**	**2006**
Scenario 11b	**2055**				**2006**	**2006**

Beech Gap Site	**ANC 0**	**ANC 20**	**ANC 50**	**ANC 100**	**Al:BC 0.1**	**Al:BC 1**
Scenario 1						**2006**
Scenario 2					**2066**	**2006**
Scenario 3					**2039**	**2006**
Scenario 4a					**2013**	**2006**
Scenario 4b					**2022**	**2006**
Scenario 5		**NOT ACHIEVABLE**			**2012**	**2006**
Scenario 6					**2011**	**2006**
Scenario 7					**2010**	**2006**
Scenario 8					**2010**	**2006**
Scenario 9					**2010**	**2006**
Scenario 10					**2009**	**2006**
Scenario 11a	**2119**				**2009**	**2006**
Scenario 11b	**2136**				**2018**	**2006**

Mixed Hardwood Site	ANC 0	ANC 20	ANC 50	ANC 100	Al:BC 0.1	Al:BC 1
Scenario 1					**2006**	**2006**
Scenario 2					**2006**	**2006**
Scenario 3					**2006**	**2006**
Scenario 4a	**2036**	**NOT ACHIEVABLE**			**2006**	**2006**
Scenario 4b	**2050**				**2006**	**2006**
Scenario 5	**2015**				**2006**	**2006**
Scenario 6	**2013**				**2006**	**2006**
Scenario 7	**2013**				**2006**	**2006**
Scenario 8	**2013**				**2006**	**2006**
Scenario 9	**2012**				**2006**	**2006**
Scenario 10	**2012**				**2006**	**2006**
Scenario 11a	**2012**				**2006**	**2006**
Scenario 11b	**2031**				**2006**	**2006**

* under this deposition scenario, the Al:BC is currently below the critical threshold, but increases over time

[1]*Not achievable* (hatched area) means that this condition was not reached by 2150, during the period for which the model was run.

Table 4.5 Modeled soil solution ANC and Al:BC for years 2018, 2040, 2064, 2100, and 2150 (by site)

	Soil Solution ANC (ueq L^{-1})					Soil Solution Al:BC (mol mol^{-1})				
Upper Spruce-Fir Site	**2018**	**2040**	**2064**	**2100**	**2150**	**2018**	**2040**	**2064**	**2100**	**2150**
Scenario 1	-216	-223	-227	-230	-232	0.78	0.85	0.90	0.94	0.95
Scenario 2	-123	-116	-110	-105	-101	0.57	0.50	0.45	0.41	0.38
Scenario 3	-116	-109	-103	-98	-93	0.55	0.47	0.42	0.38	0.35
Scenario 4a	-84	-75	-68	-61	-55	0.46	0.36	0.30	0.24	0.20
Scenario 4b	-113	-87	-71	-63	-56	0.54	0.42	0.32	0.26	0.21
Scenario 5	-67	-58	-51	-44	-38	0.41	0.30	0.24	0.18	0.14
Scenario 6	-51	-43	-37	-30	-24	0.36	0.25	0.19	0.13	0.09
Scenario 7	-48	-40	-33	-27	-21	0.34	0.24	0.17	0.12	0.09
Scenario 8	-39	-32	-27	-21	-15	0.31	0.21	0.15	0.10	0.07
Scenario 9	-31	-25	-20	-15	-10	0.28	0.18	0.13	0.08	0.05
Scenario 10	-23	-18	-14	-9	-5	0.24	0.15	0.10	0.07	0.04
Scenario 11a	-17	-12	-8	-5	-1	0.21	0.13	0.09	0.06	0.03
Scenario 11b	-107	-38	-11	-6	-2	0.53	0.27	0.12	0.07	0.04
Lower Spruce-Fir Site	**2018**	**2040**	**2064**	**2100**	**2150**	**2018**	**2040**	**2064**	**2100**	**2150**
Scenario 1	-76	-83	-89	-98	-106	0.11	0.12	0.14	0.16	0.18
Scenario 2	-43	-38	-34	-29	-25	0.08	0.06	0.06	0.05	0.04
Scenario 3	-40	-35	-31	-26	-22	0.07	0.06	0.05	0.04	0.03
Scenario 4a	-29	-24	-19	-15	-10	0.06	0.05	0.04	0.03	0.02
Scenario 4b	-39	-28	-21	-16	-11	0.07	0.05	0.04	0.03	0.02
Scenario 5	-23	-18	-14	-9	-5	0.06	0.04	0.03	0.02	0.01
Scenario 6	-18	-13	-9	-5	0	0.05	0.03	0.02	0.02	0.01
Scenario 7	-16	-11	-8	-3	1	0.05	0.03	0.02	0.02	0.01
Scenario 8	-13	-9	-5	-1	3	0.04	0.03	0.02	0.01	0.01
Scenario 9	-10	-6	-2	2	6	0.04	0.03	0.02	0.01	0.01

Scenario 10	-7	-3	0	4	8	0.04	0.02	0.02	0.01	0.01
Scenario 11a	-4	0	3	7	11	0.03	0.02	0.01	0.01	0.00
Scenario 11b	-37	-12	1	6	10	0.07	0.04	0.02	0.01	0.01
Beech Gap	**2018**	**2040**	**2064**	**2100**	**2150**	**2018**	**2040**	**2064**	**2100**	**2150**
Scenario 1	-50	-51	-52	-53	-55	0.14	0.14	0.15	0.15	0.16
Scenario 2	-30	-30	-29	-29	-28	0.11	0.11	0.11	0.10	0.10
Scenario 3	-29	-28	-28	-27	-26	0.11	0.10	0.10	0.10	0.09
Scenario 4a	-22	-21	-20	-19	-18	0.10	0.09	0.09	0.08	0.07
Scenario 4b	-28	-23	-21	-20	-18	0.11	0.10	0.09	0.08	0.08
Scenario 5	-18	-17	-16	-15	-14	0.09	0.08	0.08	0.07	0.07
Scenario 6	-13	-13	-12	-11	-10	0.08	0.08	0.07	0.06	0.06
Scenario 7	-12	-12	-11	-10	-9	0.08	0.07	0.07	0.06	0.05
Scenario 8	-10	-9	-9	-8	-6	0.07	0.07	0.06	0.06	0.05
Scenario 9	-8	-7	-6	-5	-4	0.07	0.06	0.06	0.05	0.05
Scenario 10	-5	-5	-4	-3	-2	0.06	0.06	0.05	0.05	0.04
Scenario 11a	-3	-2	-1	0	1	0.06	0.05	0.05	0.04	0.04
Scenario 11b	-27	-10	-2	-1	0	0.10	0.07	0.05	0.05	0.04
Mixed Hardwood	**2018**	**2040**	**2064**	**2100**	**2150**	**2018**	**2040**	**2064**	**2100**	**2150**
Scenario 1	-16	-16	-16	-17	-18	0.04	0.04	0.04	0.04	0.04
Scenario 2	-6	-5	-4	-3	-2	0.03	0.02	0.02	0.02	0.02
Scenario 3	-6	-6	-5	-4	-3	0.03	0.03	0.02	0.02	0.02
Scenario 4a	-1	0	1	2	4	0.02	0.02	0.02	0.02	0.01
Scenario 4b	-6	-2	1	2	4	0.03	0.02	0.02	0.02	0.01
Scenario 5	2	3	4	5	7	0.02	0.02	0.02	0.01	0.01
Scenario 6	5	6	7	8	10	0.02	0.02	0.01	0.01	0.01
Scenario 7	5	6	7	9	11	0.02	0.02	0.01	0.01	0.01
Scenario 8	6	8	9	10	12	0.02	0.01	0.01	0.01	0.01
Scenario 9	8	9	10	11	13	0.02	0.01	0.01	0.01	0.01
Scenario 10	9	10	11	13	15	0.02	0.01	0.01	0.01	0.01
Scenario 11a	10	11	13	14	16	0.01	0.01	0.01	0.01	0.01
Scenario 11b	-5	5	12	13	15	0.03	0.02	0.01	0.01	0.01

Table 4.6 Modeled soil solution ANC and Al:BC for years 2018, 2040, 2064, 2100, and 2150 (by scenario)

	Soil Solution ANC (ueq L^{-1})					Soil Solution Al:BC (mol mol^{-1})				
Site	**2018**	**2040**	**2064**	**2100**	**2150**	**2018**	**2040**	**2064**	**2100**	**2150**
	Scenario 1									
Upper Spruce-Fir	-216	-223	-227	-230	-232	0.78	0.85	0.90	0.94	0.95
Lower Spruce-Fir	-76	-83	-89	-98	-106	0.11	0.12	0.14	0.16	0.18
Beech Gap	-50	-51	-52	-53	-55	0.14	0.14	0.15	0.15	0.16
Mixed Hardwoods	-16	-16	-16	-17	-18	0.04	0.04	0.04	0.04	0.04
	Scenario 2									
Upper Spruce-Fir	-123	-116	-110	-105	-101	0.57	0.50	0.45	0.41	0.38
Lower Spruce-Fir	-43	-38	-34	-29	-25	0.08	0.06	0.06	0.05	0.04
Beech Gap	-30	-30	-29	-29	-28	0.11	0.11	0.11	0.10	0.10
Mixed Hardwoods	-6	-5	-4	-3	-2	0.03	0.02	0.02	0.02	0.02

	Scenario 3									
Upper Spruce-Fir	-116	-109	-103	-98	-93	0.55	0.47	0.42	0.38	0.35
Lower Spruce-Fir	-40	-35	-31	-26	-22	0.07	0.06	0.05	0.04	0.03
Beech Gap	-29	-28	-28	-27	-26	0.11	0.10	0.10	0.10	0.09
Mixed Hardwoods	-6	-6	-5	-4	-3	0.03	0.03	0.02	0.02	0.02
	Scenario 4a									
Upper Spruce-Fir	-84	-75	-68	-61	-55	0.46	0.36	0.30	0.24	0.20
Lower Spruce-Fir	-29	-24	-19	-15	-10	0.06	0.05	0.04	0.03	0.02
Beech Gap	-22	-21	-20	-19	-18	0.10	0.09	0.09	0.08	0.07
Mixed Hardwoods	-1	0	1	2	4	0.02	0.02	0.02	0.02	0.01
	Scenario 4b									
Upper Spruce-Fir	-113	-87	-71	-63	-56	0.54	0.42	0.32	0.26	0.21
Lower Spruce-Fir	-39	-28	-21	-16	-11	0.07	0.05	0.04	0.03	0.02
Beech Gap	-28	-23	-21	-20	-18	0.11	0.10	0.09	0.08	0.08
Mixed Hardwoods	-6	-2	1	2	4	0.03	0.02	0.02	0.02	0.01
	Scenario 5									
Upper Spruce-Fir	-67	-58	-51	-44	-38	0.41	0.30	0.24	0.18	0.14
Lower Spruce-Fir	-23	-18	-14	-9	-5	0.06	0.04	0.03	0.02	0.01
Beech Gap	-18	-17	-16	-15	-14	0.09	0.08	0.08	0.07	0.07
Mixed Hardwoods	2	3	4	5	7	0.02	0.02	0.02	0.01	0.01
	Scenario 6									
Upper Spruce-Fir	-51	-43	-37	-30	-24	0.36	0.25	0.19	0.13	0.09
Lower Spruce-Fir	-18	-13	-9	-5	0	0.05	0.03	0.02	0.02	0.01
Beech Gap	-13	-13	-12	-11	-10	0.08	0.08	0.07	0.06	0.06
Mixed Hardwoods	5	6	7	8	10	0.02	0.02	0.01	0.01	0.01
	Scenario 7									
Upper Spruce-Fir	-48	-40	-33	-27	-21	0.34	0.24	0.17	0.12	0.09
Lower Spruce-Fir	-16	-11	-8	-3	1	0.05	0.03	0.02	0.02	0.01
Beech Gap	-12	-12	-11	-10	-9	0.08	0.07	0.07	0.06	0.05
Mixed Hardwoods	5	6	7	9	11	0.02	0.02	0.01	0.01	0.01
	Scenario 8									
Upper Spruce-Fir	-39	-32	-27	-21	-15	0.31	0.21	0.15	0.10	0.07
Lower Spruce-Fir	-13	-9	-5	-1	3	0.04	0.03	0.02	0.01	0.01
Beech Gap	-10	-9	-9	-8	-6	0.07	0.07	0.06	0.06	0.05
Mixed Hardwoods	6	8	9	10	12	0.02	0.01	0.01	0.01	0.01
	Scenario 9									
Upper Spruce-Fir	-31	-25	-20	-15	-10	0.28	0.18	0.13	0.08	0.05
Lower Spruce-Fir	-10	-6	-2	2	6	0.04	0.03	0.02	0.01	0.01
Beech Gap	-8	-7	-6	-5	-4	0.07	0.06	0.06	0.05	0.05
Mixed Hardwoods	8	9	10	11	13	0.02	0.01	0.01	0.01	0.01
	Scenario 10									
Upper Spruce-Fir	-23	-18	-14	-9	-5	0.24	0.15	0.10	0.07	0.04
Lower Spruce-Fir	-7	-3	0	4	8	0.04	0.02	0.02	0.01	0.01
Beech Gap	-5	-5	-4	-3	-2	0.06	0.06	0.05	0.05	0.04
Mixed Hardwoods	9	10	11	13	15	0.02	0.01	0.01	0.01	0.01

	Scenario 11a									
Upper Spruce-Fir	-17	-12	-8	-5	-1	0.21	0.13	0.09	0.06	0.03
Lower Spruce-Fir	-4	0	3	7	11	0.03	0.02	0.01	0.01	0.00
Beech Gap	-3	-2	-1	0	1	0.06	0.05	0.05	0.04	0.04
Mixed Hardwoods	10	11	13	14	16	0.01	0.01	0.01	0.01	0.01
	Scenario 11b									
Upper Spruce-Fir	-107	-38	-11	-6	-2	0.53	0.27	0.12	0.07	0.04
Lower Spruce-Fir	-37	-12	1	6	10	0.07	0.04	0.02	0.01	0.01
Beech Gap	-27	-10	-2	-1	0	0.10	0.07	0.05	0.05	0.04
Mixed Hardwoods	-5	5	12	13	15	0.03	0.02	0.01	0.01	0.01

Table 4.7 S+N Deposition (eq ha^{-1} y^{-1}) required to achieve ecosystem endpoint in target year

YEAR	**2018**	**2040**	**2064**	**2080**	**2100**	**2150**
Upper Spruce-Fir						
ANC 0						
ANC 20						
ANC 50			**NOT ACHIEVABLE**			
ANC 100						
Al:BC 0.1			**701**	**879**	**1065**	**1322**
Base saturation: 7.6%	**1322**	**2890**	**3050**	**3103**	**3139**	**3180**
Lower Spruce-Fir						
ANC 0		**594**	**791**	**910**	**1046**	**1331**
ANC 20						
ANC 50			**NOT ACHIEVABLE**			
ANC 100						
Al:BC 0.1	**2695**	**2695**	**2695**	**2695**	**2695**	**2695**
Base Saturation: 9%	**2472**	**3112**	**3289**	**3348**	**3396**	**3455**
Beech Gap						
ANC 0						**259**
ANC 20						
ANC 50			**NOT ACHIEVABLE**			
ANC 100						
Al:BC 0.1	**998**	**1322**	**1322**	**1349**	**1349**	**1349**
Base Saturation: 21%	**509**	**1196**	**1385**	**1456**	**1504**	**1569**
Mixed Hardwoods						
ANC 0	**403**	**509**	**509**	**509**	**509**	**509**
ANC 20						
ANC 50			**NOT ACHIEVABLE**			
ANC 100						
Al:BC 0.1	**1232**	**1232**	**1232**	**1232**	**1232**	**1232**
Base saturation: 11%	**727**	**727**	**727**	**727**	**727**	**727**

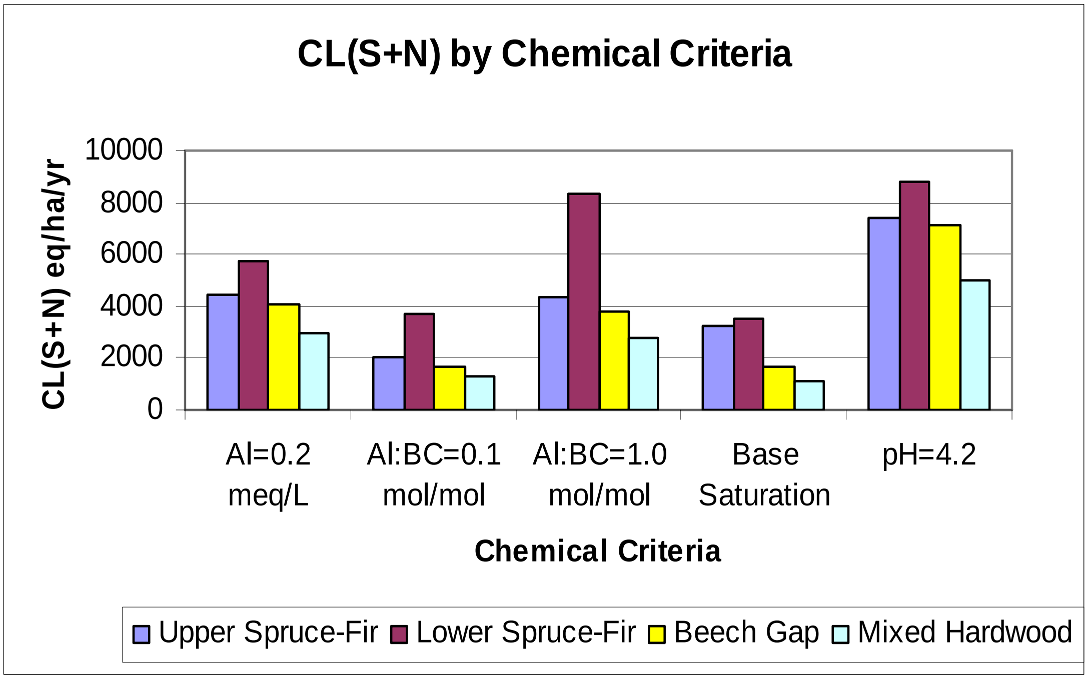


Figure 4.1a CL (S+N) by chemical criteria

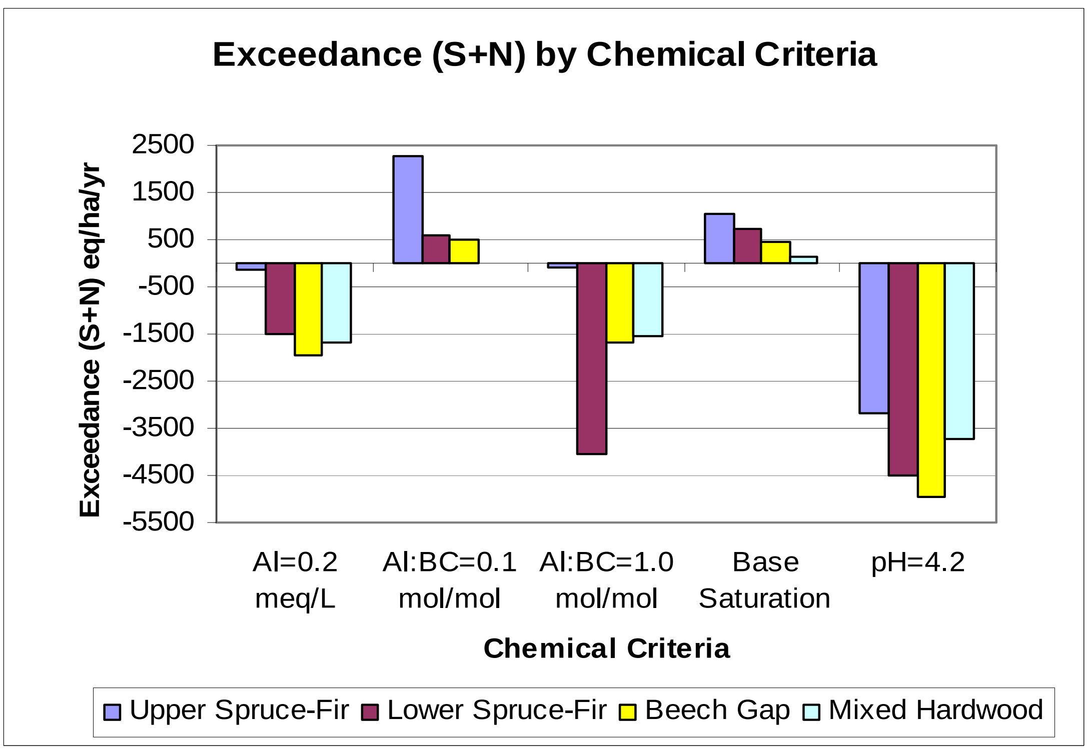


Figure 4.1b Exceedance (S+N) by chemical criteria

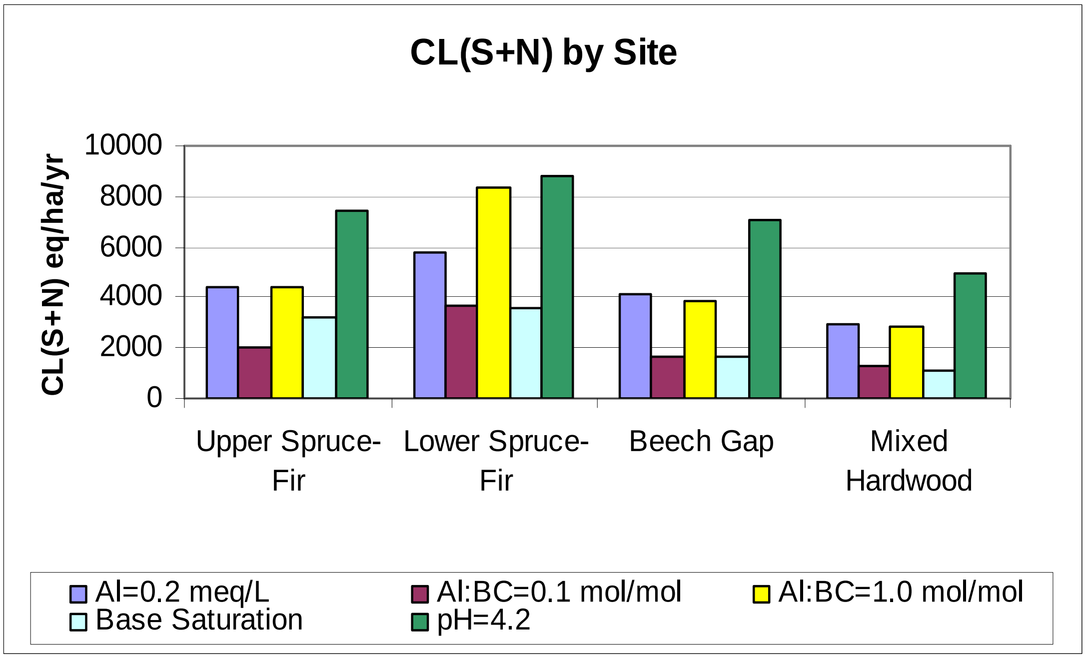


Figure 4.2a CL for (S+N) by site

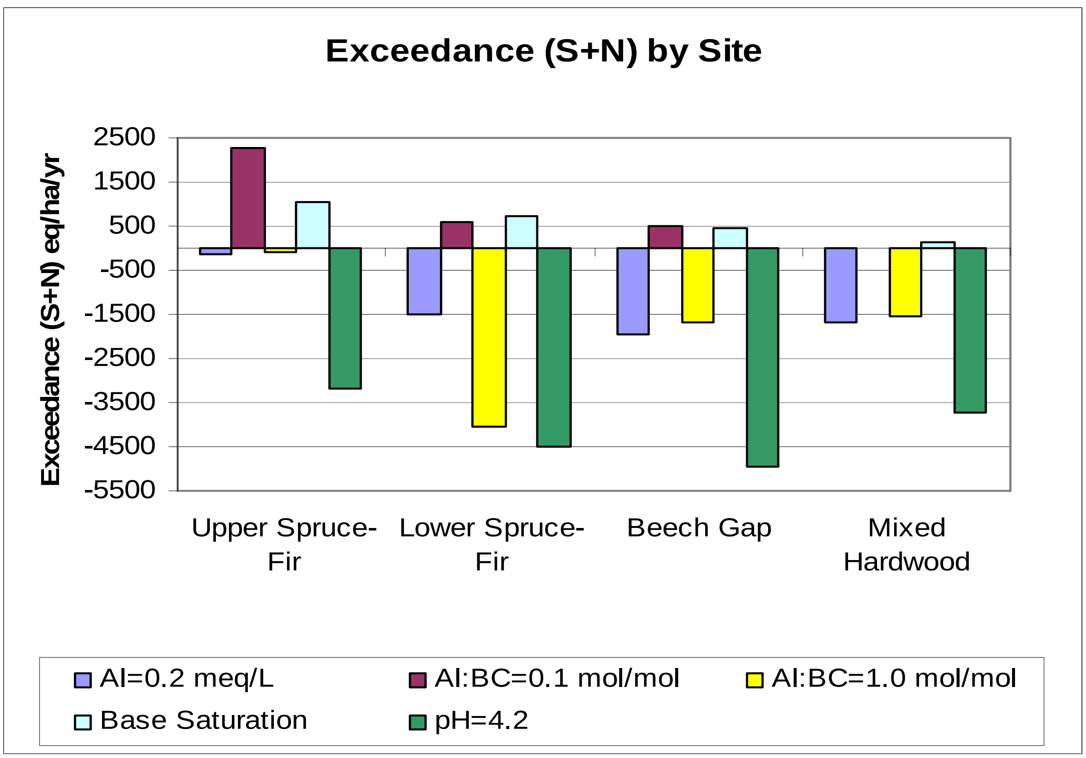


Figure 4.2b Exceedance by site

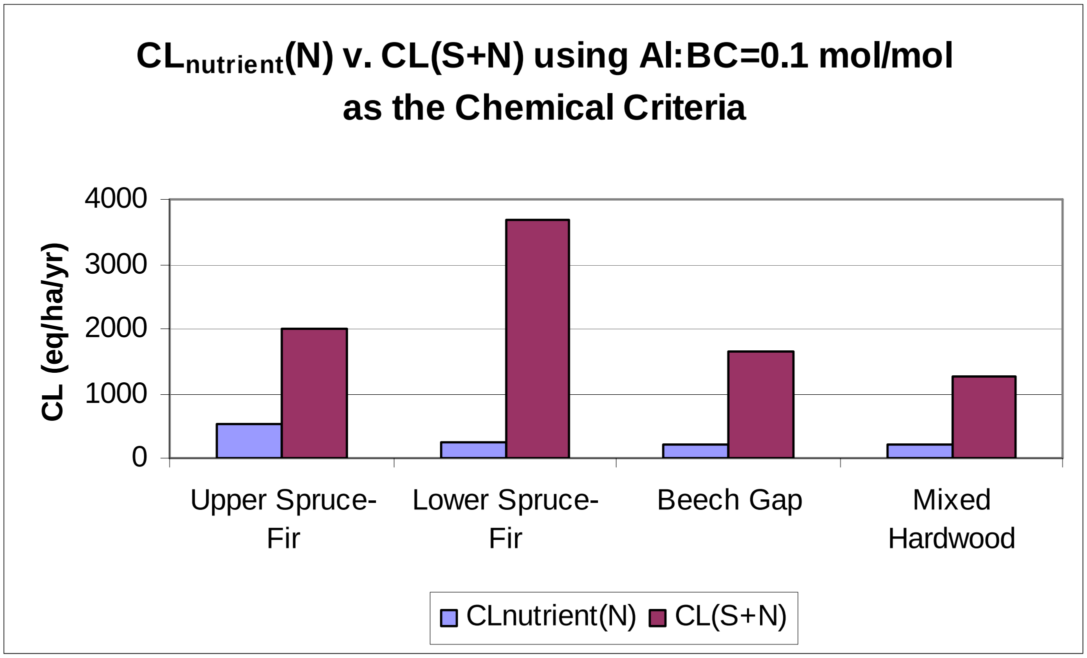


Figure 4.3a CL $_{nutrient}$N and CL (S+N) using Al:BC=0.1

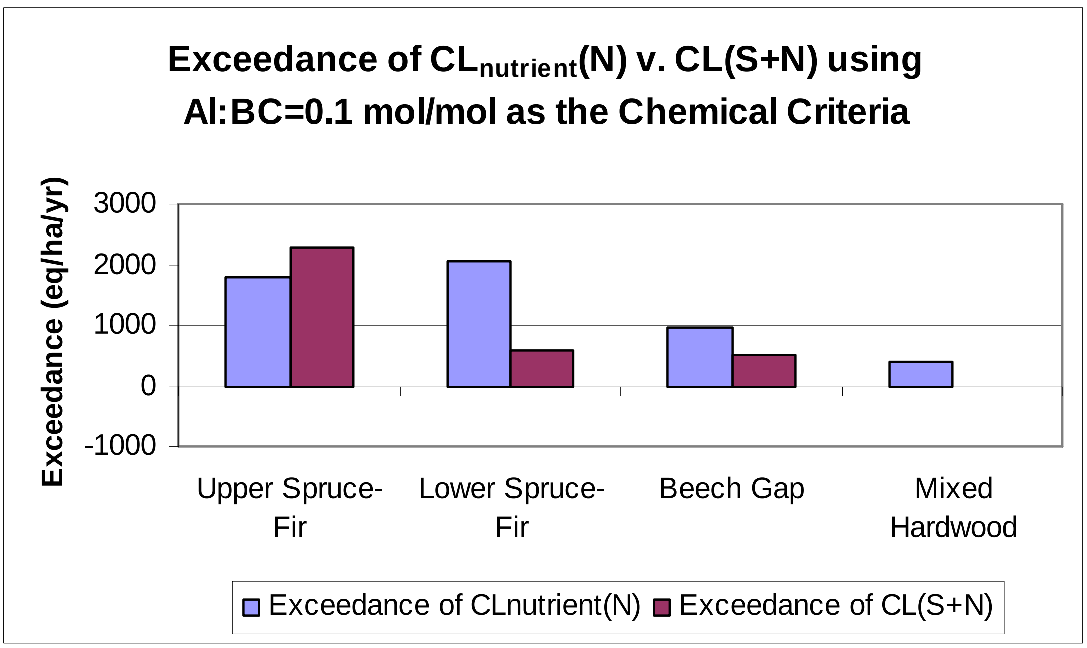


Figure 4.3b Exceedance CL $_{nutrient}$N and CL (S+N) using Al:BC=0.1

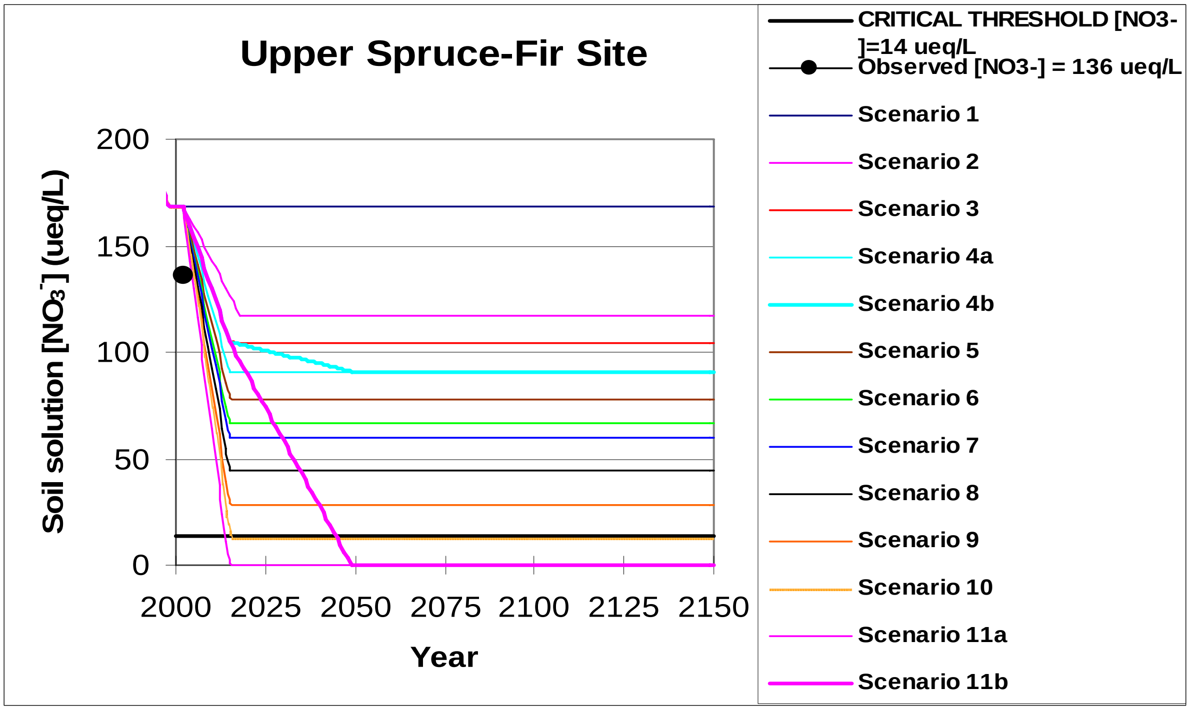


Figure 4.4a Modeled soil solution nitrate concentration at the Upper Spruce-Fir site
Measured soil solution nitrate concentration is shown (black circle).
Deposition scenarios are described in Table 3.2. The critical threshold is exceeded when nitrate concentration >14 μeq/L is shown (black line).

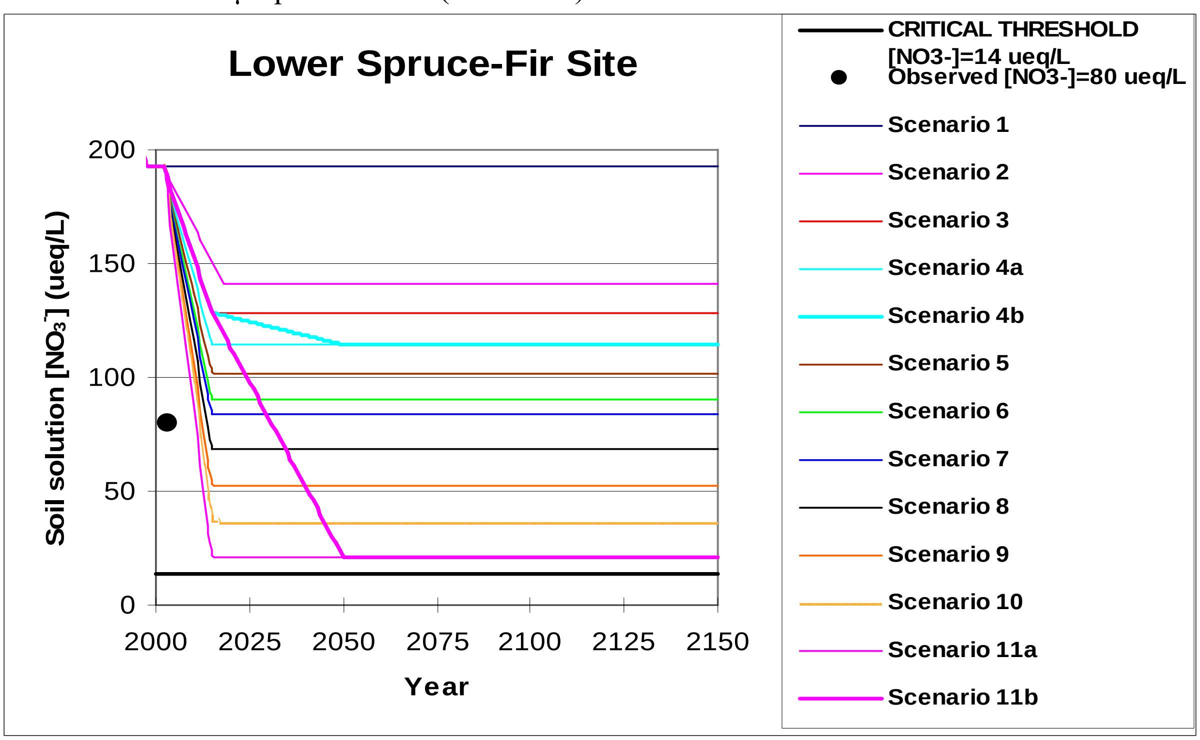


Figure 4.4b Modeled soil solution nitrate concentration at the Lower Spruce-Fir site
Measured soil solution nitrate concentration is shown (black circle).

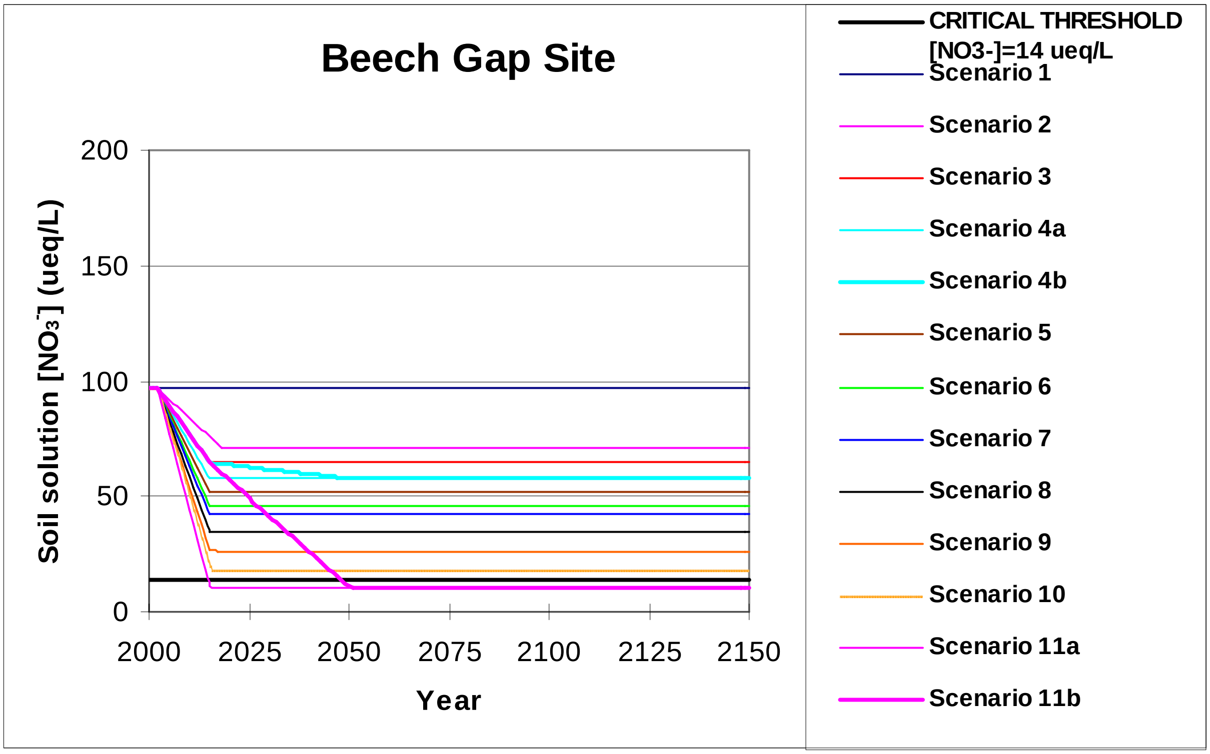


Figure 4.4c Modeled soil solution nitrate concentration at the Beech Gap site

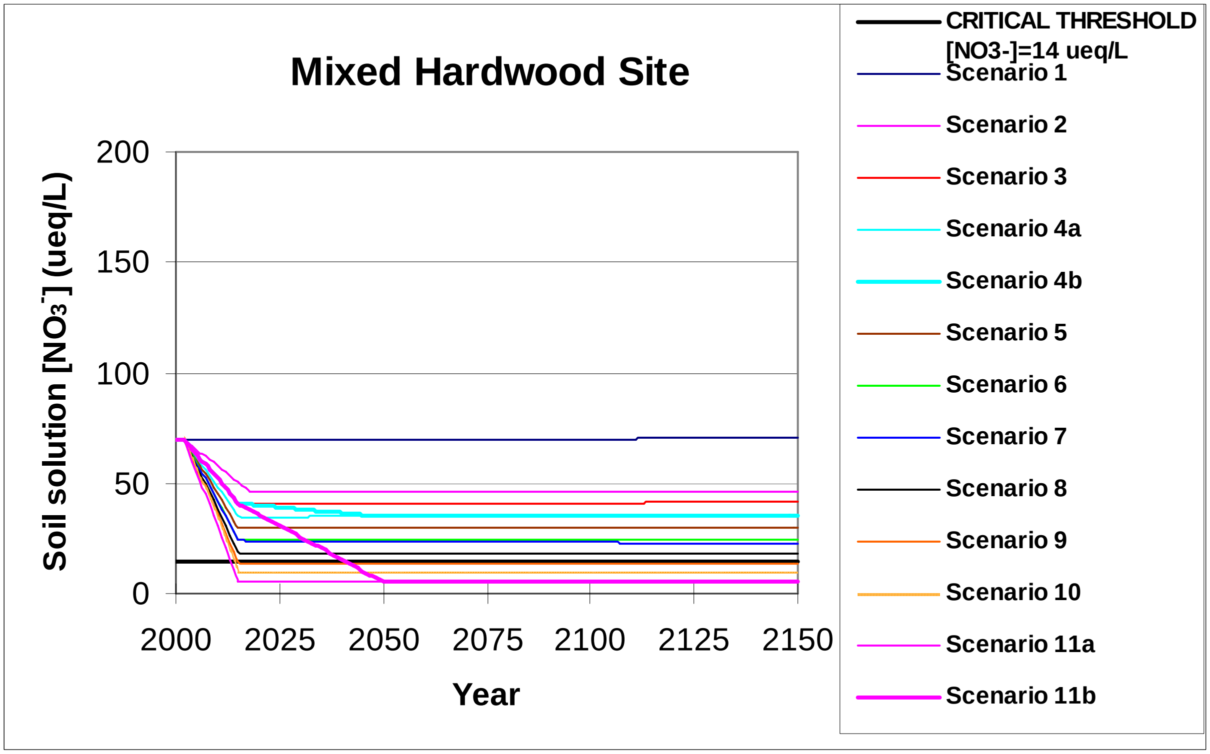


Figure 4.4d Modeled soil solution nitrate concentration at the Mixed Hardwood site

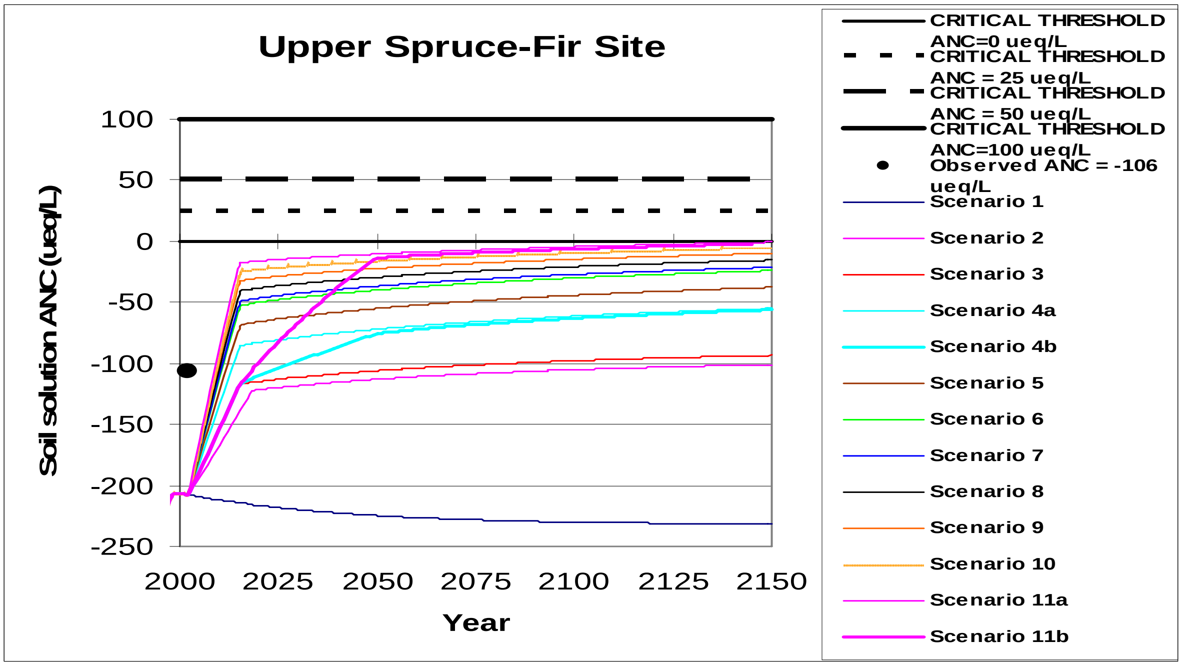


Figure 4.5a Modeled soil solution ANC at the Upper Spruce-Fir site
Measured soil solution ANC concentration is shown (black circle).
Deposition scenarios are described in Table 3.2. Several critical thresholds are shown for ANC corresponding to different levels of ecosystem projection (see section 4.1). For ANC, the critical threshold represents the minimum acceptable, so the desired condition is an ANC in excess of the threshold. The ANC thresholds are shown in heavy black and dotted lines, ranging from 0 µeq/L (to protect against detrimental effects from chronic acidification) to 100 µeq/L (to protect against episodic acidification).

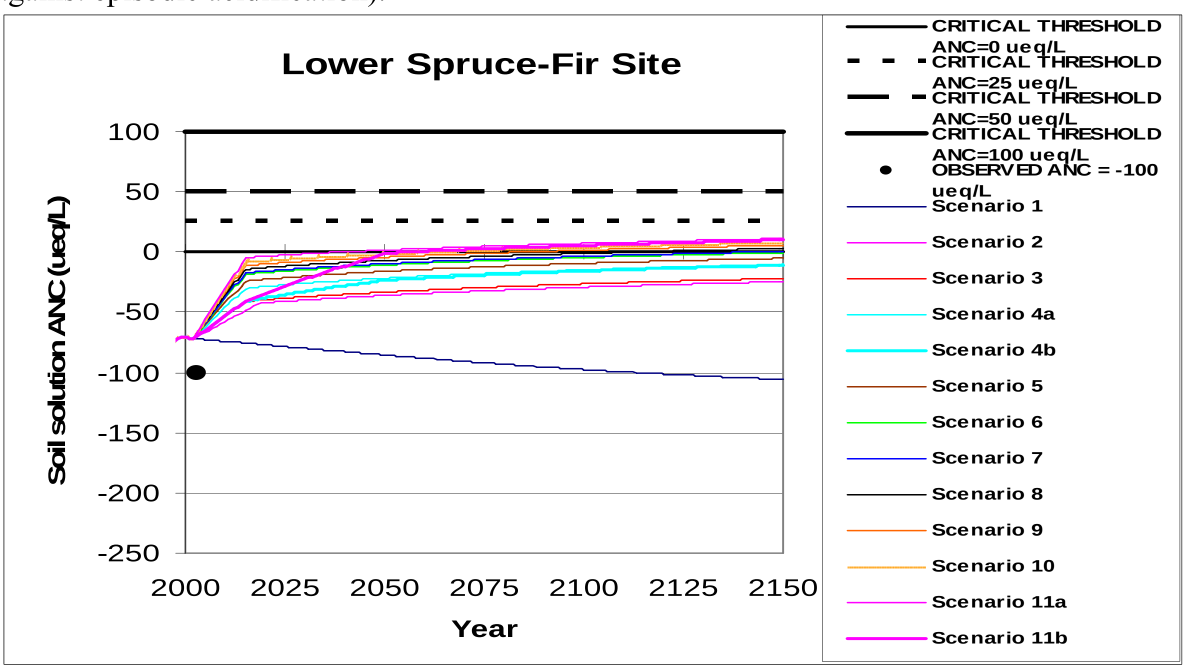


Figure 4.5b Modeled soil solution ANC at the Lower Spruce-Fir site
Measured soil solution ANC concentration is shown (black circle).

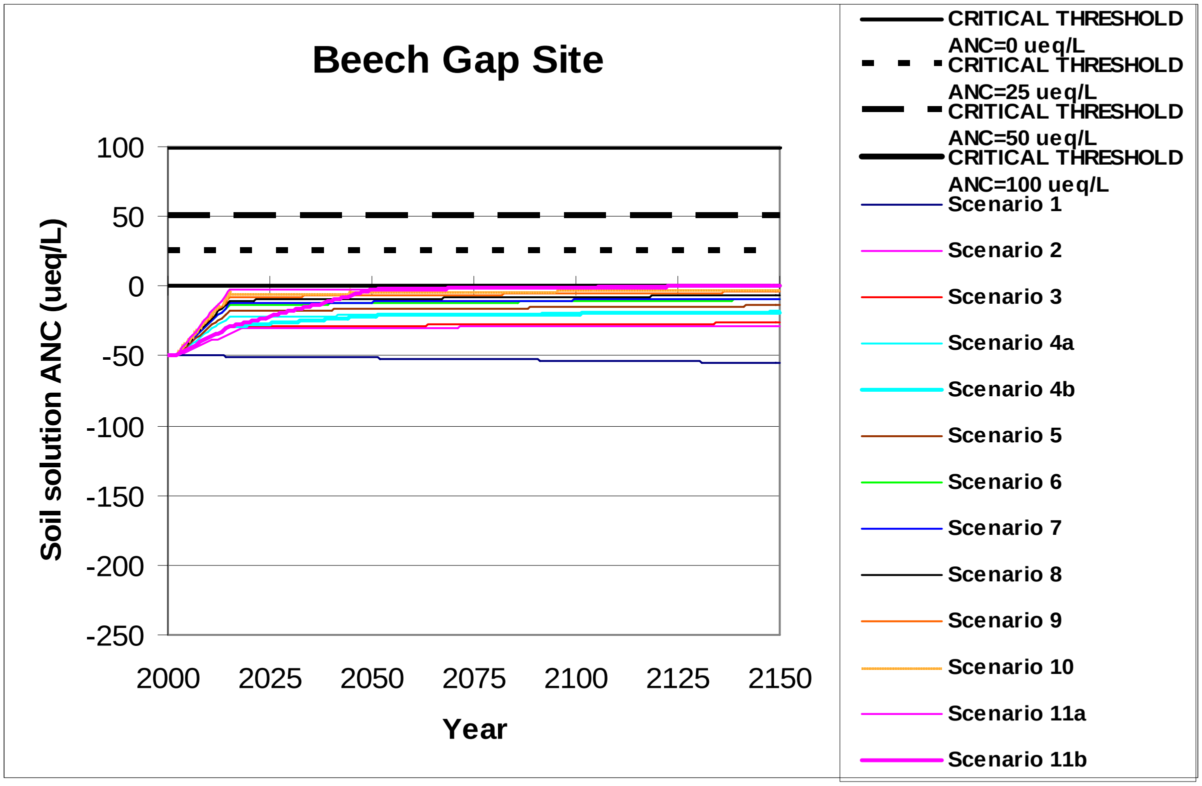


Figure 4.5c Modeled soil solution ANC at the Beech Gap Site

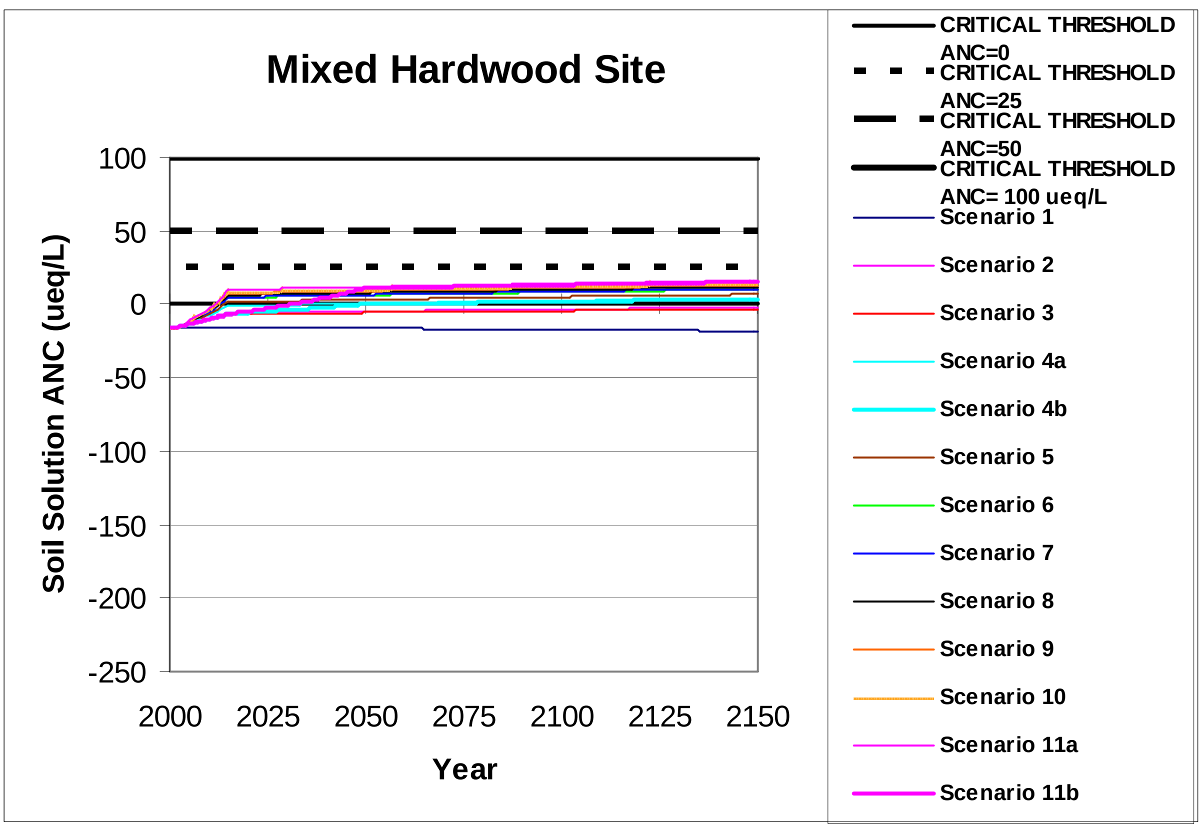


Figure 4.5d Modeled soil solution ANC at the Mixed Hardwood site

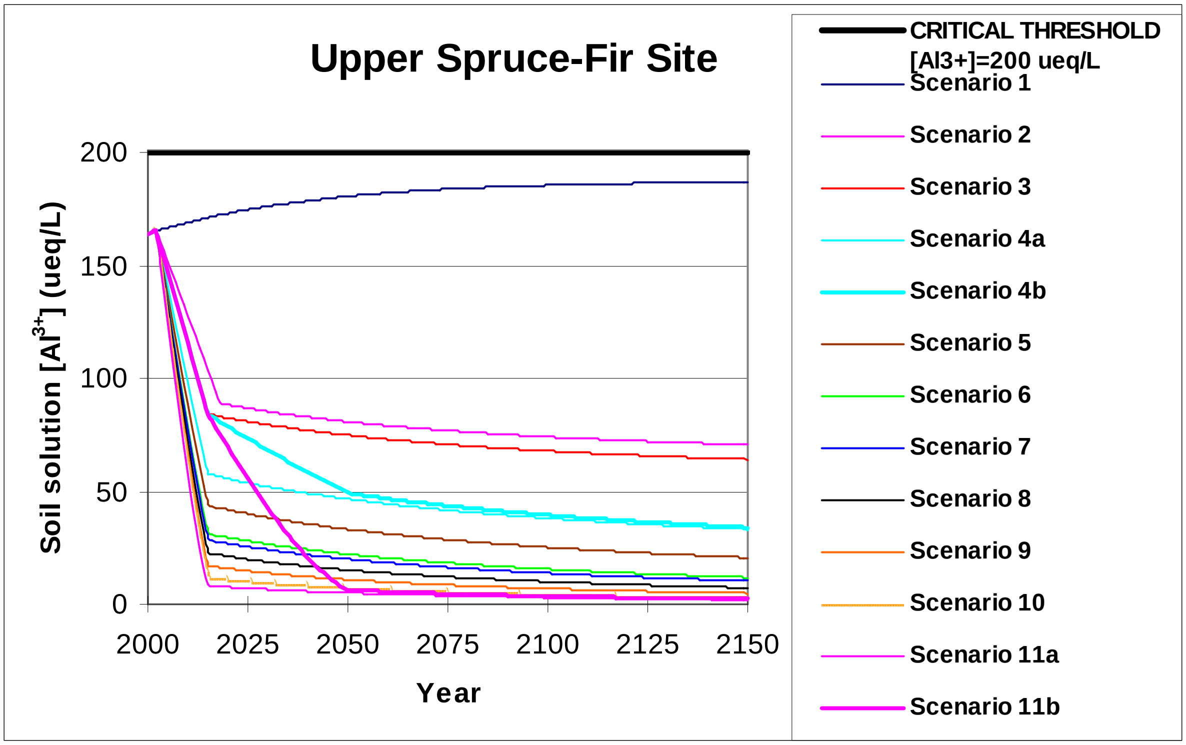


Figure 4.6a Modeled soil solution Al concentration at the Upper Spruce-Fir site
Deposition scenarios are described in Table 3.2. The critical threshold is exceeded when aluminum concentration >200 μeq/L is shown (black line).

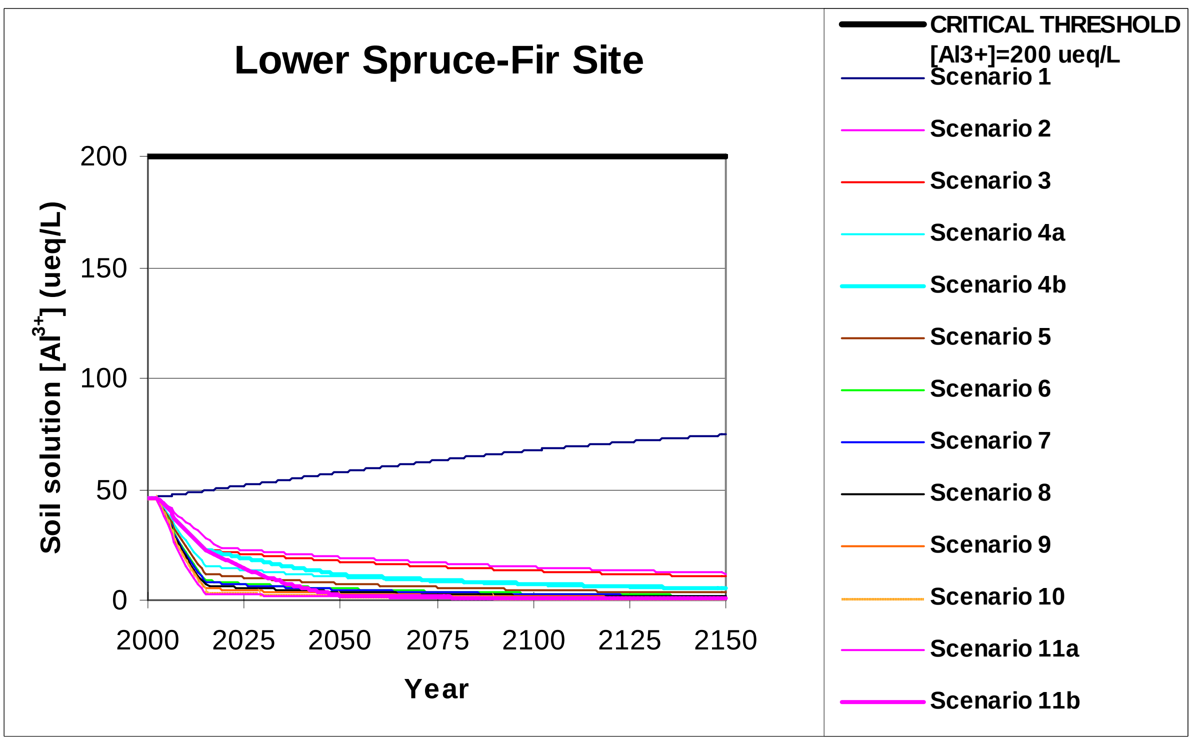


Figure 4.6b Modeled soil solution Al concentration at the Lower Spruce-Fir site

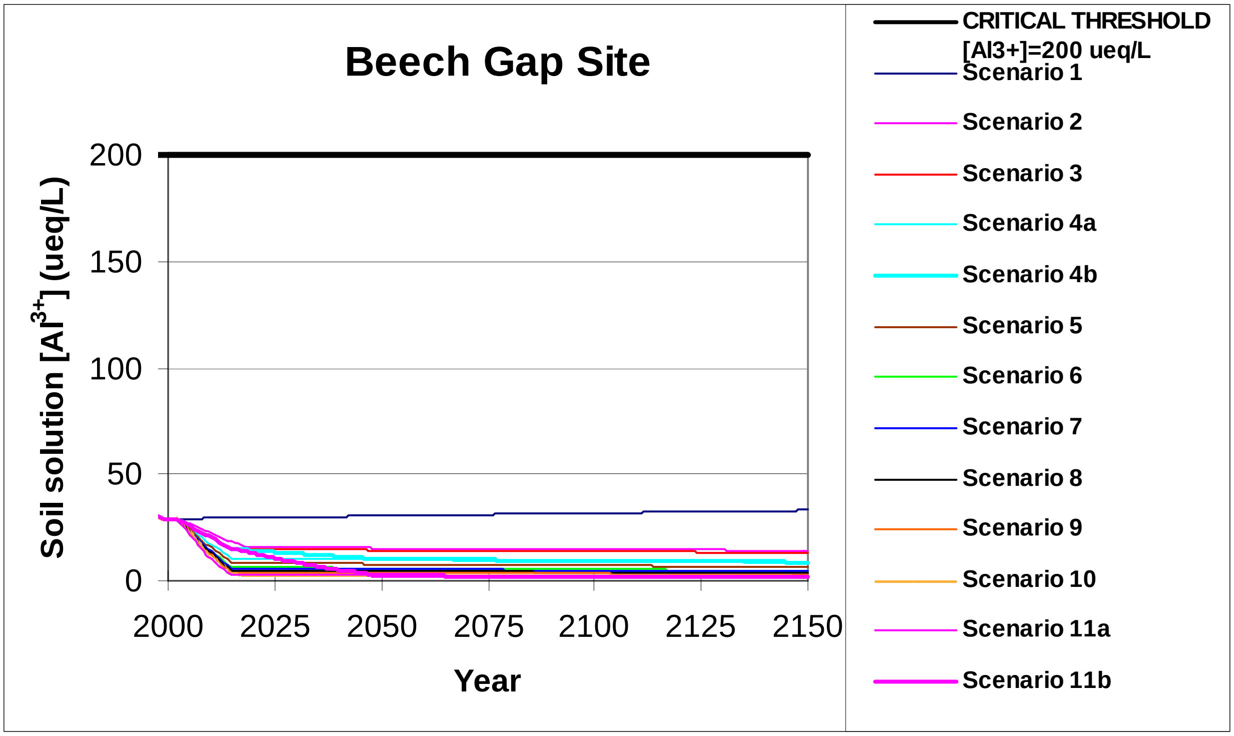


Figure 4.6c Modeled soil solution Al concentration at the Beech Gap site

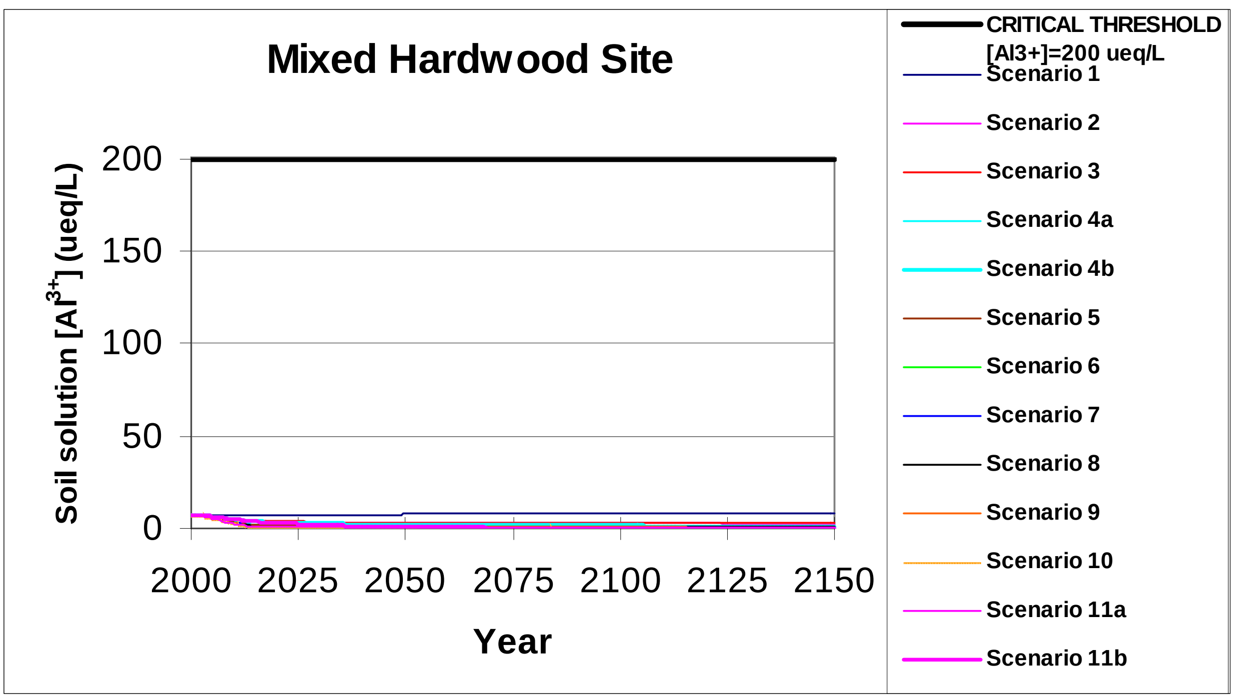


Figure 4.6d Modeled soil solution Al concentration at the Mixed Hardwood site

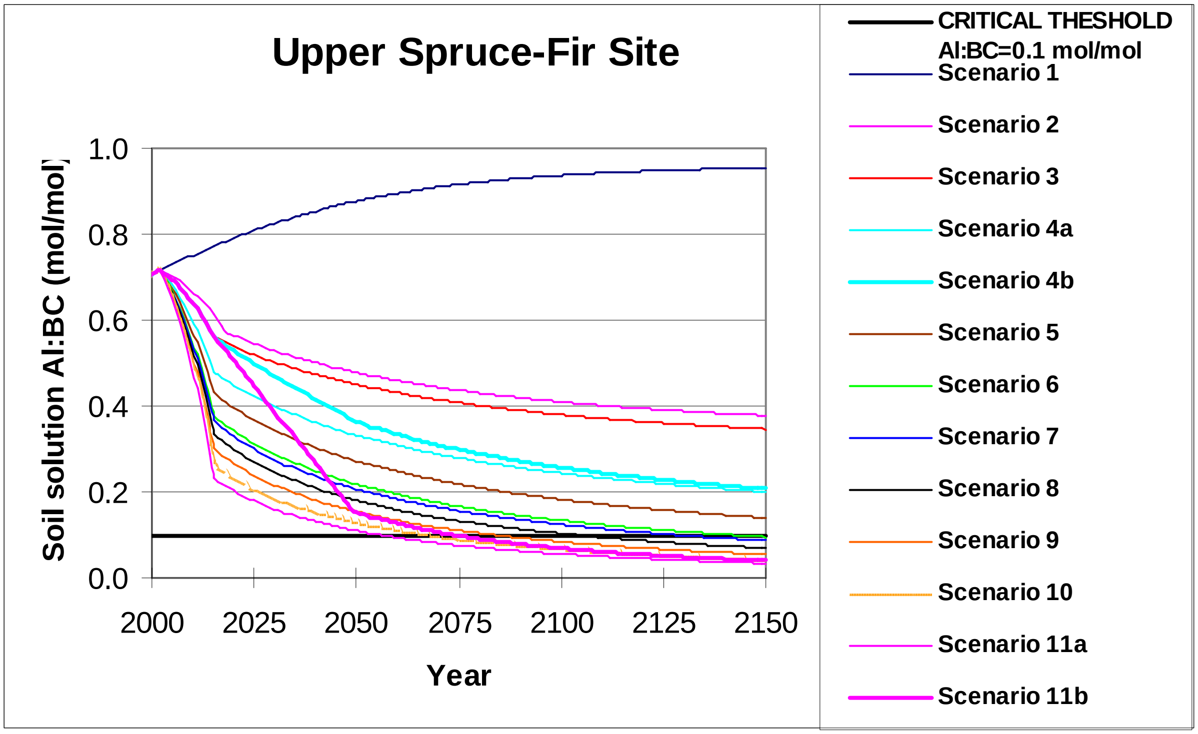


Figure 4.7a Modeled soil solution Al:BC ratio at the Upper Spruce-Fir site
Deposition scenarios are described in Table 3.2. The critical threshold is exceeded when aluminum:base catio ratio >0.1 (mol/mol) is shown (black line).

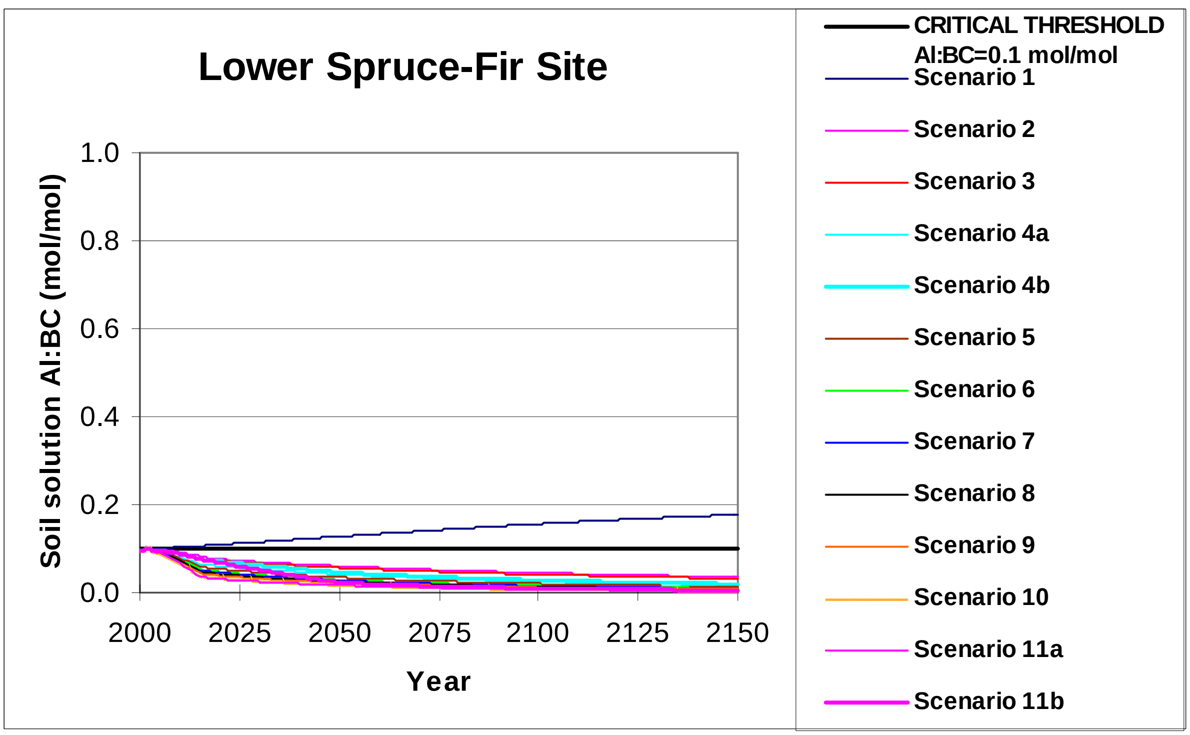


Figure 4.7b Modeled soil solution Al:BC ratio at the Lower Spruce-Fir site

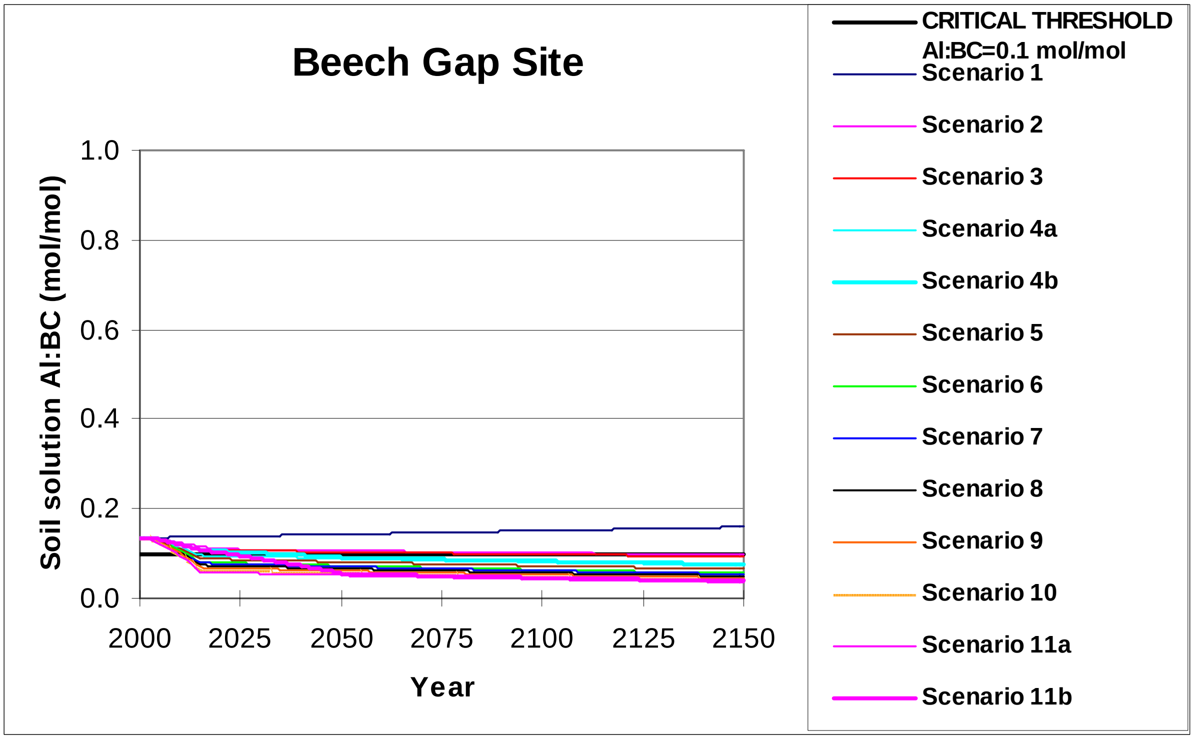


Figure 4.7c Modeled soil solution Al:BC ratio at the Beech Gap site

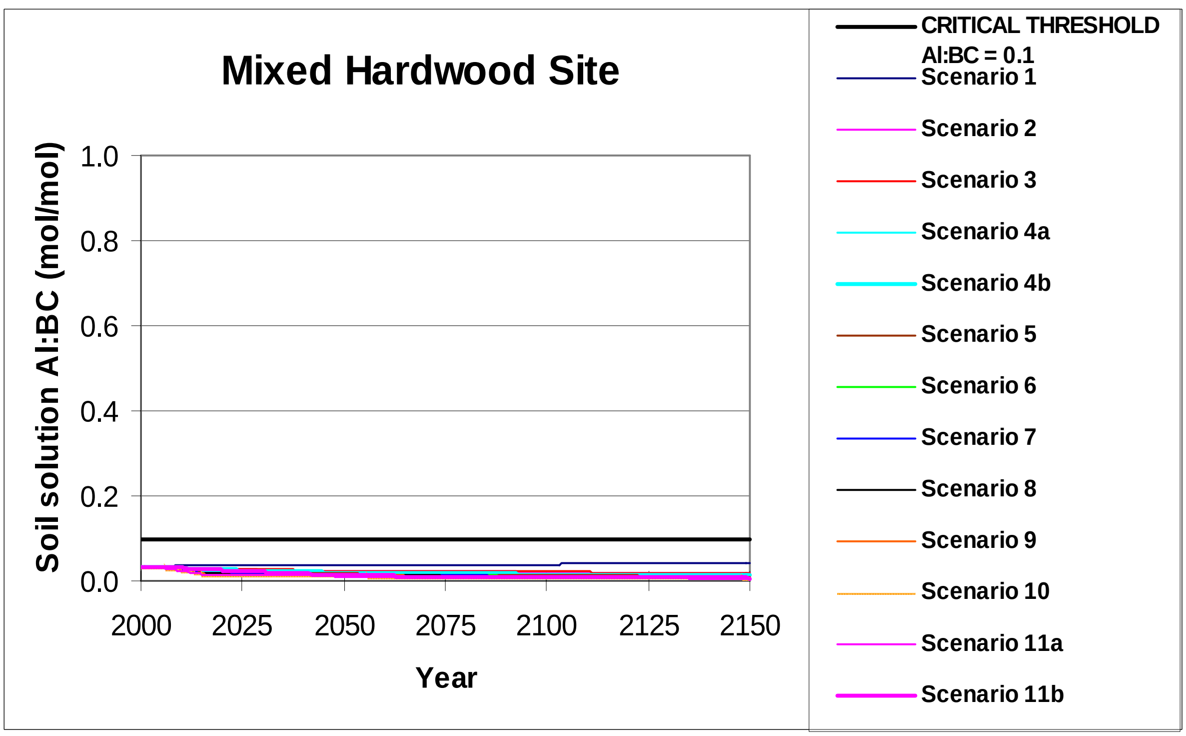


Figure 4.7d Modeled soil solution Al:BC ratio at the Mixed Hardwood site

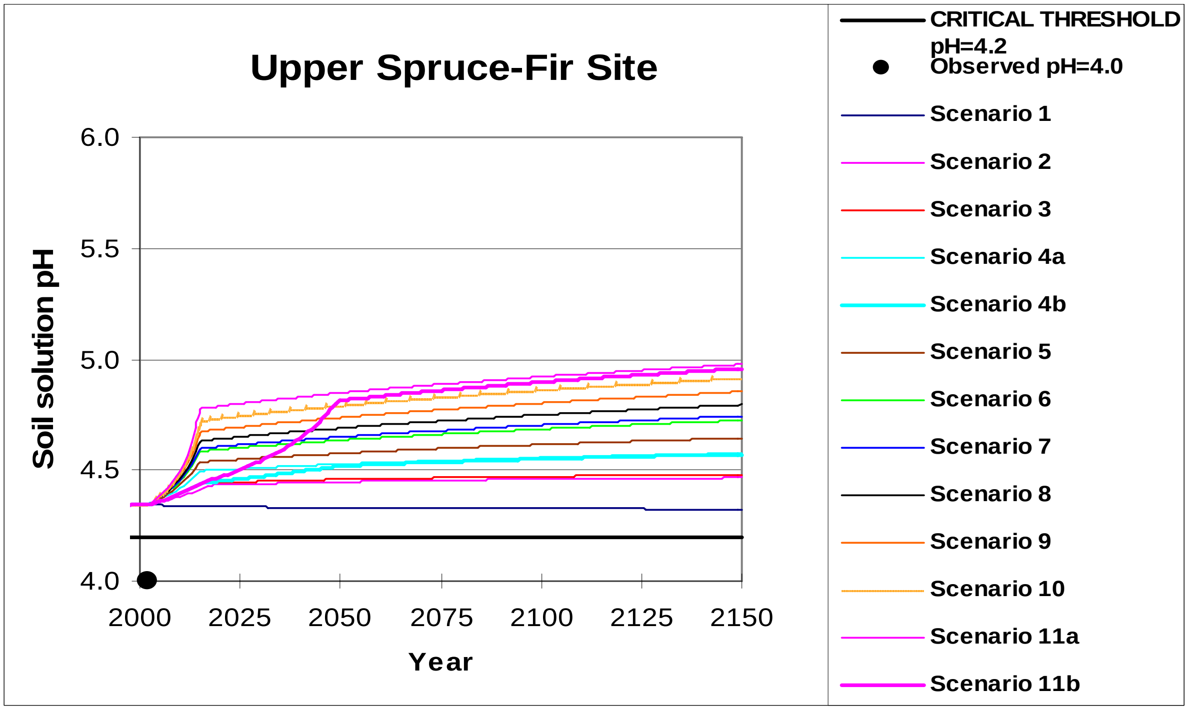


Figure 4.8a Modeled soil solution pH at the Upper Spruce-Fir site
Measured soil solution pH shown (black circle).
Deposition scenarios are described in Table 3.2. For pH, the critical threshold represents the minimum acceptable value, so the desired condition is a pH in excess of the threshold of 4.2. The pH threshold is shown (black line).

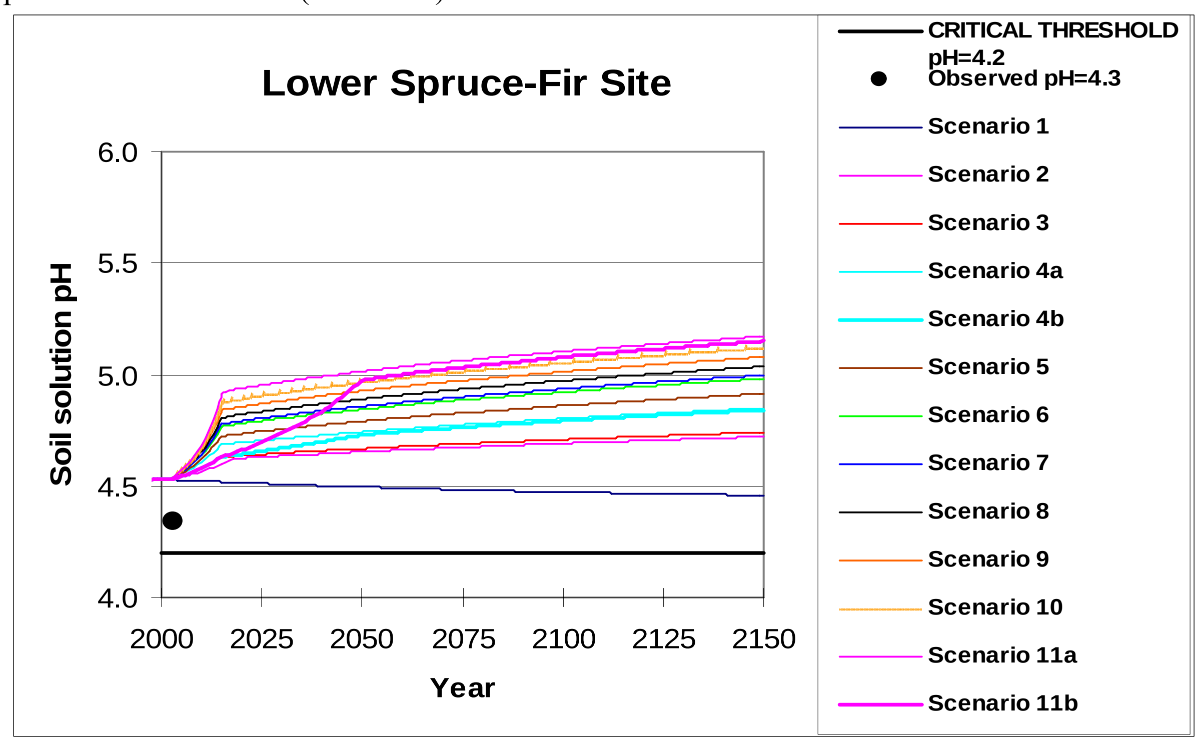


Figure 4.8b Modeled soil solution pH at the Lower Spruce-Fir site
Measured soil solution pH shown (black circle).

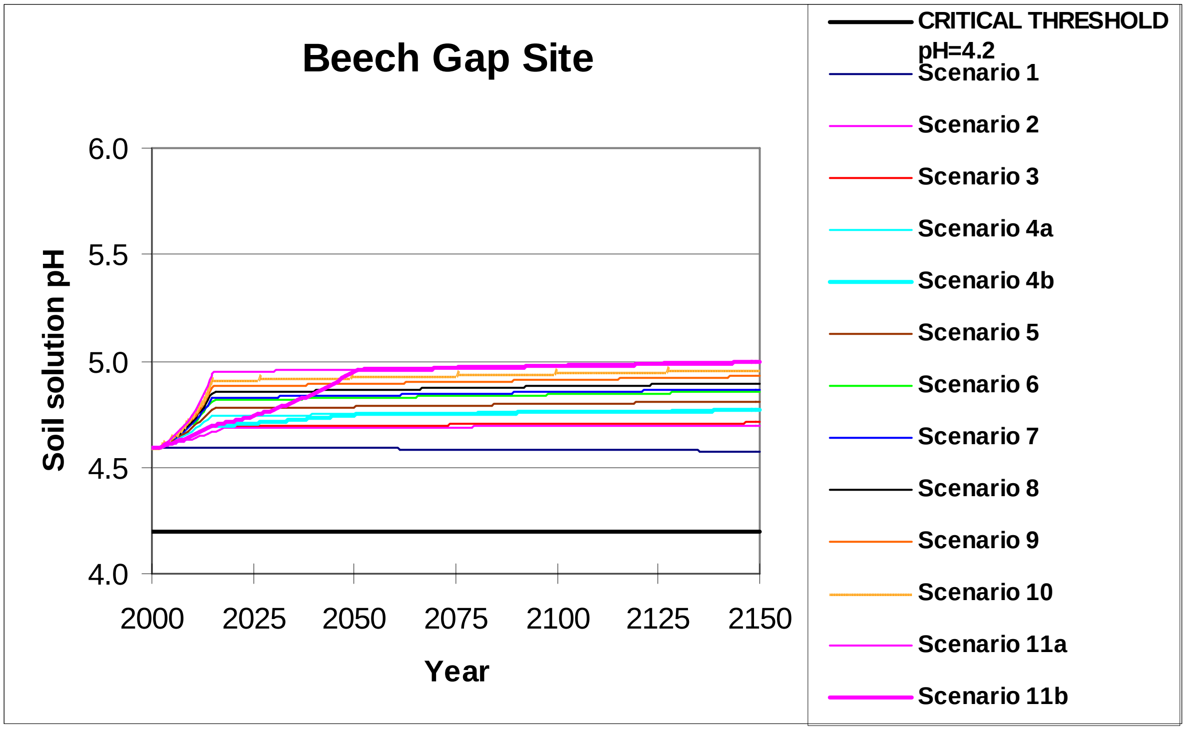


Figure 4.8c Modeled soil solution pH at the Beech Gap site

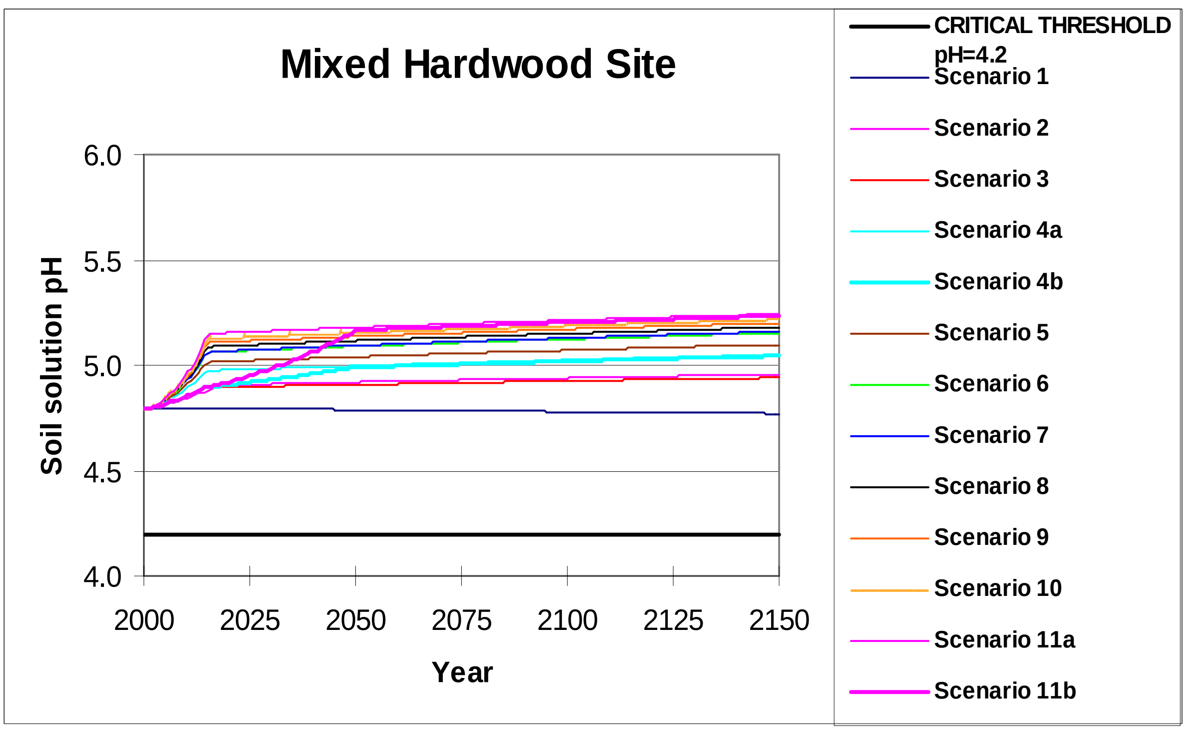


Figure 4.8d Modeled soil solution pH at the Mixed Hardwood site

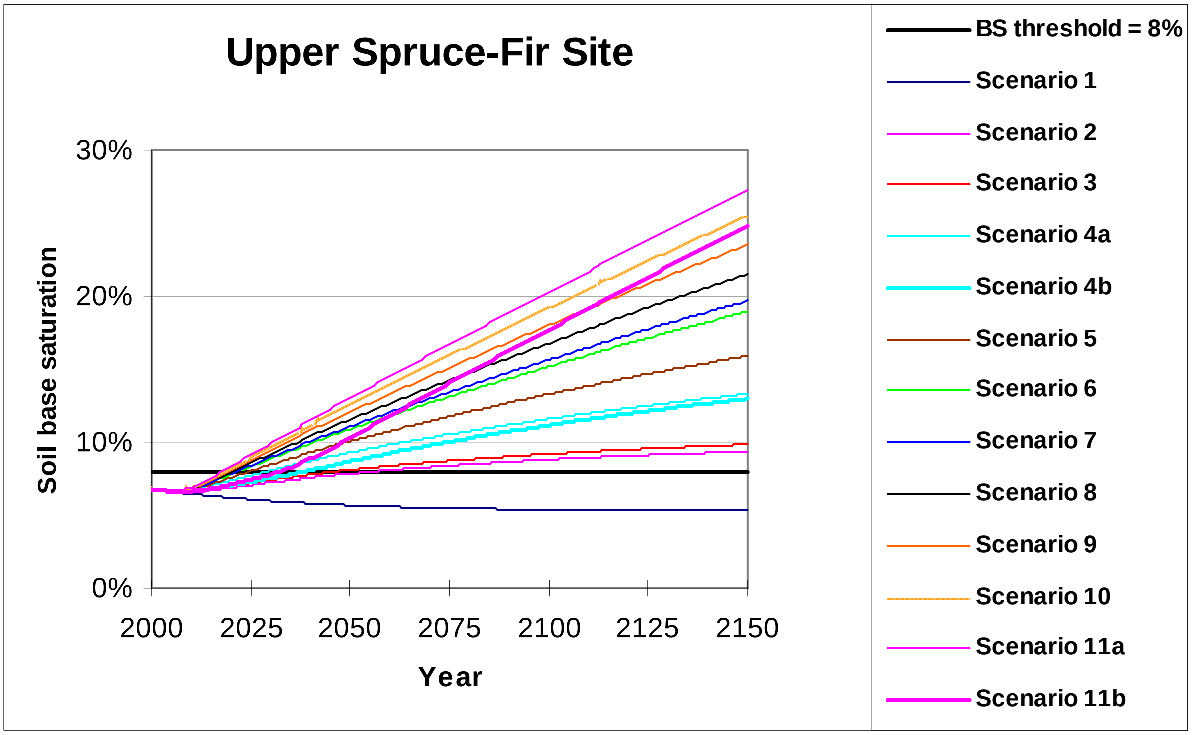


Figure 4.9a Modeled soil base saturation at the Upper Spruce-Fir site
Deposition scenarios are described in Table 3.2. Measured base saturation is noted. For base saturation, the desired condition is no decrease in base saturation below current condition.

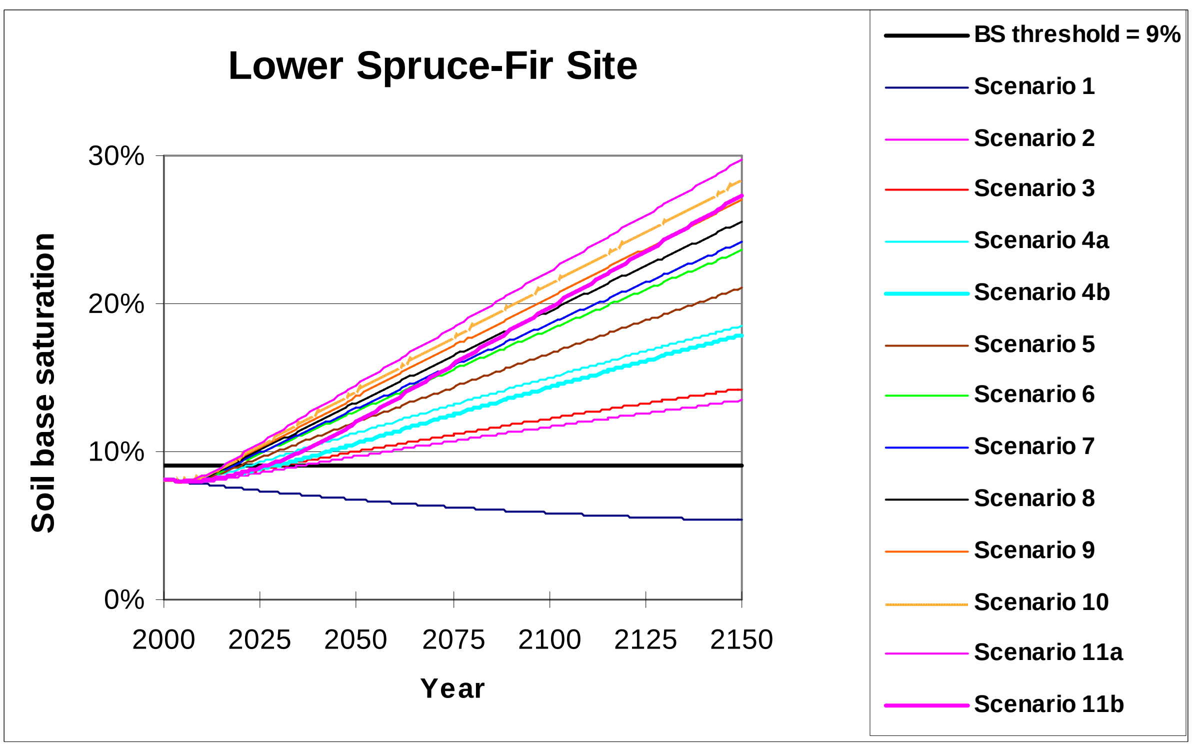


Figure 4.9b Modeled soil base saturation at the Lower Spruce-Fir site

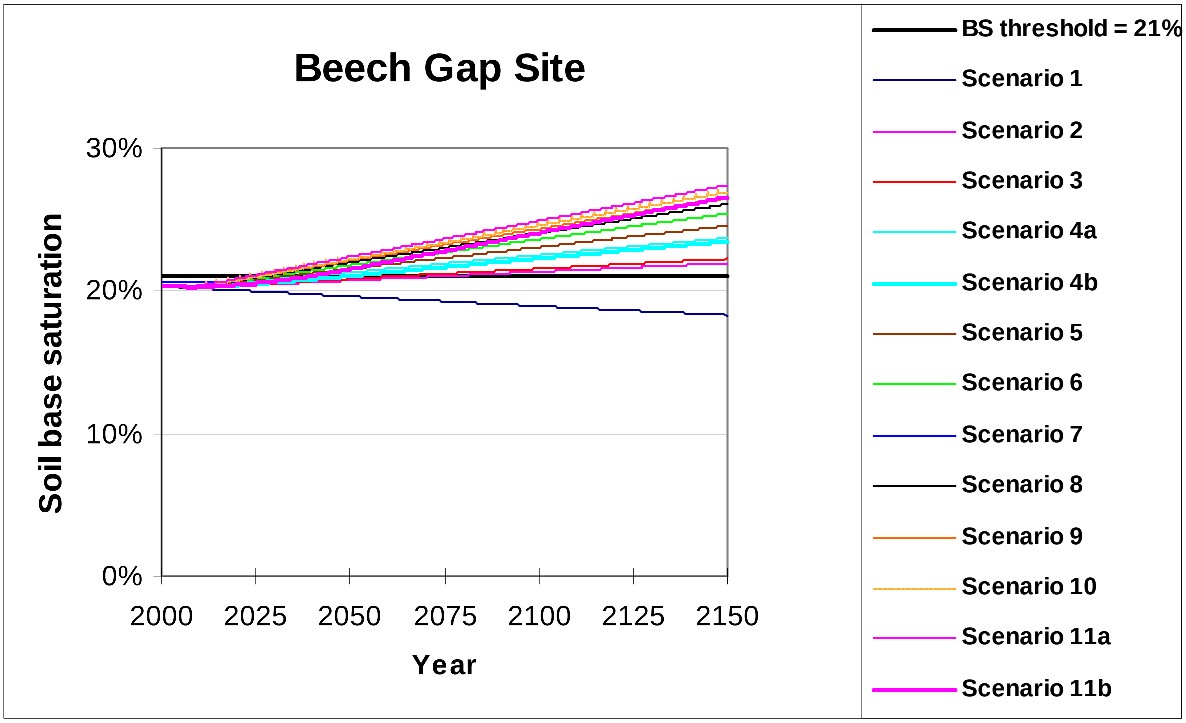


Figure 4.9c Modeled soil base saturation at the Beech Gap site

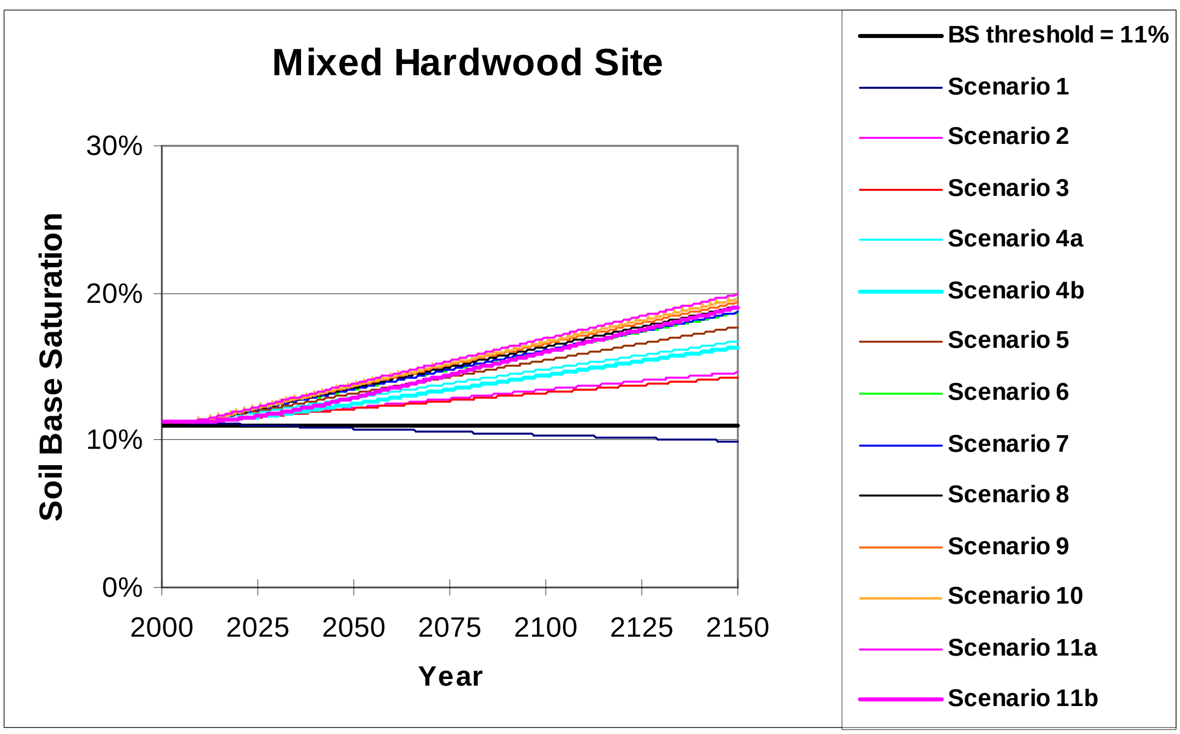


Figure 4.9d Modeled soil base saturation at the Mixed Hardwood site

5 Discussion

5.1 Critical loads and exceedances for Acidity (S+N)

In this analysis, we calculated several different critical loads using various critical thresholds. The lowest critical load calculated should be selected as the loading that would protect all the types of ecosystems and indicators examined in this study. In some instances a target load may be identified. A target load is the level of deposition that would allow the ecosystem to recover to a certain condition by a certain date. For example, based on Table 4.7, at the Lower Spruce-Fir site, in order to increase the ANC in soil solution to 0 $\mu eq\ L^{-1}$ by the year 2100, the target load would be 1046 eq $ha^{-1}\ y^{-1}$. Target loads can be a useful management guideline to facilitate recovery of sensitive ecosystem components.

The two biggest factors driving the critical load for S+N were the BC weathering and the BC deposition. In some cases, the soil mineral weathering was significantly greater than the inputs of BC in deposition (Lower Spruce-Fir and Mixed Hardwood; Tables 3.1 and 3.4). At the Upper Spruce-Fir site, the BC deposition was greater than the mineral soil weathering; at the Beech Gap site, they were of similar magnitude (Table 3.1 and 3.4). The net input of BC (BC deposition + BC weathering –BC uptake) is a measure of BC availability within the ecosystem. The site with the lowest net BC inputs had the lowest critical load (using the chemical criteria Al:BC =0.1) and as the net BC input increased across sites, the critical load also increased. When the critical load is lower at a given site, it means that a lower level of deposition can cause harm at that site than at another. However, just because the critical load is lower does not mean that a site is more susceptible to detrimental effects for N and S deposition than another site. In order to assess susceptibility, we calculate the exceedance, which tells us whether the current deposition is greater than the critical load, in which case the ecosystem is susceptible to detrimental effects from S and N deposition. If the current deposition is lower than the critical load, the ecosystem is not likely to be damaged by S and N deposition.

The critical load function (Figure 5.1) shows the combinations of S and N deposition that would be less than the critical load for acidity for all sites.

The fact that neither sulfate adsorption nor organic acids are included in the VSD model represents a limitation of this approach. Both of these omissions will cause the critical load to be underestimated. Sulfate adsorption is an abiotic process of retention of sulfate in soil. Sulfate adsorption may decrease leaching of BC and will affect the input/output budget of sulfur, such that inputs do not equal outputs. Further, sulfate adsorption and desorption will affect the time course of sulfate flux in stream water in response to decreasing atmospheric inputs of sulfur (Reuss and Johnson, 1986). The net sulfate retention observed at this site (Nodvin et al. 1995) suggests that sulfate adsorption has been significant at this site. Measurement of sulfate adsorption capacity at this site, however, is relatively low (Harrison et al. 1989). If adsorbed sulfate remains on the soil exchange complex over the long term, the acceptable amount of acid deposition would increase (i.e., the critical load would increase). In that case, the critical load that we report may be too low. However, because we do not have any current estimates of sulfate adsorption, and the declining sulfate deposition may cause adsorbed sulfate to desorb from the exchanger (Reuss and Johnson, 1986), we make no adjustment for sulfate adsorption in our calculations of critical loads.

Leaching of organic acids is not considered currently in the VSD model. Accounting for organic acids could lead to an increase in the critical load.

5.1.1 Trends in critical loads and exceedances for Acidity (S+N) over time

In all cases, deposition reductions improved the quality of soil solution: pH increased, Al concentration decreased, Al:BC ratio decreased, nitrate concentration decreased. In some cases, these improvements included crossing a critical threshold (e.g., Al:BC ratio). In other cases, for example, Al concentration and pH, the values were already on the “healthy” side of the threshold (above for pH, below for Al concentration). Further deposition reductions decrease the risk of detrimental effects of acid deposition. Because critical loads are calculated over the long term and the VSD operates on an annual time step, responses to episodic acidification are not modeled. When the Al concentration declines below the critical threshold or the pH increases above the critical threshold, that provides further protection against the risk of detrimental effects as a result of episodic acidification. Similarly, an increase in base saturation means that there is a net accumulation of BC on the soil exchange complex, which protects against any future acidification that would tend to remove BCs.

Deposition reductions required to reduce deposition below the critical load would range from 14% at the Beech Gap site to 53% at the Upper Spruce-Fir site (Table 5.1). However, these reductions would not result in reducing soil solution concentrations to below the critical thresholds before 2150 (Table 4.5). The CAIR and VISTAS deposition reduction scenarios would represent reductions of only 40 and 37%, respectively, and would therefore not be adequate to reduce deposition below the critical load at the Upper Spruce-Fir site. Both scenarios would result in the deposition being reduced below the critical load at the other three sites.

Table 5.1 Reduction of S+N Deposition required for no Exceedance of CL(S+N)

	Noland Divide			
Site:	**Upper Spruce-Fir**	**Lower Spruce-Fir**	**Beech Gap**	**Mixed Hardwood**
VSD CL Criteria				
Al=0.2 meq/L				
Al:BC=0.1 mol/mol	53%	14%	23%	
Al:BC=1.0 mol/mol				
Base Saturation	25%	17%	21%	12%
pH=4.2				

5.2 Critical loads and exceedances for nutrient N

The critical load for nutrient N is equal to the amount of N the ecosystem can retain and release without detrimental effect. The critical load $_{nutrient}$N, therefore, is determined by two acceptable values that are set (the acceptable soil N accumulation and the acceptable N leaching loss) plus an additional N sequestration term. The N sequestration term is to allow for the effect of disturbance at the high elevation sites. These systems are not at steady-state, so we recognized that a certain level of additional N inputs can be accommodated during the aggrading phase of forest stand re-development, until these disturbed stands reach their quasi-steady-state. In ecosystems where harvesting is permitted, the removal of N via biomass removal is included in the calculation of the critical load for $_{nutrient}N$ and can be quite significant.

The critical load $_{nutrient}N$ is a small fraction of the critical load S+N, even when we use the most conservative critical threshold (Al:BC=0.1; Figure 3.3). The critical load function (Figure 5.2) is shown for each site including the critical load $_{nutrient}N$. These figures suggest that to protect an ecosystem from detrimental effects of both acidification and N saturation the N deposition should not exceed the critical load $_{nutrient}N$ and the S deposition should be lower than the critical load function line.

There is some concern that the critical thresholds used in calculating the critical load for $_{nutrient}N$ are too low. There is a range suggested for the acceptable soil N accumulation term, which would generally not be higher than 1 kg ha^{-1} y^{-1}. We used the value of 0.5 kg ha^{-1} y^{-1} which is widely used for temperate forests. The range of acceptable N leaching loss for old growth stands is 4-5 kg ha^{-1} y^{-1}; the method we used gave us a value of about 3 kg ha^{-1} y^{-1}. This means that if we add 0.5 kg ha^{-1} y^{-1} for additional acceptable soil N accumulation and 2 kg ha^{-1} y^{-1} for additional acceptable N leaching loss (to reach the maximum acceptable leaching loss of 5 kg ha^{-1} y^{-1}), we would be at a maximum critical load for $_{nutrient}N$. To explore how the critical load for $_{nutrient}N$ would change using these values, we added them to the range we had calculated, which would add a total of about 2.5 kg ha^{-1} y^{-1} (200 eq ha^{-1} y^{-1}) of allowable inputs. Thus the maximum critical load for $_{nutrient}N$ would range from 5.6-10 kg ha^{-1} y^{-1} (400-700 eq ha^{-1} y^{-1}) Note that in all cases, the critical load for $_{nutrient}N$ would still be exceeded and would be significantly lower than the critical load for S+N, even if the critical load for $_{nutrient}N$ were increased by 200 eq ha^{-1} y^{-1}.

5.2.1 Trends in critical loads and exceedances for nutrient N over time

Nitrate concentration is significant both as an indication of acidification and an indication of nitrogen saturation. High nitrate leaching suggests a disruption of the internal nitrogen cycle, which is an early step in the progression towards nitrogen saturation (Aber et al., 1989; Stoddard, 1994). Since the critical load for N nutrient is exceeded in all cases, it is not surprising that modeled nitrate concentrations in stream water are exceed even when the critical load for acidity (S+N) is not exceeded.

The mean annual volume-weighted soil solution NO_3^- was also higher than the critical threshold, but lower than the modeled value. Because the model is a simplified one, especially with respect to nitrogen cycling, and includes certain assumptions of equilibrium, there may be a time lag before modeled conditions occur in the ecosystem. Nonetheless, there is a considerable body of evidence that suggests that the upper sites are N saturated. This evidence includes high nitrification rates and long-term elevated streamwater NO_3^- concentrations (Garten, 2000; Van Miegroet et al., 2001), in spite of the rapid N uptake in the upper elevation spruce-fir zone (Barker et al., 2002)

Deposition reductions of 90% for nitrate and 60% for ammonium at the Upper Spruce-Fir site, and 80% for ammonium at the Beech Gap site, and 40% for ammonium at the Mixed Hardwood site lower the total N deposition below the $CL_{nutrient}N$ (Figure 5.3). None of the deposition reduction scenarios lowers the total N deposition below the $CL_{nutrient}N$ at the Lower Spruce-Fir site (Figure 5.3b); at this site a reduction of 89% would be necessary and the most stringent reduction scenario (11) results in a reduction of total N deposition (NO_3^- + NH_4^+) of ~86%. Deposition reductions to lower deposition below the critical load for nutrient N would range from 68% of total N deposition at the Mixed Hardwood site to 90% of total N deposition at the Lower Spruce-Fir site (Table 5.2). Note that the deposition reduction scenarios do not include a 90% reduction of ammonium, so the 90% reduction of total N inputs is not achieved with these deposition reduction scenarios.

Table 5.2 Reduction of N Deposition required for no Exceedance of $CL_{nutrient}(N)$

Upper Spruce-Fir	Lower Spruce-Fir	Beech Gap	Mixed Hardwood
77%	89%	83%	68%

5.3 Comparison to other CL in the region/country

The critical loads reported at these sites fall within the range reported for mountainous areas in the northeastern U.S. (NEG/ECP 2003; Duarte et al. 2004). Miller (2005) reported that critical loads in New Hampshire and Vermont ranged from less than 250 eq ha^{-1} y^{-1} to over 2500 eq ha^{-1} y^{-1}. Exceedance in New Hampshire and Vermont ranged from 250-2000 eq ha^{-1} y^{-1} (Miller, 2005). In a study in Eastern Canada (Environment Canada 2004), Ouimet et al. (2006) report mean critical loads ranging from 519 -2063 eq ha^{-1} y^{-1} by province. Mean exceedance by province ranged from 0-700 eq ha^{-1} y^{-1} based on protecting 95% of forest area. Earlier assessments in this region suggest that the critical load for acidity has been exceeded for both terrestrial and aquatic ecosystems (Fox et al., 1989; Sullivan and Cosby 2002; Sullivan et al. 2003; Sullivan and Cosby 2004). Previous calculations of terrestrial critical loads within GSMNP were made using IFS data (Oja and Arp, 1998). Oja and Arp (1998) report critical loads for S+N to range from 593-922 eq ha^{-1} y^{-1} for Beech Gap, Upper and Lower Spruce-Fir sites. They report critical loads for N nutrient to range from 178-614 eq ha^{-1} y^{-1} for the Beech Gap, Upper and Lower Spruce-Fir sites. These estimates are somewhat lower than the values we report for critical loads of S+N and very similar to the range that we report for critical loads of nutrient N.

5.4 Uncertainty

Sources of uncertainty in these critical loads calculations come both from measured and modeled parameters. Deposition, soil mineral weathering, and nutrient sequestration all introduce uncertainty into these calculations. Overall, we assume that our methods have an uncertainty of at least 100-200 eq ha^{-1} y^{-1}, therefore, we consider critical loads that fall within that range to be equivalent.

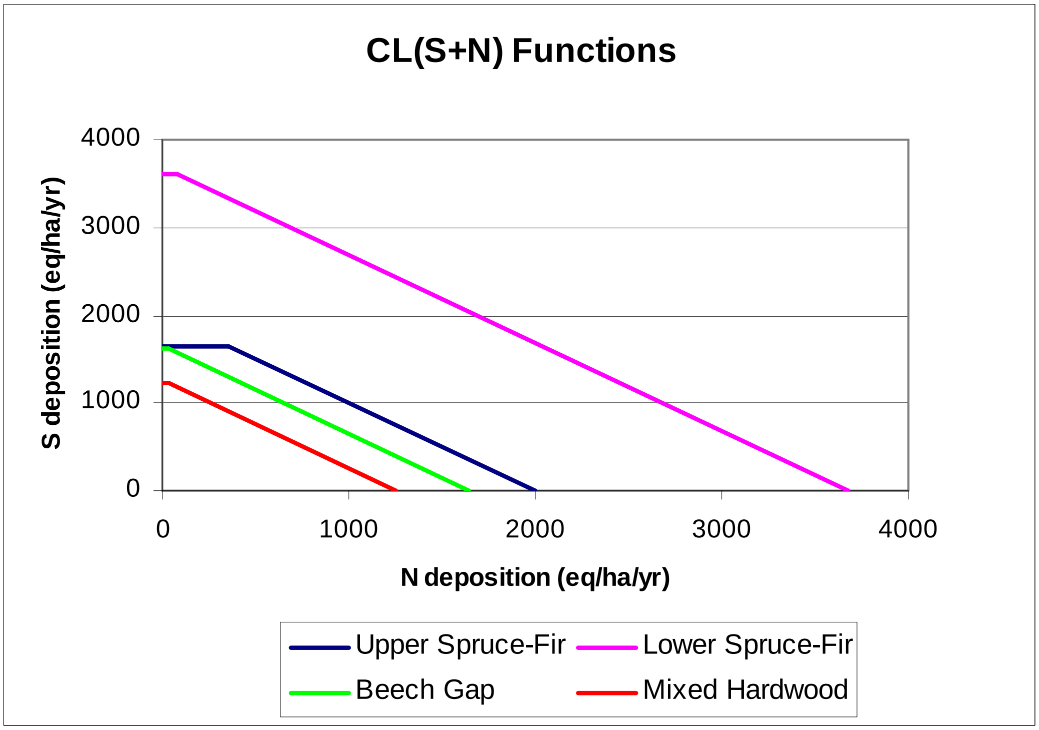


Figure 5.1 Critical Load functions using the chemical criteria Al:BC = 0.1 mol mol^{-1}

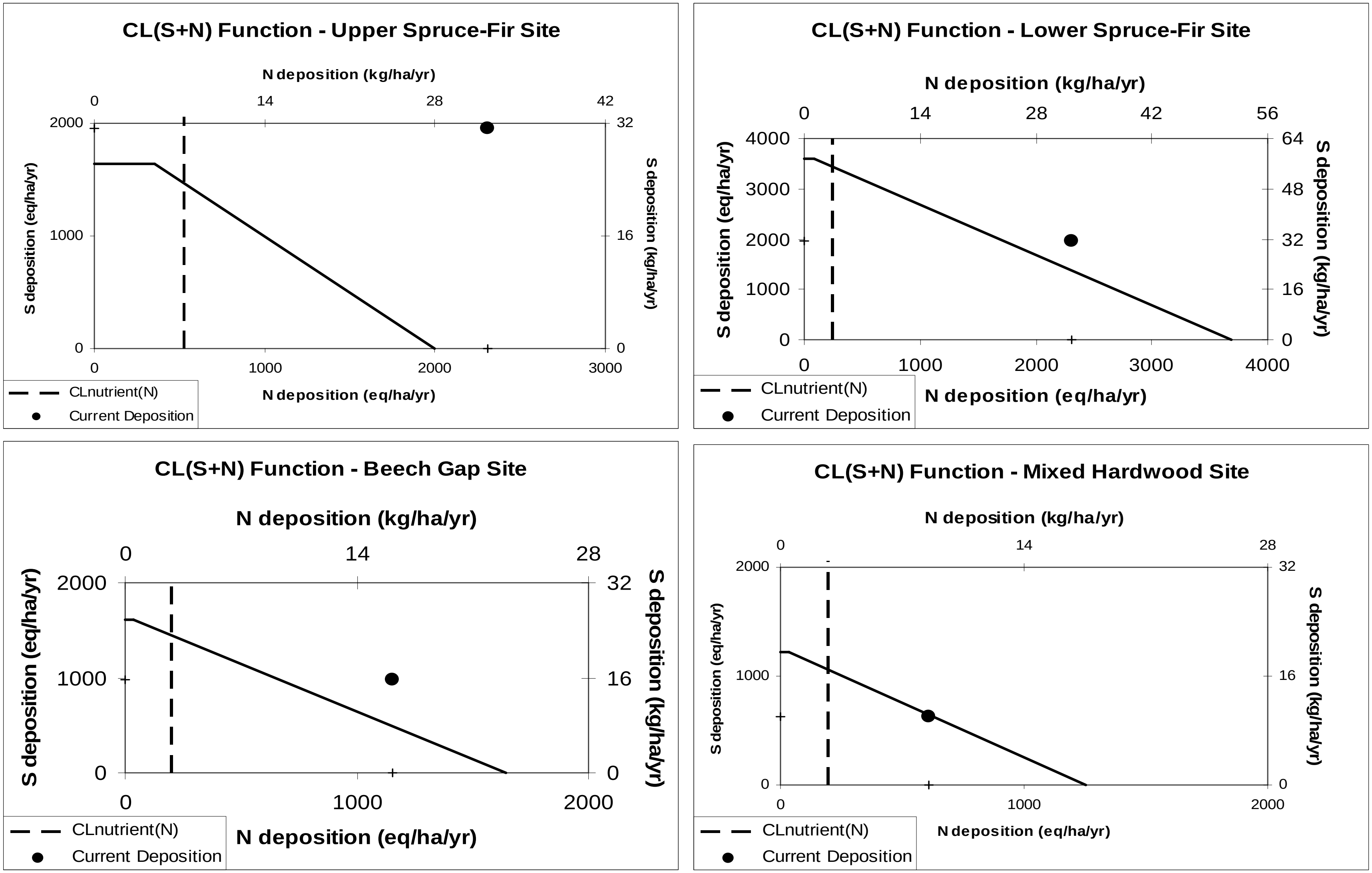


Figure 5.2 Critical load function with nutrient N marked

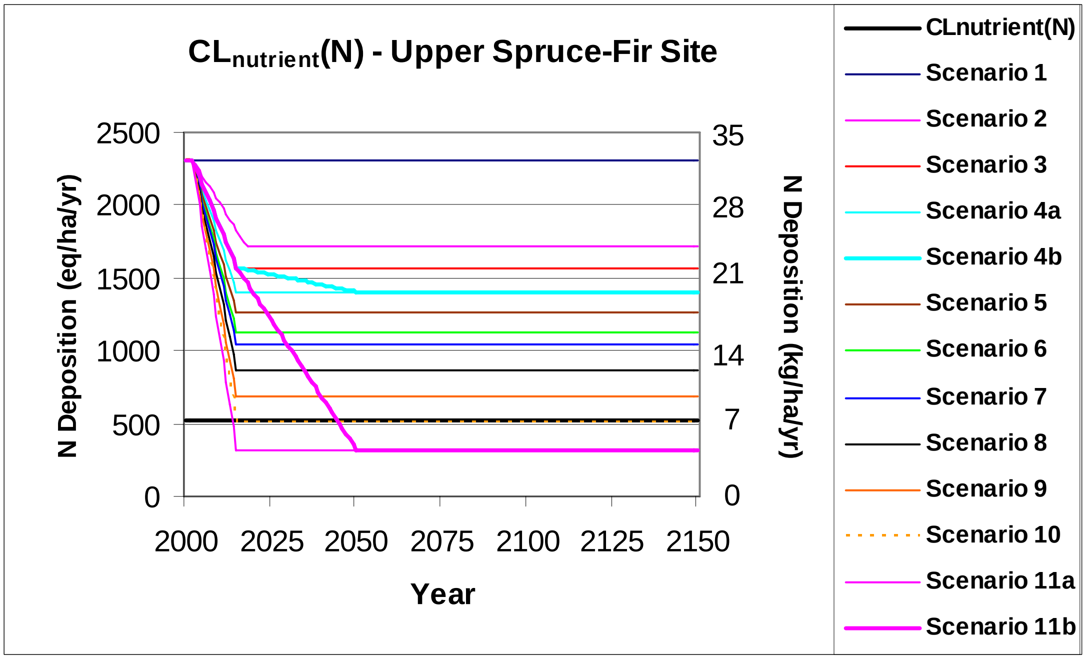


Figure 5.3a CL $_{nutrient}$N and N deposition scenarios for the Upper Spruce-Fir site

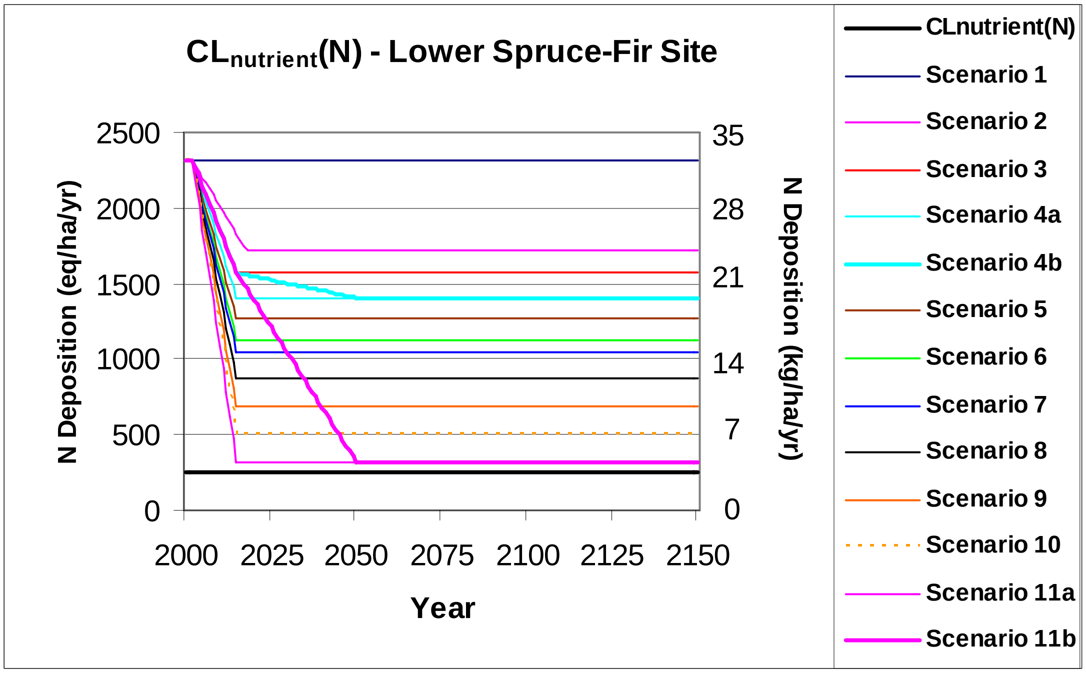


Figure 5.3b CL $_{nutrient}$N and N deposition scenarios for the Lower Spruce-Fir site

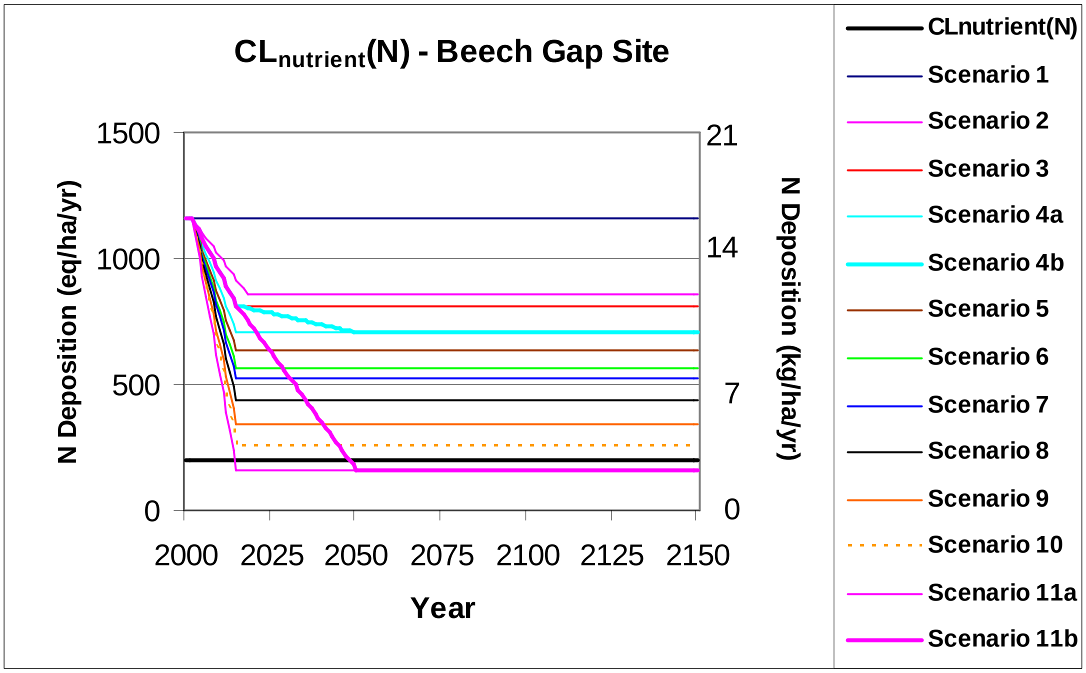


Figure 5.3c CL $_{nutrient}$N and N deposition scenarios for the Beech Gap site

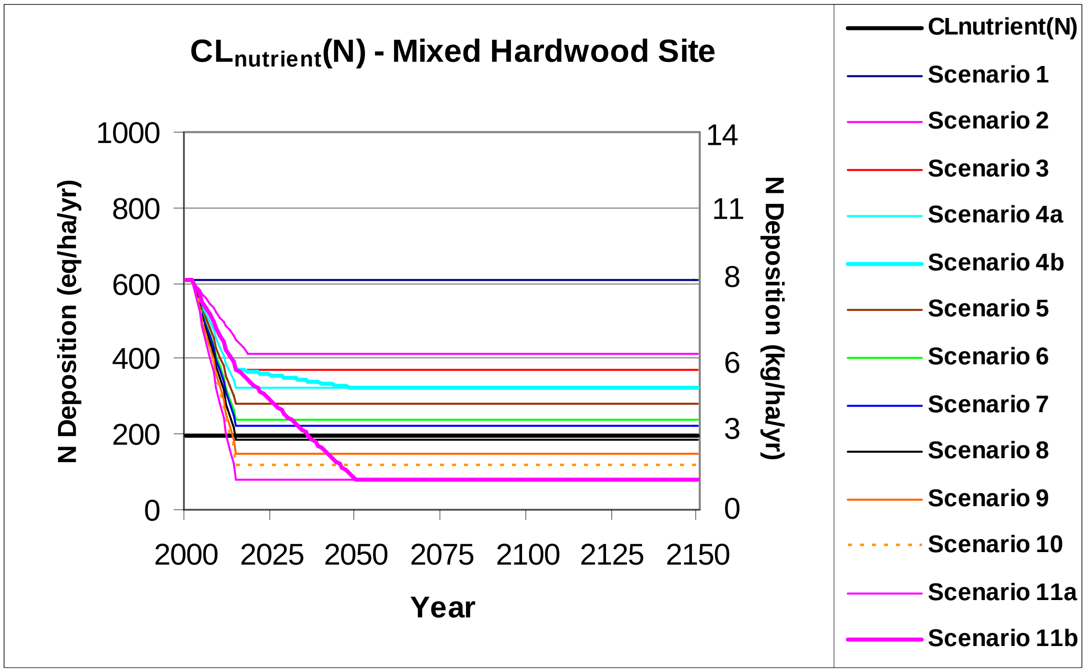


Figure 5.3d CL $_{nutrient}$N and N deposition scenarios for the Mixed Hardwood site

6 Monitoring next steps

Data availability is typically the factor that most limits critical loads calculations. Even at extensively studied sites such as those included in this analysis, data were not available for every parameter. The most important values for critical loads of S+N are soil parameters. Of these, the mineral soil weathering is the most uncertain. Estimates of mineral weathering from additional pits around the sites would improve our confidence in these values. The base saturation at the Beech Gap site was extremely high relative to the mineral weathering rate. If additional measures of weathering were made, the current base saturation could be measured as the mean of these additional soil pits. Accurate estimates of current total base cation deposition would also be helpful. Periodic measurement of soil solution chemistry including Al concentration would be helpful, particularly for calibration of the VSD model. Continued monitoring of N cycling and N fluxes are important for continued evaluation of ecosystem N status. Hourly temperature and precipitation measurements are needed annually at Noland Divide.

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8 Appendices

8.1 GSMNP Database Description

Brief overview of database

The Great Smoky Mountains National Park (GSMNP) critical loads database was created to support the calculation and analysis of critical loads for acidity (S+N) and nutrient N for three sites within the GSMNP. It includes descriptive data for the four sites as well as climate, deposition, and throughfall data, soil physical and chemical data, soil lysimeter data, and surface water data. The database is not intended to be an exhaustive collection of datasets for the GSMNP as many data sets were identified but not included. Examples of data excluded from this database are the understory vegetation data from the Integrated Forest Study (IFS) study, ozone data, deposition data from the Clean Air Status and Trends Network (CASTNET) and Mountain Acid Deposition Program (MADPro), Aluminum in Streams Study (ALSS) data, and soil and stream data for GSMNP sites not included in the Critical Loads study (e.g., data for Ravenfork). These data sets were excluded either because they did not pertain to the Critical Loads project, or because they were not in the format required, e.g. the MADPro data were expressed as air concentrations and not deposition rates, as is required for calculating critical loads. All of the data assembled at the outset of this project, but excluded from this database, are provided in a separate folder titled "Additional GSMNP Data".

The primary sources of data for the database are IFS, Natural Resources Conservation Service (NRCS), the Tennessee Valley Authority, the Resource Management & Science Division of Great Smoky Mountains National Park, and the University of Tennessee. The sources are identified for each piece of data in the database and there is a Data Source table which provides full references and/or contact information for the data providers. The tables that make up the Microsoft ACCESS relational database are shown in Figure 8.1, as are the relationships that link the tables. Eight of the database tables are connected by *CL Site ID* while four of these tables have additional "child" tables that provide data at a finer resolution (Figure 8.1). An alphabetized list of parameter descriptions is attached as Appendix A.

Database Table Descriptions

Site Description table

The *Site Description* table provides the following information: A unique identifier used for the Critical Load study, the names of the sites, names of other sites related to those used in the Critical Load study, descriptions of the site locations, latitude, longitude, elevation, dominant forest type, extended forest type, understory species, and the source for the site description information.

The unique identifier, *CL_Site_ID*, relates this table to all of the other tables in the GSMNP Database in a "one to many" relationship (Figure 8.1).

Long-Term Mean Climate Data table

The *Long-Term Mean Climate Data* table provides the summary climate inputs used to calculate critical loads. The parameters included in this table are: long-term mean annual precipitation volume, percent of precipitation that falls as snow, modeled evapotranspiration and runoff, and data sources for each of the parameters.

The *Long-Term Mean Climate Data* table is related to the *Site Description* table in a "one to one" relationship through the *CL_Site_ID* parameter (Figure 8.1).

Annual Deposition Data table

The Annual Deposition Data table provides annual precipitation volume and wet and dry deposition data for S, N, base cations, Cl^-, and H^+ for the low elevation Mixed Hardwood site. Also included in this table are data sources, number of days the data were collected, and start and end dates.

The *Annual Deposition Data* table is related to the *Site Description* table in a "many to one" relationship through the *CL_Site_ID* parameter and in a "one to many" relationship with the *Monthly Deposition Data* table through the *Location_ID* and *Year* parameters (Figure 8.1).

Monthly Deposition Data table

The *Monthly Deposition Data* table provides monthly precipitation volume, conductivity, and wet deposition data for S, N, base cations, Cl^-, and H^+ for the low elevation Mixed Hardwood site. Also included in this table are data sources, number of days the data were collected, and start and end dates.

The *Monthly Deposition Data* table is related to the *Annual Deposition Data* table in a "many to one" relationship through the *Location_ID* and *Year* parameters (Figure 8.1).

Volume-Weighted Mean Throughfall Rates table

The *Volume-weighted Mean Throughfall* table provides volume-weighted annual throughfall rates from under-canopy and open collectors for S, N, base cations, and Cl^- for the high elevation Lower Spruce-Fir site.

The *Volume-weighted Mean Throughfall Rates* table is connected to the *Site Description* table in a "many to one" relationship through the *CL_Site_ID* parameter and in a "one to many" relationship with the *Throughfall Raw Data* table through the *Collector_Placement* and *TF_Year* parameters (Figure 8.1).

Throughfall Raw Data table

The *Throughfall Raw Data* table provides throughfall and open collector sample volume, conductivity, S, N, base cations, and Cl^- concentrations from individual samples for the high elevation Lower Spruce-Fir site.

The *Throughfall Raw Data* table is connected to the *Volume-weighted Mean Throughfall Rates* table in a "many to one" relationship through the *Collector_Placement* and *TF_Year* parameters (Figure 8.1).

Deposition Scenario table

The *Deposition Scenario* table provides mean S, NO_3^-, and NH_4^+ deposition rates for the 11 deposition scenarios used in the Critical Load study (Table 8.1). The data are presented as kg ha^{-1} yr^{-1}, eq ha^{-1} yr^{-1}, and eq m^{-2} yr^{-1} because different units are required for the different Critical Loads models.

Table 8.1. Deposition Scenarios used in the Critical Loads study.

Scenario	**Total S**	**NO_3^-**	**NH_4^+**	**Deposition reductions**
1	No change	No change	No change	Current deposition (1999-2004 mean)
2	-50%	-48%	+9%	Deposition reductions evenly distributed from 2002 - 2018
3	-48%	-56%	+5%	Deposition reductions evenly distributed from 2002 - 2015
4a	-70%	-70%	+9%	Deposition reductions evenly distributed from 2002 - 2015
4b	-70%	-70%	+9%	Scenario 3 reductions were used through 2015, the remainder of the deposition reductions are evenly distributed from 2015 - 2050
5	-80%	-80%	+9%	Deposition reductions evenly distributed from 2002 - 2015
6	-90%	-90%	+9%	Deposition reductions evenly distributed from 2002 - 2015
7	-90%	-90%	No change	Deposition reductions evenly distributed from 2002 - 2015
8	-90%	-90%	-20%	Deposition reductions evenly distributed from 2002 - 2015
9	-90%	-90%	-40%	Deposition reductions evenly distributed from 2002 - 2015
10	-90%	-90%	-60%	Deposition reductions evenly distributed from 2002 - 2015
11a	-90%	-90%	-80%	Deposition reductions evenly distributed from 2002 - 2015
11b	-90%	-90%	-80%	Scenario 3 reductions were used through 2015, the remainder of the deposition reductions are evenly distributed from 2015 - 2050

The *Deposition Scenario* table is connected to the *Site Description* table in a "many to one" relationship through the *CL_Site_ID* parameter (Figure 8.1).

Historic Deposition table

The *Historic Deposition* table provides the modeled annual deposition rates for each site from 1860 - 1999 for S, NO_3^-, NH_4^+, base actions, and Cl^- used in the Critical Load study.

The *Historic Deposition* table is connected to the *Site Description* table in a "many to one" relationship through the *CL_Site_ID* parameter (Figure 8.1).

Depth-Weighted Soil Pedon Data table

The *Depth-weighted Soil Pedon Data* table provides soil series and soil taxonomy for the soils associated with each site. In addition, soil depth and depth-weighted values for clay percent, bulk density, soil water content, cation exchange capacity (CEC), base saturation, C pool, C:N ratio and soil mineral weathering rates are included in this table.

The *Depth-weighted Soil Pedon Data* table is connected to the *Site Description* table in a "many to one" relationship through the *CL_Site_ID* parameter and to the *Soil Horizon Data* table through a "one to many" relationship through the *Pedon_Key* parameter (Figure 8.1).

Soil Horizon Data table

The *Soil Horizon Data* table provides soil horizon data from individual soil pits. The parameters included are: top and bottom of horizons, horizon designation, bulk density, C %, N% S%, C:N ratio, extractable cations, acidity, cation exchange capacity (CEC), effective, CEC, Al saturation, base saturation, pH, organic C%, organic N%, organic C:N ratio, organic pH, full particle size and coarse fragment analysis, NO_3^- concentration, soluble salts, and organic matter %. Additionally, information on data sources is included.

The *Soil Horizon Data* table is connected in a "many to one" relationship to the *Depth-weighted Soil Pedon Data* table through the *Pedon_Key* parameter (Figure 8.1).

Volume-Weighted Mean Lysimeter Data table

The *Volume-weighted Mean Lysimeter Data* table provides volume-weighted mean conductivity, pH, SO_4^{-2}, NO_3^-, NH_4^+, base cations, Cl^-, and ANC for the high elevation Lower Spruce-Fir site.

The *Volume-weighted Mean Lysimeter Data* table is connected to the *Site Description* table in a "many to one" relationship through the *CL_Site_ID* parameter and to the *Lysimeter Raw Data* table through a "one to many" relationship through the *CL_Site_ID* and *Lysimeter Year* parameters (Figure 8.1).

Lysimeter Raw Data table

The *Lysimeter Raw Data* table provides sample volume, conductivity, pH, SO_4^{-2}, NO_3^-, NH_4^+, base cations, Cl^-, Al^{3+}, and data source information for individual lysimeter samples for the high elevation Lower Spruce-Fir site.

The *Lysimeter Raw Data* table is connected to the *Volume-weighted Mean Lysimeter Data* table in a "many to one" relationship through the *CL_Site_ID* and *Lysimeter Year* parameters (Figure 8.1).

Mean Surface Water Data table

The *Mean Surface Water Data* table provides annual pH, SO_4^{-2}, NO_3^-, NH_4^+, base cations, Cl^-, and ANC values for northeast and southwest streamlets near the high elevation Lower Spruce-Fir site. Note that, due to lake of flow data, the means presented in this table are not volume-weighted.

The *Mean Surface Water Data* table is connected to the *Site Description* table in a "many to one" relationship through the *CL_Site_ID* parameter and to the *Surface Water Raw Data* table through a "one to many" relationship through the *Surface_Water_ID* parameter (Figure 8.1).

Surface Water Raw Data table

The *Surface Water Raw Data* table provides annual pH, SO_4^{-2}, NO_3^-, NH_4^+, base cations, Cl^-, and ANC values for individual samples from the northeast and southwest streamlets near the high elevation Lower Spruce-Fir site.

The *Surface Water Raw Data* table is connected to the *Mean Surface Water Data* table in a "many to one" relationship through the *Surface_Water_ID* parameter (Figure 8.1).

Data Sources table

The *Data Sources* table provides full references and/or contact information for the data providers that are referenced throughout all of the other database tables. This table is a stand-alone table and is intended for reference only.

Acknowledgments

Many data were assembled from Johnson and Lindberg (1992). In addition, the following individuals provided published and unpublished data as well as guidance on the use of the data: Jack Cosby (University of Virginia), Suzanne Fisher (Tennessee Valley Authority), Anthony Khiel (NRCS), Jim Renfro (National Park Service), Bruce Robinson (University of Tennessee), Helga van Miegroet (University of Utah).

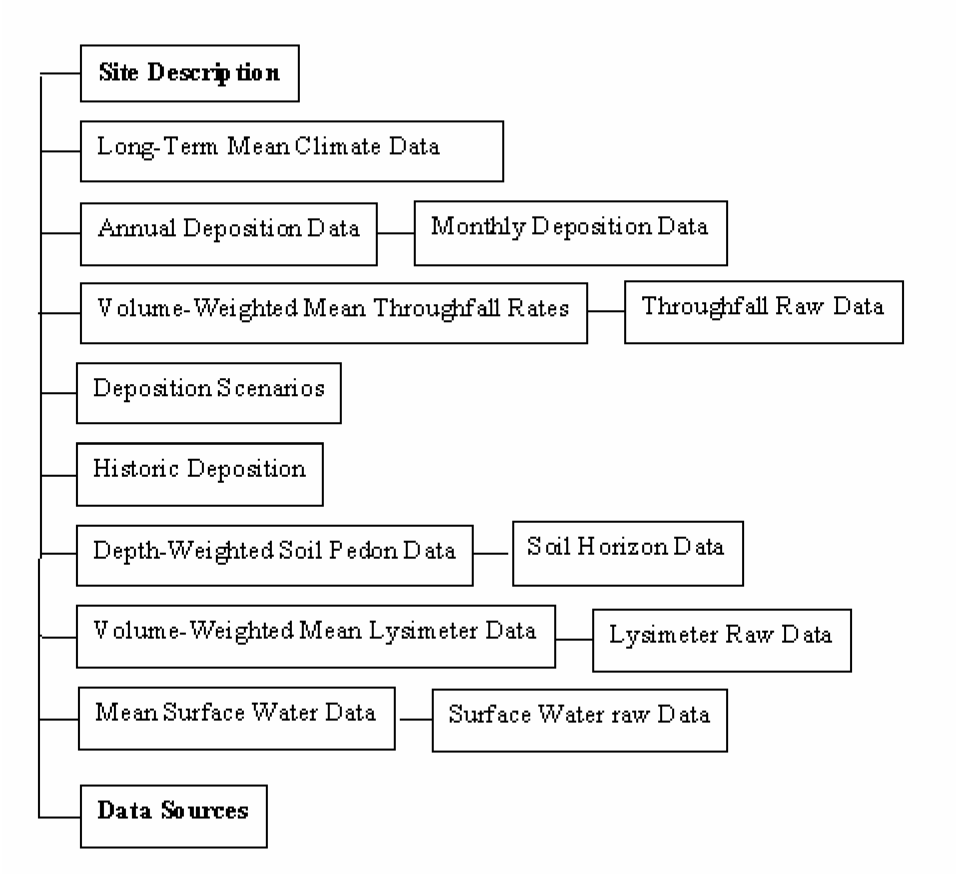

Figure 8.1. GSMNP Database Structure

8.2 GSMNP Database Parameter Descriptions, by Database Table

Parameter	Table	Data Type	Units	Description
CL_Site_ID	Site Description	Number		Site ID for sites used in Critical Load assessment
CL_Site_Name	Site Description	Text		Site name for sites used in Critical Load assessment
Related_Site	Site Description	Text		Sites from which data were used for CL site
Site Location	Site Description	Text		Descriptive location
Latitude_dd	Site Description	Number	Decimal Degrees	
Longitude_dd	Site Description	Number	Decimal Degrees	
Elevation_m	Site Description	Number	m	
Forest Type	Site Description	Text		Dominant forest type
Extended_FT	Site Description	Text		Extended forest type
Understory	Site Description	Text		Dominant understory vegetation
Site Description Data Source	Site Description	Text		
Climate_ID	Long-Term Mean Climate Data	Number		
CL_Site_ID	Long-Term Mean Climate Data	Number		
Long-term_mean_an_ppt_cm	Long-Term Mean Climate Data	Number	cm	Long-term mean annual precipitation volume
Long-term_mean_an_ppt_Source	Long-Term Mean Climate Data	Text		
%_snow	Long-Term Mean Climate Data	Number	%	% of precipitation volume received as snow
%_snow_Source	Long-Term Mean Climate Data	Text		
Modeled_ET_cm	Long-Term Mean Climate Data	Number	cm	Modeled evapotranspiration
Modeled_ET_Source	Long-Term Mean Climate Data	Text		

Parameter	Table	Data Type	Units	Description
Modeled_runoff_cm	Long-Term Mean Climate Data	Number	cm	
Modeled_runoff_Source	Long-Term Mean Climate Data	Text		
Annual_dep_ID	Annual Deposition Rates	Number		
CL_Site_ID	Annual Deposition Rates	Number		
DepositionSource	Annual Deposition Rates	Text		
Location_ID	Annual Deposition Rates	Text		
Location_Name	Annual Deposition Rates	Text		
Dep_Year	Annual Deposition Rates	Number		
Precip_Vol_cm	Annual Deposition Rates	Number	cm	
SO4_WET_S_kg/ha/yr	Annual Deposition Rates	Number	kg ha^{-1} yr^{-1}	
SO2_DRY_S_kg/ha/yr	Annual Deposition Rates	Number	kg ha^{-1} yr^{-1}	
SO4_DRY_S_kg/ha/yr	Annual Deposition Rates	Number	kg ha^{-1} yr^{-1}	
S_DRY_kg/ha/yr	Annual Deposition Rates	Number	kg ha^{-1} yr^{-1}	
NO3_WET_N_kg/ha/yr	Annual Deposition Rates	Number	kg ha^{-1} yr^{-1}	
NH4_WET_N_kg/ha/yr	Annual Deposition Rates	Number	kg ha^{-1} yr^{-1}	

Parameter	Table	Data Type	Units	Description
InorgN_Wet_kg/ha/yr	Annual Deposition Rates	Number	kg ha^{-1} yr^{-1}	
HNO3_DRY_N_kg/ha/yr	Annual Deposition Rates	Number	kg ha^{-1} yr^{-1}	
NO3_DRY_N_kg/ha/yr	Annual Deposition Rates	Number	kg ha^{-1} yr^{-1}	
NH4_DRY_N_kg/ha/yr	Annual Deposition Rates	Number	kg ha^{-1} yr^{-1}	
N_WET_kg/ha/yr	Annual Deposition Rates	Number	kg ha^{-1} yr^{-1}	
N_DRY_kg/ha/yr	Annual Deposition Rates	Number	kg ha^{-1} yr^{-1}	
N_Wet+Dry_kg/h/yr a	Annual Deposition Rates	Number	kg ha^{-1} yr^{-1}	
Ca_kg/ha/yr	Annual Deposition Rates	Number	kg ha^{-1} yr^{-1}	
Mg_kg/ha/yr	Annual Deposition Rates	Number	kg ha^{-1} yr^{-1}	
K_kg/ha/yr	Annual Deposition Rates	Number	kg ha^{-1} yr^{-1}	
Na_kg/ha/yr	Annual Deposition Rates	Number	kg ha^{-1} yr^{-1}	
Cl_kg/ha/yr	Annual Deposition Rates	Number	kg ha^{-1} yr^{-1}	
H_lab_kg/ha/yr	Annual Deposition Rates	Number	kg ha^{-1} yr^{-1}	H+ measured in lab
H_field_kg/ha/yr	Annual Deposition Rates	Number	kg ha^{-1} yr^{-1}	H+ measured in field
Deposition Units	Annual Deposition Rates	Text		
Days	Annual Deposition Rates	Number		

Parameter	Table	Data Type	Units	Description
StartDate	Annual Deposition Rates	Number		
EndDate	Annual Deposition Rates	Number		
Monthly_Wet_Dep_ID	Monthly Wet Deposition Rates	Number		
Location_ID	Monthly Wet Deposition Rates	Text		
Location_Name	Monthly Wet Deposition Rates	Text		
Month	Monthly Wet Deposition Rates	Number		
Deposition_Year	Monthly Wet Deposition Rates	Number		
Ca_wet_kg/ha/mo	Monthly Wet Deposition Rates	Number	kg ha^{-1} mo^{-1}	
Mg_wet_kg/ha/mo	Monthly Wet Deposition Rates	Number	kg ha^{-1} mo^{-1}	
K_wet_kg/ha/mo	Monthly Wet Deposition Rates	Number	kg ha^{-1} mo^{-1}	
Na_wet_kg/ha/mo	Monthly Wet Deposition Rates	Number	kg ha^{-1} mo^{-1}	
NH4_wet_kg/ha/mo	Monthly Wet Deposition Rates	Number	kg ha^{-1} mo^{-1}	
NO3_wet_kg/ha/mo	Monthly Wet Deposition Rates	Number	kg ha^{-1} mo^{-1}	
Cl_wet_kg/ha/mo	Monthly Wet Deposition Rates	Number	kg ha^{-1} mo^{-1}	
SO4_wet_kg/ha/mo	Monthly Wet Deposition Rates	Number	kg ha^{-1} mo^{-1}	

Parameter	Table	Data Type	Units	Description
H_wet_kg/ha/mo	Monthly Wet Deposition Rates	Number	kg ha^{-1} mo^{-1}	
Conductivity_µmhos/cm	Monthly Wet Deposition Rates	Number	µmhos cm^{-1}	
Precipitation_cm	Monthly Wet Deposition Rates	Number	cm	
Days	Monthly Wet Deposition Rates	Number		
StartDate	Monthly Wet Deposition Rates	Number		
EndDate	Monthly Wet Deposition Rates	Number		
Mean_Annual_TF_ID	Mean Annual Throughfall Rates	Number		
CL_Site_ID	Mean Annual Throughfall Rates	Number		
Collector Placement	Mean Annual Throughfall Rates	Text		Open field or canopy throughfall
Throughfall_Year	Mean Annual Throughfall Rates	Number		
SampleVolume_cm	Mean Annual Throughfall Rates	Number	cm	
Cl_eq/ha/yr	Mean Annual Throughfall Rates	Number	eq ha^{-1} yr^{-1}	
NO3_eq.ha.yr	Mean Annual Throughfall Rates	Number	eq ha^{-1} yr^{-1}	
So4_eq/ha/yr	Mean Annual Throughfall Rates	Number	eq ha^{-1} yr^{-1}	
Na_eq/ha/yr	Mean Annual Throughfall Rates	Number	eq ha^{-1} yr^{-1}	

Parameter	Table	Data Type	Units	Description
NH4_eq/ha/yr	Mean Annual Throughfall Rates	Number	eq ha^{-1} yr^{-1}	
Total Inorganic N_eq/ha/yr	Mean Annual Throughfall Rates	Number	eq ha^{-1} yr^{-1}	
K_eq/ha/yr	Mean Annual Throughfall Rates	Number	eq ha^{-1} yr^{-1}	
IC Mg_eq/ha/yr	Mean Annual Throughfall Rates	Number	eq ha^{-1} yr^{-1}	Simples analyzed with IC
IC Ca_eq/ha/yr	Mean Annual Throughfall Rates	Number	eq ha^{-1} yr^{-1}	Simples analyzed with IC
F_eq/ha/yr	Mean Annual Throughfall Rates	Number	eq ha^{-1} yr^{-1}	
AA or ICP Mg_eq/ha/yr	Mean Annual Throughfall Rates	Number	eq ha^{-1} yr^{-1}	Simples analyzed with AA or ICP
AA or ICP Ca_eq/ha/yr	Mean Annual Throughfall Rates	Number	eq ha^{-1} yr^{-1}	Simples analyzed with AA or ICP
Throughfall Comment	Mean Annual Throughfall Rates	Text		
Throughfall Data Source	Mean Annual Throughfall Rates	Text		
TF_Raw_Data_ID	Throughfall Raw Data	Number		
CL_Site_ID	Throughfall Raw Data	Number		
CollectorPlacement	Throughfall Raw Data	Text		Open field or canopy throughfall
TF_Year	Throughfall Raw Data	Number		
Sample_Date	Throughfall Raw Data	Number		

Parameter	Table	Data Type	Units	Description
Total_wedge_cm	Throughfall Raw Data	Number	cm	
Total_bucket_cm	Throughfall Raw Data	Number	cm	
Total_Belfort_cm	Throughfall Raw Data	Number	cm	
Precipitation_cm	Throughfall Raw Data	Number	cm	
Conductivity_uS/cm2	Throughfall Raw Data	Number	uS cm^{-2}	
Cl_ueq/L	Throughfall Raw Data	Number	ueq L^{-1}	
NO3_ueq/L	Throughfall Raw Data	Number	ueq L^{-1}	
SO4_ueq/L	Throughfall Raw Data	Number	ueq L^{-1}	
Na_ueq/L	Throughfall Raw Data	Number	ueq L^{-1}	
NH4_ueq/L	Throughfall Raw Data	Number	ueq L^{-1}	
K_ueq/L	Throughfall Raw Data	Number	ueq L^{-1}	
ICP K_ueq/L	Throughfall Raw Data	Number	ueq L^{-1}	Simples analyzed with ICP
H_ueq/L	Throughfall Raw Data	Number	ueq L^{-1}	
AA Mg_ueq/L	Throughfall Raw Data	Number	ueq L^{-1}	Simples analyzed with AA
AA or ICP Mg	Throughfall Raw Data	Number	ueq L^{-1}	Simples analyzed with AA or ICP
AA Ca_ueq/L	Throughfall Raw Data	Number	ueq L^{-1}	Simples analyzed with AA

Parameter	Table	Data Type	Units	Description
AA or ICP Ca_ueq/L	Throughfall Raw Data	Number	ueq L^{-1}	Simples analyzed with AA or ICP
ICP Na_ueq/L	Throughfall Raw Data	Number	ueq L^{-1}	Simples analyzed with ICP
Al_umol/L	Throughfall Raw Data	Number	ueq L^{-1}	
Cu_ umol/L	Throughfall Raw Data	Number	ueq L^{-1}	
Fe_ umol/L	Throughfall Raw Data	Number	ueq L^{-1}	
Mn_ umol/L	Throughfall Raw Data	Number	ueq L^{-1}	
Si_umol/L	Throughfall Raw Data	Number	ueq L^{-1}	
Zn_ umol/L	Throughfall Raw Data	Number	ueq L^{-1}	
Throughfall_Comments	Throughfall Raw Data	Text		
Throughfall Data Source	Throughfall Raw Data	Text		
Depostion_Scenario_ID	Deposition Scenario	Number		
CL_Site_ID	Deposition Scenario	Number		
Scenario	Deposition Scenario	Text		
Deposition Changes	Deposition Scenario	Text		Description of Deposition Scenario
Total S_kg/ha/yr	Deposition Scenario	Number	kg ha^{-1} yr^{-1}	

Parameter	Table	Data Type	Units	Description
NO3-N_kg/ha/yr	Deposition Scenario	Number	kg ha^{-1} yr^{-1}	
NH4-N_kg/ha/yr	Deposition Scenario	Number	kg ha^{-1} yr^{-1}	
Total N_kg/ha/yr	Deposition Scenario	Number	kg ha^{-1} yr^{-1}	
Total S_eq/ha/yr	Deposition Scenario	Number	eq ha^{-1} yr^{-1}	
NO3-N_eq/ha/yr	Deposition Scenario	Number	eq ha^{-1} yr^{-1}	
NH4-N_eq/ha/yr	Deposition Scenario	Number	eq ha^{-1} yr^{-1}	
Total N_eq/ha/yr	Deposition Scenario	Number	eq ha^{-1} yr^{-1}	
Total S_eq/m2/yr	Deposition Scenario	Number	eq m^{-2} yr^{-1}	
NO3-N_ eq/m2/yr	Deposition Scenario	Number	eq m^{-2} yr^{-1}	
NH4-N_ eq/m2/yr	Deposition Scenario	Number	eq m^{-2} yr^{-1}	
Total N_ eq/m2/yr	Deposition Scenario	Number	eq m^{-2} yr^{-1}	
Historic_dep_ID	Historic Deposition	Number		
CL_Site_ID	Historic Deposition	Number		
Year	Historic Deposition	Number		
Total S_eq/ha/yr	Historic Deposition	Number	eq m^{-2} yr^{-1}	
Total NO3_eq/ha/yr	Historic Deposition	Number	eq m^{-2} yr^{-1}	
Total NH4_eq/ha/yr	Historic Deposition	Number	eq m^{-2} yr^{-1}	
Total BC_eq/ha/yr	Historic Deposition	Number	eq m^{-2} yr^{-1}	
Total Cl_eq/ha/yr	Historic Deposition	Number	eq m^{-2} yr^{-1}	

Parameter	Table	Data Type	Units	Description
Soil_Pedon_ID	Depth-weighted Soil Pedon Data	Number		
CL_Site_ID	Depth-weighted Soil Pedon Data	Number		
Pit Lat_dd	Depth-weighted Soil Pedon Data	Number	decimal degrees	
Pit lon_dd	Depth-weighted Soil Pedon Data	Number	decimal degrees	
Pit Elevation_m	Depth-weighted Soil Pedon Data	Number	m	
Pedon_key	Depth-weighted Soil Pedon Data	Number		Unique soil pit identifier
User_pedon_id	Depth-weighted Soil Pedon Data	Number		For NRCS pits, link to NRCS database
Sampled_taxon_name	Depth-weighted Soil Pedon Data	Text		Soil taxonomic name
Sampled_class_name	Depth-weighted Soil Pedon Data	Text		Soil series name
Depth_m	Depth-weighted Soil Pedon Data	Number	m	
Clay%	Depth-weighted Soil Pedon Data	Number	%	
BulkDensity_g/cm3	Depth-weighted Soil Pedon Data	Number	$g\ cm^{-3}$	
SoilWaterContent_m/m	Depth-weighted Soil Pedon Data	Number	$m\ /m^{-1}$	
CEC_meq/kg	Depth-weighted Soil Pedon Data	Number	$meq\ kg^{-1}$	
BaseSaturation%	Depth-weighted Soil Pedon Data	Number	%	
Cpool_g/m2	Depth-weighted Soil Pedon Data	Number	$g\ m^{2}$	

Parameter	**Table**	**Data Type**	**Units**	**Description**
TotalC%	Depth-weighted Soil Pedon Data	Number	%	
C:N	Depth-weighted Soil Pedon Data	Number		
Soil Data Source	Depth-weighted Soil Pedon Data	Text		
SoilWeatheringRates_eq/ha/yr	Depth-weighted Soil Pedon Data	Number	eq ha^{-1} yr^{-1}	
Weathering_Source	Depth-weighted Soil Pedon Data	Text		
Weathering_Comments	Depth-weighted Soil Pedon Data	Text		
NRCS_Soil_Horizon_ID	Soil Horizon Data	Number		
Pedon_key	Soil Horizon Data	Number		Unique soil pit identifier
Soil_Source	Soil Horizon Data	Text		
Layer_key	Soil Horizon Data	Number		Unique soil horizon identifier within pedon
Layer_sequence	Soil Horizon Data	Number		
Hzn_top_cm	Soil Horizon Data	Number	cm	Top of horizon layer
Hzn_bot_cm	Soil Horizon Data	Number	cm	Bottom of horizon layer
Hzn_desgn	Soil Horizon Data	Text		Horizon designation
Bulk Density_g/cm3	Soil Horizon Data	Number	g cm^{-3}	Oven dry soil bulk density
Bulk Density_g/cm3_Method	Soil Horizon Data	Text		
Carbon%	Soil Horizon Data	Number	%	Carbon%
Carbon%_Method	Soil Horizon Data	Text		
Nitrogen%	Soil Horizon Data	Number	%	Nitrogen%
Nitrogen%_Method	Soil Horizon Data	Text		
Sulfur%	Soil Horizon Data	Number	%	Sulfur%
Sulfur%_Method	Soil Horizon Data	Text		
CN_ratio	Soil Horizon Data	Number	ratio	Ratio of Carbon to Nitrogen
Calcium_extractable	Soil Horizon Data	Number	cmol kg^{-1}	Extractable Calcium

Parameter	Table	Data Type	Units	Description
Calcium_extractable_Method	Soil Horizon Data	Text		
Magnesium_extractable	Soil Horizon Data	Number	cmol kg^{-1}	Extractable Magnesium
Magnesium_extractable_Method	Soil Horizon Data	Text		
Sodium_extractable	Soil Horizon Data	Number	cmol kg^{-1}	Extractable Sodium
Sodium_extractable_Method	Soil Horizon Data	Text		
Potasium_extractable	Soil Horizon Data	Number	cmol kg^{-1}	Extractable Potassium
Potasium_extractable_Method	Soil Horizon Data	Text		
Sum_Extractable_Bases	Soil Horizon Data	Number	cmol kg^{-1}	Sum of Extractable Bases
Sum_Extractable_Bases_Method	Soil Horizon Data	Text		
Acidity_cmol/kg	Soil Horizon Data	Number	cmol kg^{-1}	Acidity_cmol/kg, BaCl2-TEA Extractable, pH 8.2
Acidity_cmol/kg_Method	Soil Horizon Data	Text		
Aluminum_cmol/kg	Soil Horizon Data	Number	cmol kg^{-1}	Extractable Aluminum
Aluminum_cmol/kg	Soil Horizon Data	Text		
Manganese_mg/kg	Soil Horizon Data	Number	mg kg^{-1}	Extractable Manganese
Manganese_mg/kg_Method	Soil Horizon Data	Text		
CECt_cmol/kg	Soil Horizon Data	Number	cmol kg^{-1}	Total Cation Exchange Capacity, standard preparation
CEC_pH7_cmol/kg	Soil Horizon Data	Number	cmol kg^{-1}	CEC_cmol/kg, NH4OAc, pH 7.0
CECe_cmol/kg	Soil Horizon Data	Number	cmol kg^{-1}	Effective Cation Exchange Capacity
AluminiumSaturation_%	Soil Horizon Data	Number	%	Aluminum Saturation%, CMS derived value default, standard prep
Base Saturation %_pH8.2	Soil Horizon Data	Number	%	Base Saturation% at pH 8.2
Base Saturation %_pH8.2_Method	Soil Horizon Data	Text		
Base Saturation %_pH7.0	Soil Horizon Data	Number	%	Base Saturation% at pH 7.0
Base Saturation %_pH7.0_Method	Soil Horizon Data	Text		
Soil_pH_w	Soil Horizon Data	Number	pH units	Soil pH in water extraction
Soil_pH_s	Soil Horizon Data	Number	pH units	Soil pH in salt extraction
OrgCarbon_%	Soil Horizon Data	Number	%	Organic Carbon%
OrgCarbon_%_Method	Soil Horizon Data	Text		
OrgNitrogen_%	Soil Horizon Data	Number	%	Organic Nitrogen%

Parameter	Table	Data Type	Units	Description
OrgNitrogen_%_Method	Soil Horizon Data	Text		
Org_CN_ratio	Soil Horizon Data	Number	ratio	Ratio of Organic Carbon to Nitrogen
Org_pH	Soil Horizon Data	Number	pH units	Organic pH
Org_pH_Method	Soil Horizon Data	Text		
Clay%_total	Soil Horizon Data	Number	%	Total Clay%
Silt%_total	Soil Horizon Data	Number	%	Total Silt%
Sand%_total	Soil Horizon Data	Number	%	Total Sand%
Clay%_fine	Soil Horizon Data	Number	%	Fine Clay%
Silt%_fine	Soil Horizon Data	Number	%	Fine Silt%
Silt%_coarse	Soil Horizon Data	Number	%	Coarse Silt%
Sand%_very fine	Soil Horizon Data	Number	%	Very Fine Sand%
Sand%_fine	Soil Horizon Data	Number	%	Fine Sand%
Sand%_medium	Soil Horizon Data	Number	%	Medium Sand%
Sand%_coarse	Soil Horizon Data	Number	%	Coarse Sand%
Sand%_very coarse	Soil Horizon Data	Number	%	Very Coarse Sand%
Coarse Frag_%_2-5mm	Soil Horizon Data	Number	%	% Coarse Fragments, 2-5mm
Coarse Frag_%_2-5mm_Method	Soil Horizon Data	Text		
Coarse Frag_%_5-20mm	Soil Horizon Data	Number	%	% Coarse Fragments, 5-20mm
Coarse Frag_%_5-20mm_Method	Soil Horizon Data	Text		
Coarse Frag_%_20-75mm	Soil Horizon Data	Number	%	% Coarse Fragments, 20-75mm
Coarse Frag_%_20-75mm_Method	Soil Horizon Data	Text		
CF_Weight%, 0.1-75mm	Soil Horizon Data	Number	%	% Coarse Fragments Weight Percentage, 0.1-75mm
CF_Weight%, 0.1-75mm_Method	Soil Horizon Data	Text		
CF_Weight %, >2mm	Soil Horizon Data	Number	%	% Coarse Fragments Weight Percentage, >2mm
CF_Weight %, >2mm_Method	Soil Horizon Data	Text		
Lysimeter_Mean_ID	Lysimeter Volume-weighted means	Number		

Parameter	Table	Data Type	Units	Description
CL_Site_ID	Lysimeter Volume-weighted means	Number		
Number of Samples	Lysimeter Volume-weighted means	Number		
Lysimeter_Year	Lysimeter Volume-weighted means	Number		
Conductivity_uS/cm^2	Lysimeter Volume-weighted means	Number	uS cm^{-2}	
pH	Lysimeter Volume-weighted means	Number		
Cl_ueq/L	Lysimeter Volume-weighted means	Number	ueq L^{-1}	
NO3_ueq/L	Lysimeter Volume-weighted means	Number	ueq L^{-1}	
SO4_ ueq/L	Lysimeter Volume-weighted means	Number	ueq L^{-1}	
Na_ueq/L	Lysimeter Volume-weighted means	Number	ueq L^{-1}	
NH4_ueq/L	Lysimeter Volume-weighted means	Number	ueq L^{-1}	
K_ueq/L	Lysimeter Volume-weighted means	Number	ueq L^{-1}	
H_ueq/L	Lysimeter Volume-weighted means	Number	ueq L^{-1}	
AA Mg_ueq/L	Lysimeter Volume-weighted means	Number	ueq L^{-1}	
AA Ca_ueq/L	Lysimeter Volume-weighted means	Number	ueq L^{-1}	
Lysimeter Source	Lysimeter Volume-weighted means	Text		
ANC_ueq/L	Lysimeter Volume-weighted means	Number	ueq L^{-1}	

Parameter	Table	Data Type	Units	Description
ANC Comment	Lysimeter Volume-weighted means	Text		
Lysimeter_Raw_Data_ID	Lysimeter Raw Data	Number		
CL_Site_ID	Lysimeter Raw Data	Number		
SiteName	Lysimeter Raw Data	Text		
Plot	Lysimeter Raw Data	Number		
Lysimeter_Year	Lysimeter Raw Data	Number		
Date	Lysimeter Raw Data	Number		
Forest_Type	Lysimeter Raw Data	Text		
Volume_ml	Lysimeter Raw Data	Number	mL	Sample volume
pH	Lysimeter Table	Number		
Conductivity_uS/cm^2	Lysimeter Table	Number	uS cm^{-2}	
NH4_ueq/L	Lysimeter Table	Number	ueq L^{-1}	
NO3_ueq/L	Lysimeter Table	Number	ueq L^{-1}	
SO4_ ueq/L	Lysimeter Table	Number	ueq L^{-1}	
Na_ueq/L	Lysimeter Table	Number	ueq L^{-1}	
Cl_ueq/L	Lysimeter Table	Number	ueq L^{-1}	
K_ueq/L	Lysimeter Table	Number	ueq L^{-1}	
H_ueq/L	Lysimeter Table	Number	ueq L^{-1}	
Mg_ueq/L	Lysimeter Table	Number	ueq L^{-1}	
Ca_ueq/L	Lysimeter Table	Number	ueq L^{-1}	
Aluminum_ppm	Lysimeter Table	Number	ppm	

Parameter	Table	Data Type	Units	Description
Lysimeter Source	Lysimeter Table	Text		
Lysimeter Comments	Lysimeter Table	Text		
Surface_Water_ID	Surface Water Mean Data	Number		
CL_Site_ID	Surface Water Mean Data	Number		
SW_Year	Surface Water Mean Data	Number		
Streamlet Location	Surface Water Mean Data	Text		
pH	Surface Water Mean Data	Number		
Conductivity_µS/cm2	Surface Water Mean Data	Number	uS cm^{-2}	
ANC_µeq/L	Surface Water Mean Data	Number	ueq L^{-1}	
Cl_ueq/L	Surface Water Mean Data	Number	ueq L^{-1}	
NO3-N_ueq/L	Surface Water Mean Data	Number	ueq L^{-1}	
SO4_ueq/L	Surface Water Mean Data	Number	ueq L^{-1}	
Na_ueq/L	Surface Water Mean Data	Number	ueq L^{-1}	
NH4-N meq/L	Surface Water Mean Data	Number	ueq L^{-1}	
K_ueq/L	Surface Water Mean Data	Number	ueq L^{-1}	
H_ueq/L	Surface Water Mean Data	Number	ueq L^{-1}	

Parameter	Table	Data Type	Units	Description
AA Ca_ueq/L	Surface Water Mean Data	Number	ueq L^{-1}	
SW Source	Surface Water Mean Data	Text		
SW Comment	Surface Water Mean Data	Text		
Surface_Water_Raw_Data_ID	Surface Water Raw Data	Number		
Surface_Water_ID	Surface Water Raw Data	Number		
CL_Site_ID	Surface Water Raw Data	Number		
Site Name	Surface Water Raw Data	Text		
Streamlet Location	Surface Water Raw Data	Text		
SW_Year	Surface Water Raw Data	Number		
cfs	Surface Water Raw Data	Number	Cf s^{-1}	Flow:
L/s	Surface Water Raw Data	Number	L s^{-1}	Flow
pH	Surface Water Raw Data	Number		
Conductivity_µS/cm2	Surface Water Raw Data	Number	uS cm^{-2}	
ANC_µeq/L	Surface Water Raw Data	Number	ueq L^{-1}	
Cl_ueq/L	Surface Water Raw Data	Number	ueq L^{-1}	

Parameter	**Table**	**Data Type**	**Units**	**Description**
NO3-N_ueq/L	Surface Water Raw Data	Number	ueq L^{-1}	
SO4_ueq/L	Surface Water Raw Data	Number	ueq L^{-1}	
Na_ueq/L	Surface Water Raw Data	Number	ueq L^{-1}	
IC Na_ueq/L	Surface Water Raw Data	Number	ueq L^{-1}	
ICP Na_ueq/L	Surface Water Raw Data	Number	ueq L^{-1}	
NH4-N meq/L	Surface Water Raw Data	Number	ueq L^{-1}	
K_ueq/L	Surface Water Raw Data	Number	ueq L^{-1}	
IC K_ueq/L	Surface Water Raw Data	Number	ueq L^{-1}	
ICP K_ueq/L	Surface Water Raw Data	Number	ueq L^{-1}	
H_ueq/L	Surface Water Raw Data	Number	ueq L^{-1}	
AA or ICP Mg_ueq/L	Surface Water Raw Data	Number	ueq L^{-1}	
AA Ca_ueq/L	Surface Water Raw Data	Number	ueq L^{-1}	
ICP Ca_ueq/L	Surface Water Raw Data	Number	ueq L^{-1}	
Estimated Ca_ueq/L	Surface Water Raw Data	Number	ueq L^{-1}	Based on regression models
Estimated Mg_ueq/L	Surface Water Raw Data	Number	ueq L^{-1}	Based on regression models
Al_umol	Surface Water Raw Data	Number	umol	

Parameter	Table	Data Type	Units	Description
Al_ umol	Surface Water Raw Data	Number	umol	
Si_umol	Surface Water Raw Data	Number	umol	
Si_ umol	Surface Water Raw Data	Number	umol	
Zn_ umol	Surface Water Raw Data	Number	umol	
SurfaceWater_Comment	Surface Water Raw Data	Text		
Surface Water Source	Surface Water Raw Data	Text		
Source_ID	Data Source	Number		
Reference	Data Source	Text		
Contact Name	Data Source	Text		
Contact Affiliation	Data Source	Text		
Contact Email	Data Source	Text		

8.3 Input and Output Tables from VSD

Table 8.2 provides the basic VSD input requirements for each of the four GSMNP sites. Deposition inputs for the Current Deposition Scenario (Scenario 1), as described in section 3 of the report, are provided in Table 8.3. VSD modeled soil solution outputs for the Current Deposition Scenario are provided in tables 8.4 – 8.7.

Table 8.2 Input Data for VSD Calculations.

Parameters	Units	High Elevation: Noland Divide		Beech Gap	Mixed Hardwood
		Upper Spruce-Fir	Lower Spruce-Fir		
Time frame		1945 - 2150	1945 - 2150	1945 - 2150	1945 - 2150
Soil Depth	M	0.46	0.57	0.74	0.83
Bulk density	g cm^{-3}	0.92	0.92	1.13	1.09
Soil Moisture	M m^{-1}	0.12	0.12	0.12	0.15
CEC	meq kg^{-1}	180	293	239	132
Base saturation (obs)	%	7.6	9	21	11
Base sat. obs year	year	1985	1985	1985	2001
C pool (obs)	g m^{-2}	5500	9500	9250	2409
C:N (obs)		10	12	11	16
C pool, C:N obs. year	year	1985	1985	1985	2001
Q	M	1.16	1.16	1.16	0.79
Soil Weathering	eq m^{-3} yr^{-1}	0.0770	0.2632	0.0682	0.0971
lgKAlBC		-0.48188	1.245	-0.6579	1.3242
lgKHBC		3.9325	4.7959	3.8444	4.8355
lgKAlox		8.77	8.77	8.77	8.77
soil solution pCO2		17	17	17	17
Nim_acc	eq m^{-2} yr^{-1}	0.0036	0.0036	0.0036	0.0036

Table 8.3 Deposition Inputs for the Base Deposition Scenarios.

Year	S deposition (eq m^{-2} yr^{-1})	NO_3 deposition (eq m^{-2} yr^{-1})	NH_4 deposition (eq m^{-2} yr^{-1})	Bc deposition (eq m^{-2} yr^{-1})	Cl deposition (eq m^{-2} yr^{-1})
Upper and Lower Spruce-Fir Sites					
1945	0.2287	0.0871	0.0562	0.2000	0.0330
1946	0.2250	0.0888	0.0573	0.1968	0.0325
1947	0.2213	0.0904	0.0583	0.1936	0.0320
1948	0.2176	0.0921	0.0594	0.1904	0.0314
1949	0.2139	0.0937	0.0605	0.1871	0.0309
1950	0.2102	0.0954	0.0615	0.1839	0.0304
1951	0.2147	0.0988	0.0637	0.1878	0.0310
1952	0.2192	0.1022	0.0659	0.1917	0.0317
1953	0.2237	0.1056	0.0681	0.1957	0.0323
1954	0.2281	0.1090	0.0703	0.1996	0.0330
1955	0.2326	0.1124	0.0725	0.2035	0.0336
1956	0.2371	0.1158	0.0747	0.2074	0.0343
1957	0.2416	0.1192	0.0769	0.2114	0.0349

Year	S deposition ($eq\ m^{-2}\ yr^{-1}$)	NO_3 deposition ($eq\ m^{-2}\ yr^{-1}$)	NH_4 deposition ($eq\ m^{-2}\ yr^{-1}$)	Bc deposition ($eq\ m^{-2}\ yr^{-1}$)	Cl deposition ($eq\ m^{-2}\ yr^{-1}$)
Upper and Lower Spruce-Fir Sites					
1958	0.2461	0.1226	0.0791	0.2153	0.0356
1959	0.2505	0.1260	0.0813	0.2192	0.0362
1960	0.2550	0.1294	0.0835	0.2231	0.0369
1961	0.2489	0.1311	0.0845	0.2177	0.0360
1962	0.2427	0.1327	0.0856	0.2123	0.0351
1963	0.2365	0.1343	0.0866	0.2069	0.0342
1964	0.2304	0.1359	0.0877	0.2015	0.0333
1965	0.2242	0.1375	0.0887	0.1961	0.0324
1966	0.2318	0.1409	0.0909	0.2028	0.0335
1967	0.2394	0.1444	0.0931	0.2094	0.0346
1968	0.2470	0.1478	0.0953	0.2161	0.0357
1969	0.2546	0.1512	0.0976	0.2227	0.0368
1970	0.2622	0.1547	0.0998	0.2294	0.0379
1971	0.2698	0.1581	0.1020	0.2360	0.0390
1972	0.2774	0.1615	0.1042	0.2427	0.0401
1973	0.2850	0.1650	0.1064	0.2494	0.0412
1974	0.2926	0.1684	0.1086	0.2560	0.0423
1975	0.3002	0.1718	0.1108	0.2627	0.0434
1976	0.2976	0.1709	0.1102	0.2604	0.0430
1977	0.2951	0.1699	0.1096	0.2581	0.0426
1978	0.2925	0.1689	0.1090	0.2559	0.0423
1979	0.2899	0.1680	0.1084	0.2536	0.0419
1980	0.2873	0.1670	0.1077	0.2514	0.0415
1981	0.2847	0.1661	0.1071	0.2491	0.0412
1982	0.2822	0.1651	0.1065	0.2469	0.0408
1983	0.2796	0.1641	0.1059	0.2446	0.0404
1984	0.2770	0.1632	0.1053	0.2423	0.0400
1985	0.2744	0.1622	0.1046	0.2401	0.0397
1986	0.2743	0.1628	0.1050	0.2400	0.0396
1987	0.2742	0.1635	0.1054	0.2399	0.0396
1988	0.2741	0.1641	0.1059	0.2398	0.0396
1989	0.2740	0.1647	0.1063	0.2397	0.0396
1990	0.2739	0.1653	0.1067	0.2396	0.0396
1991	0.2647	0.1623	0.1047	0.2316	0.0383
1992	0.2554	0.1592	0.1027	0.2235	0.0369
1993	0.2462	0.1561	0.1007	0.2154	0.0356
1994	0.2369	0.1530	0.0987	0.2073	0.0342
1995	0.2277	0.1499	0.0967	0.1992	0.0329
1996	0.2184	0.1468	0.0947	0.1911	0.0316
1997	0.2092	0.1437	0.0927	0.1830	0.0302
1998	0.1999	0.1406	0.0907	0.1749	0.0289
1999	0.1958	0.1406	0.0907	0.1713	0.0283
2150[1]	0.1958	0.1406	0.0907	0.1713	0.0283
Beech Gap Site					
1945	0.1143	0.0436	0.0281	0.1001	0.0166
1946	0.1125	0.0444	0.0286	0.0985	0.0163

Year	S deposition (eq m^{-2} yr^{-1})	NO_3 deposition (eq m^{-2} yr^{-1})	NH_4 deposition (eq m^{-2} yr^{-1})	Bc deposition (eq m^{-2} yr^{-1})	Cl deposition (eq m^{-2} yr^{-1})
Beech Gap Site					
1947	0.1106	0.0452	0.0291	0.0969	0.0160
1948	0.1088	0.0460	0.0297	0.0952	0.0158
1949	0.1069	0.0469	0.0302	0.0936	0.0155
1950	0.1051	0.0477	0.0307	0.0920	0.0152
1951	0.1073	0.0494	0.0318	0.0940	0.0156
1952	0.1096	0.0511	0.0329	0.0959	0.0159
1953	0.1118	0.0528	0.0340	0.0979	0.0162
1954	0.1141	0.0545	0.0351	0.0999	0.0165
1955	0.1163	0.0562	0.0362	0.1018	0.0169
1956	0.1186	0.0579	0.0373	0.1038	0.0172
1957	0.1208	0.0596	0.0384	0.1057	0.0175
1958	0.1230	0.0613	0.0395	0.1077	0.0178
1959	0.1253	0.0630	0.0406	0.1097	0.0182
1960	0.1275	0.0647	0.0417	0.1116	0.0185
1961	0.1244	0.0655	0.0422	0.1089	0.0180
1962	0.1213	0.0663	0.0427	0.1062	0.0176
1963	0.1183	0.0671	0.0433	0.1035	0.0172
1964	0.1152	0.0679	0.0438	0.1008	0.0167
1965	0.1121	0.0688	0.0443	0.0981	0.0163
1966	0.1159	0.0705	0.0454	0.1015	0.0168
1967	0.1197	0.0722	0.0465	0.1048	0.0174
1968	0.1235	0.0739	0.0476	0.1081	0.0179
1969	0.1273	0.0756	0.0487	0.1114	0.0185
1970	0.1311	0.0773	0.0498	0.1148	0.0190
1971	0.1349	0.0790	0.0509	0.1181	0.0196
1972	0.1387	0.0808	0.0520	0.1214	0.0201
1973	0.1425	0.0825	0.0531	0.1247	0.0207
1974	0.1463	0.0842	0.0543	0.1281	0.0212
1975	0.1501	0.0859	0.0554	0.1314	0.0218
1976	0.1488	0.0854	0.0550	0.1303	0.0216
1977	0.1475	0.0849	0.0547	0.1291	0.0214
1978	0.1462	0.0845	0.0544	0.1280	0.0212
1979	0.1449	0.0840	0.0541	0.1269	0.0210
1980	0.1437	0.0835	0.0538	0.1258	0.0208
1981	0.1424	0.0830	0.0535	0.1246	0.0206
1982	0.1411	0.0825	0.0532	0.1235	0.0205
1983	0.1398	0.0821	0.0529	0.1224	0.0203
1984	0.1385	0.0816	0.0526	0.1212	0.0201
1985	0.1372	0.0811	0.0523	0.1201	0.0199
1986	0.1372	0.0814	0.0525	0.1201	0.0199
1987	0.1371	0.0817	0.0527	0.1200	0.0199
1988	0.1371	0.0820	0.0529	0.1200	0.0199
1989	0.1370	0.0824	0.0531	0.1199	0.0199
1990	0.1370	0.0827	0.0533	0.1199	0.0199
1991	0.1323	0.0811	0.0523	0.1158	0.0192
1992	0.1277	0.0796	0.0513	0.1118	0.0185

Year	S deposition (eq m^{-2} yr^{-1})	NO_3 deposition (eq m^{-2} yr^{-1})	NH_4 deposition (eq m^{-2} yr^{-1})	Bc deposition (eq m^{-2} yr^{-1})	Cl deposition (eq m^{-2} yr^{-1})
Beech Gap Site					
1993	0.1231	0.0780	0.0503	0.1077	0.0179
1994	0.1185	0.0765	0.0493	0.1037	0.0172
1995	0.1138	0.0749	0.0483	0.0996	0.0165
1996	0.1092	0.0734	0.0473	0.0956	0.0158
1997	0.1046	0.0718	0.0463	0.0915	0.0152
1998	0.1000	0.0703	0.0453	0.0875	0.0145
1999	0.0979	0.0703	0.0453	0.0857	0.0142
2150[1]	0.0979	0.0703	0.0453	0.0857	0.0142
Mixed Hardwood Site					
1945	0.0730	0.0265	0.0110	0.0202	0.0047
1946	0.0718	0.0270	0.0112	0.0199	0.0046
1947	0.0706	0.0275	0.0114	0.0196	0.0045
1948	0.0695	0.0280	0.0117	0.0192	0.0044
1949	0.0683	0.0285	0.0119	0.0189	0.0044
1950	0.0671	0.0290	0.0121	0.0186	0.0043
1951	0.0685	0.0301	0.0125	0.0190	0.0044
1952	0.0700	0.0311	0.0129	0.0194	0.0045
1953	0.0714	0.0322	0.0134	0.0198	0.0046
1954	0.0728	0.0332	0.0138	0.0202	0.0047
1955	0.0743	0.0342	0.0142	0.0206	0.0048
1956	0.0757	0.0353	0.0147	0.0209	0.0048
1957	0.0771	0.0363	0.0151	0.0213	0.0049
1958	0.0785	0.0373	0.0155	0.0217	0.0050
1959	0.0800	0.0384	0.0160	0.0221	0.0051
1960	0.0814	0.0394	0.0164	0.0225	0.0052
1961	0.0794	0.0399	0.0166	0.0220	0.0051
1962	0.0775	0.0404	0.0168	0.0214	0.0050
1963	0.0755	0.0409	0.0170	0.0209	0.0048
1964	0.0735	0.0414	0.0172	0.0204	0.0047
1965	0.0716	0.0419	0.0174	0.0198	0.0046
1966	0.0740	0.0429	0.0178	0.0205	0.0047
1967	0.0764	0.0439	0.0183	0.0212	0.0049
1968	0.0788	0.0450	0.0187	0.0218	0.0050
1969	0.0813	0.0460	0.0191	0.0225	0.0052
1970	0.0837	0.0471	0.0196	0.0232	0.0054
1971	0.0861	0.0481	0.0200	0.0238	0.0055
1972	0.0886	0.0492	0.0204	0.0245	0.0057
1973	0.0910	0.0502	0.0209	0.0252	0.0058
1974	0.0934	0.0513	0.0213	0.0259	0.0060
1975	0.0958	0.0523	0.0218	0.0265	0.0061
1976	0.0950	0.0520	0.0216	0.0263	0.0061
1977	0.0942	0.0517	0.0215	0.0261	0.0060
1978	0.0934	0.0514	0.0214	0.0258	0.0060
1979	0.0925	0.0511	0.0213	0.0256	0.0059
1980	0.0917	0.0508	0.0211	0.0254	0.0059
1981	0.0909	0.0505	0.0210	0.0252	0.0058

Year	S deposition ($eq\ m^{-2}\ yr^{-1}$)	NO_3 deposition ($eq\ m^{-2}\ yr^{-1}$)	NH_4 deposition ($eq\ m^{-2}\ yr^{-1}$)	Bc deposition ($eq\ m^{-2}\ yr^{-1}$)	Cl deposition ($eq\ m^{-2}\ yr^{-1}$)
Mixed Hardwood Site					
1982	0.0901	0.0503	0.0209	0.0249	0.0058
1983	0.0892	0.0500	0.0208	0.0247	0.0057
1984	0.0884	0.0497	0.0207	0.0245	0.0057
1985	0.0876	0.0494	0.0205	0.0242	0.0056
1986	0.0876	0.0496	0.0206	0.0242	0.0056
1987	0.0875	0.0498	0.0207	0.0242	0.0056
1988	0.0875	0.0500	0.0208	0.0242	0.0056
1989	0.0875	0.0501	0.0209	0.0242	0.0056
1990	0.0874	0.0503	0.0209	0.0242	0.0056
1991	0.0845	0.0494	0.0205	0.0234	0.0054
1992	0.0815	0.0484	0.0201	0.0226	0.0052
1993	0.0786	0.0475	0.0198	0.0218	0.0050
1994	0.0756	0.0466	0.0194	0.0209	0.0048
1995	0.0727	0.0456	0.0190	0.0201	0.0047
1996	0.0697	0.0447	0.0186	0.0193	0.0045
1997	0.0668	0.0437	0.0182	0.0185	0.0043
1998	0.0638	0.0428	0.0178	0.0177	0.0041
1999	0.0625	0.0428	0.0178	0.0173	0.0040
2150[1]	0.0625	0.0428	0.0178	0.0173	0.0040

[1]The "Current Deposition" Scenario assumes that deposition inputs remain constant through the year 2150. VSD does not require deposition inputs for each year when no changes occur.

Table 8.4 VSD Soil Solution Output for the Upper Spruce-Fir Site, using the Current Deposition Scenario.

Year	Base Sat.	pH	$[NO_3^-]$ ($eq\ m^{-3}$)	[ANC] ($eq\ m^{-3}$)	molar Al/(Ca+Mg+K) ratio	$[Al^{3+}]$ ($eq\ m^{-3}$)
1945	8%	4.4	0.0928	-0.1638	0.54	0.1254
1946	8%	4.4	0.0951	-0.1632	0.54	0.1249
1947	8%	4.4	0.0974	-0.1625	0.54	0.1242
1948	8%	4.4	0.0998	-0.1618	0.54	0.1237
1949	8%	4.4	0.1021	-0.1612	0.54	0.1231
1950	8%	4.4	0.1045	-0.1607	0.54	0.1226
1951	8%	4.4	0.1092	-0.1659	0.55	0.1273
1952	8%	4.4	0.1140	-0.1715	0.56	0.1324
1953	8%	4.4	0.1188	-0.1771	0.56	0.1374
1954	8%	4.4	0.1237	-0.1828	0.57	0.1425
1955	8%	4.4	0.1285	-0.1885	0.58	0.1476
1956	8%	4.4	0.1333	-0.1942	0.59	0.1529
1957	8%	4.3	0.1382	-0.2000	0.60	0.1581
1958	8%	4.3	0.1430	-0.2058	0.61	0.1634
1959	8%	4.3	0.1478	-0.2116	0.61	0.1687
1960	8%	4.3	0.1527	-0.2175	0.62	0.1740
1961	8%	4.3	0.1551	-0.2160	0.62	0.1726
1962	8%	4.3	0.1574	-0.2141	0.62	0.1709
1963	8%	4.3	0.1597	-0.2122	0.62	0.1692
1964	8%	4.3	0.1620	-0.2105	0.62	0.1677

Year	Base Sat.	pH	$[NO_3^-]$ (eq m^{-3})	[ANC] (eq m^{-3})	molar Al/(Ca+Mg+K) ratio	$[Al^{3+}]$ (eq m^{-3})
1965	8%	4.3	0.1643	-0.2087	0.62	0.1660
1966	8%	4.3	0.1690	-0.2164	0.64	0.1730
1967	8%	4.3	0.1739	-0.2245	0.65	0.1804
1968	8%	4.3	0.1787	-0.2326	0.66	0.1879
1969	7%	4.3	0.1836	-0.2408	0.67	0.1954
1970	7%	4.3	0.1885	-0.2490	0.68	0.2030
1971	7%	4.3	0.1934	-0.2572	0.69	0.2106
1972	7%	4.3	0.1982	-0.2654	0.70	0.2181
1973	7%	4.3	0.2031	-0.2737	0.71	0.2258
1974	7%	4.3	0.2080	-0.2818	0.72	0.2334
1975	7%	4.3	0.2128	-0.2900	0.73	0.2410
1976	7%	4.3	0.2118	-0.2883	0.73	0.2394
1977	7%	4.3	0.2104	-0.2862	0.73	0.2374
1978	7%	4.3	0.2090	-0.2840	0.73	0.2354
1979	7%	4.3	0.2077	-0.2819	0.73	0.2334
1980	7%	4.3	0.2063	-0.2796	0.73	0.2313
1981	7%	4.3	0.2050	-0.2775	0.73	0.2294
1982	7%	4.3	0.2036	-0.2754	0.73	0.2274
1983	7%	4.3	0.2022	-0.2732	0.73	0.2254
1984	7%	4.3	0.2009	-0.2711	0.73	0.2234
1985	7%	4.3	0.1995	-0.2689	0.73	0.2214
1986	7%	4.3	0.2002	-0.2696	0.73	0.2220
1987	7%	4.3	0.2012	-0.2705	0.74	0.2228
1988	7%	4.3	0.2021	-0.2714	0.74	0.2237
1989	7%	4.3	0.2030	-0.2722	0.74	0.2245
1990	7%	4.3	0.2038	-0.2731	0.75	0.2252
1991	7%	4.3	0.1998	-0.2653	0.74	0.2180
1992	7%	4.3	0.1954	-0.2570	0.73	0.2104
1993	7%	4.3	0.1910	-0.2489	0.73	0.2028
1994	7%	4.3	0.1866	-0.2407	0.72	0.1953
1995	7%	4.3	0.1822	-0.2326	0.72	0.1879
1996	7%	4.3	0.1778	-0.2245	0.71	0.1805
1997	7%	4.3	0.1734	-0.2165	0.70	0.1731
1998	7%	4.3	0.1690	-0.2085	0.70	0.1659
1999	7%	4.3	0.1688	-0.2063	0.70	0.1638
2000	7%	4.3	0.1688	-0.2068	0.70	0.1642
2001	7%	4.3	0.1688	-0.2073	0.71	0.1648
2002	7%	4.3	0.1688	-0.2079	0.71	0.1653
2003	7%	4.3	0.1688	-0.2084	0.72	0.1658
2004	7%	4.3	0.1688	-0.2090	0.72	0.1663
2005	7%	4.3	0.1688	-0.2095	0.73	0.1668
2006	7%	4.3	0.1688	-0.2101	0.73	0.1672
2007	7%	4.3	0.1688	-0.2106	0.74	0.1677
2008	6%	4.3	0.1688	-0.2111	0.74	0.1682
2009	6%	4.3	0.1688	-0.2116	0.75	0.1686
2010	6%	4.3	0.1688	-0.2120	0.75	0.1691
2011	6%	4.3	0.1688	-0.2125	0.76	0.1695
2012	6%	4.3	0.1688	-0.2130	0.76	0.1699

Year	Base Sat.	pH	$[NO_3^-]$ (eq m^{-3})	[ANC] (eq m^{-3})	molar Al/(Ca+Mg+K) ratio	$[Al^{3+}]$ (eq m^{-3})
2013	6%	4.3	0.1688	-0.2134	0.76	0.1703
2014	6%	4.3	0.1688	-0.2139	0.77	0.1707
2015	6%	4.3	0.1688	-0.2143	0.77	0.1711
2016	6%	4.3	0.1688	-0.2147	0.78	0.1715
2017	6%	4.3	0.1688	-0.2152	0.78	0.1719
2018	6%	4.3	0.1688	-0.2156	0.78	0.1723
2019	6%	4.3	0.1688	-0.2160	0.79	0.1726
2020	6%	4.3	0.1688	-0.2164	0.79	0.1730
2021	6%	4.3	0.1688	-0.2167	0.79	0.1733
2022	6%	4.3	0.1688	-0.2171	0.80	0.1737
2023	6%	4.3	0.1688	-0.2175	0.80	0.1740
2024	6%	4.3	0.1688	-0.2178	0.81	0.1743
2025	6%	4.3	0.1688	-0.2182	0.81	0.1747
2026	6%	4.3	0.1688	-0.2185	0.81	0.1750
2027	6%	4.3	0.1688	-0.2189	0.82	0.1753
2028	6%	4.3	0.1688	-0.2192	0.82	0.1756
2029	6%	4.3	0.1688	-0.2195	0.82	0.1759
2030	6%	4.3	0.1688	-0.2198	0.83	0.1762
2031	6%	4.3	0.1688	-0.2201	0.83	0.1764
2032	6%	4.3	0.1688	-0.2204	0.83	0.1767
2033	6%	4.3	0.1688	-0.2207	0.83	0.1770
2034	6%	4.3	0.1688	-0.2210	0.84	0.1772
2035	6%	4.3	0.1688	-0.2213	0.84	0.1775
2036	6%	4.3	0.1688	-0.2215	0.84	0.1777
2037	6%	4.3	0.1688	-0.2218	0.85	0.1780
2038	6%	4.3	0.1688	-0.2221	0.85	0.1782
2039	6%	4.3	0.1688	-0.2223	0.85	0.1784
2040	6%	4.3	0.1688	-0.2226	0.85	0.1787
2041	6%	4.3	0.1688	-0.2228	0.86	0.1789
2042	6%	4.3	0.1688	-0.2230	0.86	0.1791
2043	6%	4.3	0.1688	-0.2233	0.86	0.1793
2044	6%	4.3	0.1688	-0.2235	0.86	0.1795
2045	6%	4.3	0.1688	-0.2237	0.87	0.1797
2046	6%	4.3	0.1688	-0.2239	0.87	0.1799
2047	6%	4.3	0.1688	-0.2241	0.87	0.1801
2048	6%	4.3	0.1688	-0.2243	0.87	0.1803
2049	6%	4.3	0.1688	-0.2245	0.87	0.1805
2050	6%	4.3	0.1688	-0.2247	0.88	0.1806
2051	6%	4.3	0.1688	-0.2249	0.88	0.1808
2052	6%	4.3	0.1688	-0.2251	0.88	0.1810
2053	6%	4.3	0.1688	-0.2253	0.88	0.1811
2054	6%	4.3	0.1688	-0.2254	0.88	0.1813
2055	6%	4.3	0.1688	-0.2256	0.89	0.1815
2056	6%	4.3	0.1688	-0.2258	0.89	0.1816
2057	6%	4.3	0.1688	-0.2259	0.89	0.1818
2058	6%	4.3	0.1688	-0.2261	0.89	0.1819
2059	6%	4.3	0.1688	-0.2262	0.89	0.1820
2060	6%	4.3	0.1688	-0.2264	0.89	0.1822

Year	Base Sat.	pH	$[NO_3^-]$ (eq m^{-3})	[ANC] (eq m^{-3})	molar Al/(Ca+Mg+K) ratio	$[Al^{3+}]$ (eq m^{-3})
2061	6%	4.3	0.1688	-0.2265	0.90	0.1823
2062	6%	4.3	0.1688	-0.2267	0.90	0.1824
2063	6%	4.3	0.1688	-0.2268	0.90	0.1826
2064	6%	4.3	0.1688	-0.2270	0.90	0.1827
2065	6%	4.3	0.1688	-0.2271	0.90	0.1828
2066	6%	4.3	0.1688	-0.2272	0.90	0.1829
2067	6%	4.3	0.1688	-0.2273	0.91	0.1831
2068	6%	4.3	0.1688	-0.2275	0.91	0.1832
2069	6%	4.3	0.1688	-0.2276	0.91	0.1833
2070	5%	4.3	0.1688	-0.2277	0.91	0.1834
2071	5%	4.3	0.1688	-0.2278	0.91	0.1835
2072	5%	4.3	0.1688	-0.2279	0.91	0.1836
2073	5%	4.3	0.1688	-0.2280	0.91	0.1837
2074	5%	4.3	0.1688	-0.2281	0.91	0.1838
2075	5%	4.3	0.1688	-0.2282	0.92	0.1839
2076	5%	4.3	0.1688	-0.2283	0.92	0.1840
2077	5%	4.3	0.1688	-0.2284	0.92	0.1841
2078	5%	4.3	0.1688	-0.2285	0.92	0.1841
2079	5%	4.3	0.1688	-0.2286	0.92	0.1842
2080	5%	4.3	0.1688	-0.2287	0.92	0.1843
2081	5%	4.3	0.1688	-0.2288	0.92	0.1844
2082	5%	4.3	0.1688	-0.2289	0.92	0.1845
2083	5%	4.3	0.1688	-0.2290	0.92	0.1845
2084	5%	4.3	0.1688	-0.2291	0.92	0.1846
2085	5%	4.3	0.1688	-0.2291	0.93	0.1847
2086	5%	4.3	0.1688	-0.2292	0.93	0.1848
2087	5%	4.3	0.1688	-0.2293	0.93	0.1848
2088	5%	4.3	0.1688	-0.2294	0.93	0.1849
2089	5%	4.3	0.1688	-0.2294	0.93	0.1850
2090	5%	4.3	0.1688	-0.2295	0.93	0.1850
2091	5%	4.3	0.1688	-0.2296	0.93	0.1851
2092	5%	4.3	0.1688	-0.2296	0.93	0.1851
2093	5%	4.3	0.1688	-0.2297	0.93	0.1852
2094	5%	4.3	0.1688	-0.2298	0.93	0.1853
2095	5%	4.3	0.1688	-0.2298	0.93	0.1853
2096	5%	4.3	0.1688	-0.2299	0.93	0.1854
2097	5%	4.3	0.1688	-0.2299	0.94	0.1854
2098	5%	4.3	0.1688	-0.2300	0.94	0.1855
2099	5%	4.3	0.1688	-0.2300	0.94	0.1855
2100	5%	4.3	0.1688	-0.2301	0.94	0.1856
2101	5%	4.3	0.1688	-0.2301	0.94	0.1856
2102	5%	4.3	0.1688	-0.2302	0.94	0.1857
2103	5%	4.3	0.1688	-0.2302	0.94	0.1857
2104	5%	4.3	0.1688	-0.2303	0.94	0.1858
2105	5%	4.3	0.1688	-0.2303	0.94	0.1858
2106	5%	4.3	0.1688	-0.2304	0.94	0.1858
2107	5%	4.3	0.1688	-0.2304	0.94	0.1859
2108	5%	4.3	0.1688	-0.2305	0.94	0.1859

Year	Base Sat.	pH	$[NO_3^-]$ (eq m^{-3})	[ANC] (eq m^{-3})	molar Al/(Ca+Mg+K) ratio	$[Al^{3+}]$ (eq m^{-3})
2109	5%	4.3	0.1688	-0.2305	0.94	0.1860
2110	5%	4.3	0.1688	-0.2306	0.94	0.1860
2111	5%	4.3	0.1688	-0.2306	0.94	0.1860
2112	5%	4.3	0.1688	-0.2306	0.94	0.1861
2113	5%	4.3	0.1688	-0.2307	0.94	0.1861
2114	5%	4.3	0.1688	-0.2307	0.94	0.1861
2115	5%	4.3	0.1688	-0.2307	0.94	0.1862
2116	5%	4.3	0.1688	-0.2308	0.95	0.1862
2117	5%	4.3	0.1688	-0.2308	0.95	0.1862
2118	5%	4.3	0.1688	-0.2308	0.95	0.1863
2119	5%	4.3	0.1688	-0.2309	0.95	0.1863
2120	5%	4.3	0.1688	-0.2309	0.95	0.1863
2121	5%	4.3	0.1688	-0.2309	0.95	0.1863
2122	5%	4.3	0.1688	-0.2310	0.95	0.1864
2123	5%	4.3	0.1688	-0.2310	0.95	0.1864
2124	5%	4.3	0.1688	-0.2310	0.95	0.1864
2125	5%	4.3	0.1688	-0.2311	0.95	0.1865
2126	5%	4.3	0.1688	-0.2311	0.95	0.1865
2127	5%	4.3	0.1688	-0.2311	0.95	0.1865
2128	5%	4.3	0.1688	-0.2311	0.95	0.1865
2129	5%	4.3	0.1688	-0.2312	0.95	0.1866
2130	5%	4.3	0.1688	-0.2312	0.95	0.1866
2131	5%	4.3	0.1688	-0.2312	0.95	0.1866
2132	5%	4.3	0.1688	-0.2312	0.95	0.1866
2133	5%	4.3	0.1688	-0.2312	0.95	0.1866
2134	5%	4.3	0.1688	-0.2313	0.95	0.1867
2135	5%	4.3	0.1688	-0.2313	0.95	0.1867
2136	5%	4.3	0.1688	-0.2313	0.95	0.1867
2137	5%	4.3	0.1688	-0.2313	0.95	0.1867
2138	5%	4.3	0.1688	-0.2314	0.95	0.1867
2139	5%	4.3	0.1688	-0.2314	0.95	0.1867
2140	5%	4.3	0.1688	-0.2314	0.95	0.1868
2141	5%	4.3	0.1688	-0.2314	0.95	0.1868
2142	5%	4.3	0.1688	-0.2314	0.95	0.1868
2143	5%	4.3	0.1688	-0.2314	0.95	0.1868
2144	5%	4.3	0.1688	-0.2315	0.95	0.1868
2145	5%	4.3	0.1688	-0.2315	0.95	0.1868
2146	5%	4.3	0.1688	-0.2315	0.95	0.1868
2147	5%	4.3	0.1688	-0.2315	0.95	0.1869
2148	5%	4.3	0.1688	-0.2315	0.95	0.1869
2149	5%	4.3	0.1688	-0.2315	0.95	0.1869
2150	5%	4.3	0.1688	-0.2315	0.95	0.1869

Table 8.5 VSD Soil Solution Output for the Lower Spruce-Fir Site, using the Current Deposition Scenario

Year	Base Sat.	pH	$[NO_3^-]$ (eq m^{-3})	[ANC] (eq m^{-3})	molar Al/(Ca+Mg+K) ratio	$[Al^{3+}]$ (eq m^{-3})
1945	11%	4.6	0.1167	-0.0472	0.06	0.0273
1946	11%	4.6	0.1189	-0.0470	0.06	0.0272

Year	Base Sat.	pH	$[NO_3^-]$ (eq m^{-3})	[ANC] (eq m^{-3})	molar Al/(Ca+Mg+K) ratio	$[Al^{3+}]$ (eq m^{-3})
1947	11%	4.6	0.1212	-0.0468	0.06	0.0270
1948	11%	4.6	0.1236	-0.0466	0.06	0.0269
1949	11%	4.6	0.1259	-0.0464	0.06	0.0268
1950	11%	4.6	0.1282	-0.0462	0.06	0.0266
1951	11%	4.6	0.1329	-0.0477	0.06	0.0277
1952	11%	4.6	0.1378	-0.0492	0.06	0.0288
1953	10%	4.6	0.1426	-0.0508	0.06	0.0300
1954	10%	4.6	0.1474	-0.0524	0.06	0.0312
1955	10%	4.6	0.1523	-0.0540	0.07	0.0324
1956	10%	4.6	0.1571	-0.0557	0.07	0.0337
1957	10%	4.6	0.1619	-0.0574	0.07	0.0350
1958	10%	4.6	0.1668	-0.0591	0.07	0.0363
1959	10%	4.6	0.1716	-0.0609	0.07	0.0377
1960	10%	4.6	0.1764	-0.0627	0.07	0.0391
1961	10%	4.6	0.1789	-0.0625	0.07	0.0389
1962	10%	4.6	0.1812	-0.0621	0.07	0.0386
1963	10%	4.6	0.1835	-0.0617	0.07	0.0383
1964	10%	4.6	0.1858	-0.0613	0.07	0.0380
1965	10%	4.6	0.1880	-0.0609	0.07	0.0377
1966	10%	4.6	0.1927	-0.0632	0.07	0.0395
1967	10%	4.5	0.1976	-0.0657	0.08	0.0415
1968	10%	4.5	0.2025	-0.0683	0.08	0.0435
1969	10%	4.5	0.2074	-0.0709	0.08	0.0456
1970	10%	4.5	0.2123	-0.0737	0.08	0.0478
1971	10%	4.5	0.2171	-0.0764	0.08	0.0501
1972	10%	4.5	0.2220	-0.0793	0.08	0.0524
1973	10%	4.5	0.2269	-0.0822	0.09	0.0548
1974	10%	4.5	0.2317	-0.0852	0.09	0.0573
1975	9%	4.5	0.2366	-0.0883	0.09	0.0598
1976	9%	4.5	0.2356	-0.0884	0.09	0.0599
1977	9%	4.5	0.2342	-0.0884	0.09	0.0599
1978	9%	4.5	0.2329	-0.0883	0.09	0.0598
1979	9%	4.5	0.2316	-0.0882	0.09	0.0597
1980	9%	4.5	0.2301	-0.0880	0.09	0.0596
1981	9%	4.5	0.2288	-0.0879	0.09	0.0595
1982	9%	4.5	0.2274	-0.0877	0.09	0.0593
1983	9%	4.5	0.2261	-0.0875	0.10	0.0592
1984	9%	4.5	0.2248	-0.0873	0.10	0.0590
1985	9%	4.5	0.2233	-0.0871	0.10	0.0588
1986	9%	4.5	0.2240	-0.0878	0.10	0.0594
1987	9%	4.5	0.2250	-0.0886	0.10	0.0601
1988	9%	4.5	0.2259	-0.0894	0.10	0.0607
1989	9%	4.5	0.2268	-0.0902	0.10	0.0614
1990	9%	4.5	0.2276	-0.0910	0.10	0.0621
1991	8%	4.5	0.2236	-0.0889	0.10	0.0603
1992	8%	4.5	0.2192	-0.0865	0.10	0.0584
1993	8%	4.5	0.2148	-0.0841	0.10	0.0564
1994	8%	4.5	0.2104	-0.0817	0.10	0.0544

Year	Base Sat.	pH	$[NO_3^-]$ (eq m^{-3})	[ANC] (eq m^{-3})	molar Al/(Ca+Mg+K) ratio	$[Al^{3+}]$ (eq m^{-3})
1995	8%	4.5	0.2060	-0.0792	0.10	0.0523
1996	8%	4.5	0.2016	-0.0767	0.10	0.0503
1997	8%	4.5	0.1972	-0.0741	0.10	0.0482
1998	8%	4.5	0.1928	-0.0716	0.10	0.0461
1999	8%	4.5	0.1926	-0.0709	0.10	0.0456
2000	8%	4.5	0.1926	-0.0711	0.10	0.0458
2001	8%	4.5	0.1926	-0.0714	0.10	0.0460
2002	8%	4.5	0.1926	-0.0717	0.10	0.0463
2003	8%	4.5	0.1926	-0.0720	0.10	0.0465
2004	8%	4.5	0.1926	-0.0723	0.10	0.0467
2005	8%	4.5	0.1926	-0.0726	0.10	0.0470
2006	8%	4.5	0.1926	-0.0729	0.10	0.0472
2007	8%	4.5	0.1926	-0.0732	0.10	0.0474
2008	8%	4.5	0.1926	-0.0735	0.10	0.0477
2009	8%	4.5	0.1926	-0.0738	0.10	0.0479
2010	8%	4.5	0.1926	-0.0741	0.10	0.0482
2011	8%	4.5	0.1926	-0.0744	0.10	0.0484
2012	8%	4.5	0.1926	-0.0747	0.10	0.0486
2013	8%	4.5	0.1926	-0.0750	0.10	0.0489
2014	8%	4.5	0.1926	-0.0752	0.11	0.0491
2015	8%	4.5	0.1926	-0.0755	0.11	0.0493
2016	8%	4.5	0.1926	-0.0758	0.11	0.0496
2017	8%	4.5	0.1926	-0.0761	0.11	0.0498
2018	8%	4.5	0.1926	-0.0764	0.11	0.0501
2019	8%	4.5	0.1926	-0.0767	0.11	0.0503
2020	8%	4.5	0.1926	-0.0770	0.11	0.0505
2021	7%	4.5	0.1926	-0.0773	0.11	0.0508
2022	7%	4.5	0.1926	-0.0776	0.11	0.0510
2023	7%	4.5	0.1926	-0.0779	0.11	0.0512
2024	7%	4.5	0.1926	-0.0782	0.11	0.0515
2025	7%	4.5	0.1926	-0.0785	0.11	0.0517
2026	7%	4.5	0.1926	-0.0787	0.11	0.0520
2027	7%	4.5	0.1926	-0.0790	0.11	0.0522
2028	7%	4.5	0.1926	-0.0793	0.11	0.0524
2029	7%	4.5	0.1926	-0.0796	0.11	0.0527
2030	7%	4.5	0.1926	-0.0799	0.12	0.0529
2031	7%	4.5	0.1926	-0.0802	0.12	0.0531
2032	7%	4.5	0.1926	-0.0805	0.12	0.0534
2033	7%	4.5	0.1926	-0.0808	0.12	0.0536
2034	7%	4.5	0.1926	-0.0810	0.12	0.0538
2035	7%	4.5	0.1926	-0.0813	0.12	0.0541
2036	7%	4.5	0.1926	-0.0816	0.12	0.0543
2037	7%	4.5	0.1926	-0.0819	0.12	0.0545
2038	7%	4.5	0.1926	-0.0822	0.12	0.0548
2039	7%	4.5	0.1926	-0.0825	0.12	0.0550
2040	7%	4.5	0.1926	-0.0827	0.12	0.0552
2041	7%	4.5	0.1926	-0.0830	0.12	0.0555
2042	7%	4.5	0.1926	-0.0833	0.12	0.0557

Year	Base Sat.	pH	$[NO_3^-]$ (eq m^{-3})	[ANC] (eq m^{-3})	molar Al/(Ca+Mg+K) ratio	$[Al^{3+}]$ (eq m^{-3})
2043	7%	4.5	0.1926	-0.0836	0.12	0.0559
2044	7%	4.5	0.1926	-0.0839	0.12	0.0562
2045	7%	4.5	0.1926	-0.0841	0.12	0.0564
2046	7%	4.5	0.1926	-0.0844	0.13	0.0566
2047	7%	4.5	0.1926	-0.0847	0.13	0.0568
2048	7%	4.5	0.1926	-0.0850	0.13	0.0571
2049	7%	4.5	0.1926	-0.0852	0.13	0.0573
2050	7%	4.5	0.1926	-0.0855	0.13	0.0575
2051	7%	4.5	0.1926	-0.0858	0.13	0.0577
2052	7%	4.5	0.1926	-0.0861	0.13	0.0580
2053	7%	4.5	0.1926	-0.0863	0.13	0.0582
2054	7%	4.5	0.1926	-0.0866	0.13	0.0584
2055	7%	4.5	0.1926	-0.0869	0.13	0.0586
2056	7%	4.5	0.1926	-0.0871	0.13	0.0589
2057	7%	4.5	0.1926	-0.0874	0.13	0.0591
2058	7%	4.5	0.1926	-0.0877	0.13	0.0593
2059	7%	4.5	0.1926	-0.0879	0.13	0.0595
2060	7%	4.5	0.1926	-0.0882	0.13	0.0597
2061	7%	4.5	0.1926	-0.0884	0.13	0.0599
2062	6%	4.5	0.1926	-0.0887	0.13	0.0602
2063	6%	4.5	0.1926	-0.0890	0.14	0.0604
2064	6%	4.5	0.1926	-0.0892	0.14	0.0606
2065	6%	4.5	0.1926	-0.0895	0.14	0.0608
2066	6%	4.5	0.1926	-0.0897	0.14	0.0610
2067	6%	4.5	0.1926	-0.0900	0.14	0.0612
2068	6%	4.5	0.1926	-0.0902	0.14	0.0614
2069	6%	4.5	0.1926	-0.0905	0.14	0.0616
2070	6%	4.5	0.1926	-0.0907	0.14	0.0619
2071	6%	4.5	0.1926	-0.0910	0.14	0.0621
2072	6%	4.5	0.1926	-0.0912	0.14	0.0623
2073	6%	4.5	0.1926	-0.0915	0.14	0.0625
2074	6%	4.5	0.1926	-0.0917	0.14	0.0627
2075	6%	4.5	0.1926	-0.0919	0.14	0.0629
2076	6%	4.5	0.1926	-0.0922	0.14	0.0631
2077	6%	4.5	0.1926	-0.0924	0.14	0.0633
2078	6%	4.5	0.1926	-0.0927	0.14	0.0635
2079	6%	4.5	0.1926	-0.0929	0.14	0.0637
2080	6%	4.5	0.1926	-0.0931	0.15	0.0639
2081	6%	4.5	0.1926	-0.0934	0.15	0.0641
2082	6%	4.5	0.1926	-0.0936	0.15	0.0643
2083	6%	4.5	0.1926	-0.0938	0.15	0.0645
2084	6%	4.5	0.1926	-0.0941	0.15	0.0646
2085	6%	4.5	0.1926	-0.0943	0.15	0.0648
2086	6%	4.5	0.1926	-0.0945	0.15	0.0650
2087	6%	4.5	0.1926	-0.0947	0.15	0.0652
2088	6%	4.5	0.1926	-0.0950	0.15	0.0654
2089	6%	4.5	0.1926	-0.0952	0.15	0.0656
2090	6%	4.5	0.1926	-0.0954	0.15	0.0658

Year	Base Sat.	pH	$[NO_3^-]$ (eq m^{-3})	[ANC] (eq m^{-3})	molar Al/(Ca+Mg+K) ratio	$[Al^{3+}]$ (eq m^{-3})
2091	6%	4.5	0.1926	-0.0956	0.15	0.0660
2092	6%	4.5	0.1926	-0.0958	0.15	0.0661
2093	6%	4.5	0.1926	-0.0961	0.15	0.0663
2094	6%	4.5	0.1926	-0.0963	0.15	0.0665
2095	6%	4.5	0.1926	-0.0965	0.15	0.0667
2096	6%	4.5	0.1926	-0.0967	0.15	0.0669
2097	6%	4.5	0.1926	-0.0969	0.15	0.0670
2098	6%	4.5	0.1926	-0.0971	0.16	0.0672
2099	6%	4.5	0.1926	-0.0973	0.16	0.0674
2100	6%	4.5	0.1926	-0.0975	0.16	0.0676
2101	6%	4.5	0.1926	-0.0977	0.16	0.0677
2102	6%	4.5	0.1926	-0.0979	0.16	0.0679
2103	6%	4.5	0.1926	-0.0981	0.16	0.0681
2104	6%	4.5	0.1926	-0.0983	0.16	0.0682
2105	6%	4.5	0.1926	-0.0985	0.16	0.0684
2106	6%	4.5	0.1926	-0.0987	0.16	0.0686
2107	6%	4.5	0.1926	-0.0989	0.16	0.0687
2108	6%	4.5	0.1926	-0.0991	0.16	0.0689
2109	6%	4.5	0.1926	-0.0993	0.16	0.0691
2110	6%	4.5	0.1926	-0.0995	0.16	0.0692
2111	6%	4.5	0.1926	-0.0997	0.16	0.0694
2112	6%	4.5	0.1926	-0.0998	0.16	0.0695
2113	6%	4.5	0.1926	-0.1000	0.16	0.0697
2114	6%	4.5	0.1926	-0.1002	0.16	0.0698
2115	6%	4.5	0.1926	-0.1004	0.16	0.0700
2116	6%	4.5	0.1926	-0.1006	0.16	0.0701
2117	6%	4.5	0.1926	-0.1007	0.16	0.0703
2118	6%	4.5	0.1926	-0.1009	0.16	0.0704
2119	6%	4.5	0.1926	-0.1011	0.17	0.0706
2120	6%	4.5	0.1926	-0.1013	0.17	0.0707
2121	6%	4.5	0.1926	-0.1014	0.17	0.0709
2122	6%	4.5	0.1926	-0.1016	0.17	0.0710
2123	6%	4.5	0.1926	-0.1018	0.17	0.0712
2124	6%	4.5	0.1926	-0.1019	0.17	0.0713
2125	6%	4.5	0.1926	-0.1021	0.17	0.0714
2126	6%	4.5	0.1926	-0.1023	0.17	0.0716
2127	6%	4.5	0.1926	-0.1024	0.17	0.0717
2128	6%	4.5	0.1926	-0.1026	0.17	0.0719
2129	6%	4.5	0.1926	-0.1027	0.17	0.0720
2130	6%	4.5	0.1926	-0.1029	0.17	0.0721
2131	6%	4.5	0.1926	-0.1031	0.17	0.0723
2132	5%	4.5	0.1926	-0.1032	0.17	0.0724
2133	5%	4.5	0.1926	-0.1034	0.17	0.0725
2134	5%	4.5	0.1926	-0.1035	0.17	0.0726
2135	5%	4.5	0.1926	-0.1037	0.17	0.0728
2136	5%	4.5	0.1926	-0.1038	0.17	0.0729
2137	5%	4.5	0.1926	-0.1040	0.17	0.0730
2138	5%	4.5	0.1926	-0.1041	0.17	0.0731

Year	Base Sat.	pH	$[NO_3^-]$ (eq m^{-3})	[ANC] (eq m^{-3})	molar Al/(Ca+Mg+K) ratio	$[Al^{3+}]$ (eq m^{-3})
2139	5%	4.5	0.1926	-0.1042	0.17	0.0733
2140	5%	4.5	0.1926	-0.1044	0.17	0.0734
2141	5%	4.5	0.1926	-0.1045	0.17	0.0735
2142	5%	4.5	0.1926	-0.1047	0.17	0.0736
2143	5%	4.5	0.1926	-0.1048	0.17	0.0737
2144	5%	4.5	0.1926	-0.1049	0.18	0.0739
2145	5%	4.5	0.1926	-0.1051	0.18	0.0740
2146	5%	4.5	0.1926	-0.1052	0.18	0.0741
2147	5%	4.5	0.1926	-0.1053	0.18	0.0742
2148	5%	4.5	0.1926	-0.1055	0.18	0.0743
2149	5%	4.5	0.1926	-0.1056	0.18	0.0744
2150	5%	4.5	0.1926	-0.1057	0.18	0.0745

Table 8.6 VSD Soil Solution Output for the Beech Gap Site, using the Current Deposition Scenario

Year	Base Sat.	pH	$[NO_3^-]$ (eq m^{-3})	[ANC] (eq m^{-3})	molar Al/(Ca+Mg+K) ratio	$[Al^{3+}]$ (eq m^{-3})
1945	21%	4.6	0.0588	-0.0416	0.12	0.0233
1946	21%	4.6	0.0598	-0.0414	0.12	0.0232
1947	21%	4.6	0.0609	-0.0412	0.12	0.0230
1948	21%	4.6	0.0621	-0.0411	0.12	0.0229
1949	21%	4.6	0.0633	-0.0409	0.12	0.0228
1950	21%	4.6	0.0645	-0.0407	0.12	0.0227
1951	21%	4.6	0.0668	-0.0419	0.12	0.0235
1952	21%	4.6	0.0692	-0.0432	0.12	0.0244
1953	21%	4.6	0.0716	-0.0444	0.12	0.0253
1954	21%	4.6	0.0740	-0.0458	0.12	0.0263
1955	21%	4.6	0.0764	-0.0471	0.13	0.0272
1956	21%	4.6	0.0789	-0.0484	0.13	0.0282
1957	21%	4.6	0.0813	-0.0497	0.13	0.0292
1958	21%	4.6	0.0837	-0.0510	0.13	0.0302
1959	21%	4.6	0.0861	-0.0524	0.13	0.0312
1960	21%	4.6	0.0885	-0.0537	0.13	0.0322
1961	21%	4.6	0.0897	-0.0533	0.13	0.0319
1962	21%	4.6	0.0909	-0.0528	0.13	0.0315
1963	21%	4.6	0.0921	-0.0524	0.13	0.0312
1964	21%	4.6	0.0932	-0.0518	0.13	0.0308
1965	21%	4.6	0.0944	-0.0514	0.13	0.0304
1966	21%	4.6	0.0967	-0.0530	0.13	0.0316
1967	21%	4.6	0.0991	-0.0548	0.14	0.0330
1968	21%	4.6	0.1015	-0.0566	0.14	0.0344
1969	21%	4.6	0.1040	-0.0584	0.14	0.0358
1970	21%	4.6	0.1064	-0.0603	0.14	0.0372
1971	21%	4.6	0.1088	-0.0621	0.14	0.0387
1972	21%	4.5	0.1113	-0.0640	0.15	0.0401
1973	21%	4.5	0.1137	-0.0659	0.15	0.0416
1974	21%	4.5	0.1162	-0.0678	0.15	0.0431
1975	21%	4.5	0.1186	-0.0697	0.15	0.0447
1976	21%	4.5	0.1181	-0.0694	0.15	0.0444

Year	Base Sat.	pH	$[NO_3^-]$ (eq m^{-3})	[ANC] (eq m^{-3})	molar Al/(Ca+Mg+K) ratio	$[Al^{3+}]$ (eq m^{-3})
1977	21%	4.5	0.1174	-0.0689	0.15	0.0440
1978	21%	4.5	0.1168	-0.0684	0.15	0.0436
1979	21%	4.5	0.1161	-0.0679	0.15	0.0432
1980	21%	4.5	0.1154	-0.0674	0.15	0.0428
1981	21%	4.5	0.1147	-0.0669	0.15	0.0424
1982	21%	4.5	0.1140	-0.0664	0.15	0.0420
1983	21%	4.5	0.1134	-0.0659	0.15	0.0416
1984	21%	4.5	0.1127	-0.0653	0.15	0.0412
1985	21%	4.5	0.1120	-0.0648	0.15	0.0408
1986	21%	4.5	0.1124	-0.0649	0.15	0.0409
1987	21%	4.5	0.1128	-0.0651	0.15	0.0410
1988	21%	4.5	0.1133	-0.0653	0.15	0.0412
1989	21%	4.5	0.1138	-0.0655	0.15	0.0413
1990	21%	4.5	0.1142	-0.0657	0.15	0.0415
1991	20%	4.5	0.1122	-0.0639	0.15	0.0400
1992	20%	4.6	0.1100	-0.0619	0.15	0.0385
1993	20%	4.6	0.1078	-0.0600	0.15	0.0370
1994	20%	4.6	0.1056	-0.0580	0.14	0.0355
1995	20%	4.6	0.1034	-0.0561	0.14	0.0340
1996	20%	4.6	0.1012	-0.0541	0.14	0.0325
1997	20%	4.6	0.0990	-0.0522	0.14	0.0310
1998	20%	4.6	0.0968	-0.0503	0.14	0.0296
1999	20%	4.6	0.0967	-0.0496	0.13	0.0291
2000	20%	4.6	0.0966	-0.0496	0.13	0.0291
2001	20%	4.6	0.0966	-0.0496	0.14	0.0291
2002	20%	4.6	0.0966	-0.0497	0.14	0.0292
2003	20%	4.6	0.0966	-0.0497	0.14	0.0292
2004	20%	4.6	0.0966	-0.0497	0.14	0.0292
2005	20%	4.6	0.0966	-0.0498	0.14	0.0292
2006	20%	4.6	0.0966	-0.0498	0.14	0.0293
2007	20%	4.6	0.0966	-0.0499	0.14	0.0293
2008	20%	4.6	0.0966	-0.0499	0.14	0.0293
2009	20%	4.6	0.0966	-0.0499	0.14	0.0293
2010	20%	4.6	0.0966	-0.0500	0.14	0.0294
2011	20%	4.6	0.0966	-0.0500	0.14	0.0294
2012	20%	4.6	0.0966	-0.0500	0.14	0.0294
2013	20%	4.6	0.0966	-0.0501	0.14	0.0295
2014	20%	4.6	0.0966	-0.0501	0.14	0.0295
2015	20%	4.6	0.0966	-0.0501	0.14	0.0295
2016	20%	4.6	0.0966	-0.0502	0.14	0.0295
2017	20%	4.6	0.0966	-0.0502	0.14	0.0296
2018	20%	4.6	0.0966	-0.0503	0.14	0.0296
2019	20%	4.6	0.0966	-0.0503	0.14	0.0296
2020	20%	4.6	0.0966	-0.0503	0.14	0.0296
2021	20%	4.6	0.0966	-0.0504	0.14	0.0297
2022	20%	4.6	0.0966	-0.0504	0.14	0.0297
2023	20%	4.6	0.0966	-0.0504	0.14	0.0297
2024	20%	4.6	0.0966	-0.0505	0.14	0.0298

Year	Base Sat.	pH	$[NO_3^-]$ (eq m^{-3})	[ANC] (eq m^{-3})	molar Al/(Ca+Mg+K) ratio	$[Al^{3+}]$ (eq m^{-3})
2025	20%	4.6	0.0966	-0.0505	0.14	0.0298
2026	20%	4.6	0.0966	-0.0506	0.14	0.0298
2027	20%	4.6	0.0966	-0.0506	0.14	0.0298
2028	20%	4.6	0.0966	-0.0506	0.14	0.0299
2029	20%	4.6	0.0966	-0.0507	0.14	0.0299
2030	20%	4.6	0.0966	-0.0507	0.14	0.0299
2031	20%	4.6	0.0966	-0.0507	0.14	0.0299
2032	20%	4.6	0.0966	-0.0508	0.14	0.0300
2033	20%	4.6	0.0966	-0.0508	0.14	0.0300
2034	20%	4.6	0.0966	-0.0508	0.14	0.0300
2035	20%	4.6	0.0966	-0.0509	0.14	0.0301
2036	20%	4.6	0.0966	-0.0509	0.14	0.0301
2037	20%	4.6	0.0966	-0.0510	0.14	0.0301
2038	20%	4.6	0.0966	-0.0510	0.14	0.0301
2039	20%	4.6	0.0966	-0.0510	0.14	0.0302
2040	20%	4.6	0.0966	-0.0511	0.14	0.0302
2041	20%	4.6	0.0966	-0.0511	0.14	0.0302
2042	20%	4.6	0.0966	-0.0511	0.14	0.0302
2043	20%	4.6	0.0966	-0.0512	0.14	0.0303
2044	20%	4.6	0.0966	-0.0512	0.14	0.0303
2045	20%	4.6	0.0966	-0.0512	0.14	0.0303
2046	20%	4.6	0.0966	-0.0513	0.14	0.0304
2047	20%	4.6	0.0966	-0.0513	0.14	0.0304
2048	20%	4.6	0.0966	-0.0514	0.14	0.0304
2049	20%	4.6	0.0966	-0.0514	0.14	0.0304
2050	20%	4.6	0.0966	-0.0514	0.14	0.0305
2051	20%	4.6	0.0966	-0.0515	0.14	0.0305
2052	20%	4.6	0.0966	-0.0515	0.14	0.0305
2053	20%	4.6	0.0966	-0.0515	0.14	0.0305
2054	20%	4.6	0.0966	-0.0516	0.14	0.0306
2055	20%	4.6	0.0966	-0.0516	0.14	0.0306
2056	20%	4.6	0.0966	-0.0516	0.14	0.0306
2057	20%	4.6	0.0966	-0.0517	0.14	0.0306
2058	19%	4.6	0.0966	-0.0517	0.14	0.0307
2059	19%	4.6	0.0966	-0.0517	0.14	0.0307
2060	19%	4.6	0.0966	-0.0518	0.14	0.0307
2061	19%	4.6	0.0966	-0.0518	0.14	0.0308
2062	19%	4.6	0.0966	-0.0519	0.15	0.0308
2063	19%	4.6	0.0966	-0.0519	0.15	0.0308
2064	19%	4.6	0.0966	-0.0519	0.15	0.0308
2065	19%	4.6	0.0966	-0.0520	0.15	0.0309
2066	19%	4.6	0.0966	-0.0520	0.15	0.0309
2067	19%	4.6	0.0966	-0.0520	0.15	0.0309
2068	19%	4.6	0.0966	-0.0521	0.15	0.0309
2069	19%	4.6	0.0966	-0.0521	0.15	0.0310
2070	19%	4.6	0.0966	-0.0521	0.15	0.0310
2071	19%	4.6	0.0966	-0.0522	0.15	0.0310
2072	19%	4.6	0.0966	-0.0522	0.15	0.0311

Year	Base Sat.	pH	$[NO_3^-]$ (eq m^{-3})	[ANC] (eq m^{-3})	molar Al/(Ca+Mg+K) ratio	$[Al^{3+}]$ (eq m^{-3})
2073	19%	4.6	0.0966	-0.0522	0.15	0.0311
2074	19%	4.6	0.0966	-0.0523	0.15	0.0311
2075	19%	4.6	0.0966	-0.0523	0.15	0.0311
2076	19%	4.6	0.0966	-0.0524	0.15	0.0312
2077	19%	4.6	0.0966	-0.0524	0.15	0.0312
2078	19%	4.6	0.0966	-0.0524	0.15	0.0312
2079	19%	4.6	0.0966	-0.0525	0.15	0.0312
2080	19%	4.6	0.0966	-0.0525	0.15	0.0313
2081	19%	4.6	0.0966	-0.0525	0.15	0.0313
2082	19%	4.6	0.0966	-0.0526	0.15	0.0313
2083	19%	4.6	0.0966	-0.0526	0.15	0.0313
2084	19%	4.6	0.0966	-0.0526	0.15	0.0314
2085	19%	4.6	0.0966	-0.0527	0.15	0.0314
2086	19%	4.6	0.0966	-0.0527	0.15	0.0314
2087	19%	4.6	0.0966	-0.0527	0.15	0.0315
2088	19%	4.6	0.0966	-0.0528	0.15	0.0315
2089	19%	4.6	0.0966	-0.0528	0.15	0.0315
2090	19%	4.6	0.0966	-0.0529	0.15	0.0315
2091	19%	4.6	0.0966	-0.0529	0.15	0.0316
2092	19%	4.6	0.0966	-0.0529	0.15	0.0316
2093	19%	4.6	0.0966	-0.0530	0.15	0.0316
2094	19%	4.6	0.0966	-0.0530	0.15	0.0316
2095	19%	4.6	0.0966	-0.0530	0.15	0.0317
2096	19%	4.6	0.0966	-0.0531	0.15	0.0317
2097	19%	4.6	0.0966	-0.0531	0.15	0.0317
2098	19%	4.6	0.0966	-0.0531	0.15	0.0317
2099	19%	4.6	0.0966	-0.0532	0.15	0.0318
2100	19%	4.6	0.0966	-0.0532	0.15	0.0318
2101	19%	4.6	0.0966	-0.0532	0.15	0.0318
2102	19%	4.6	0.0966	-0.0533	0.15	0.0319
2103	19%	4.6	0.0966	-0.0533	0.15	0.0319
2104	19%	4.6	0.0966	-0.0533	0.15	0.0319
2105	19%	4.6	0.0966	-0.0534	0.15	0.0319
2106	19%	4.6	0.0966	-0.0534	0.15	0.0320
2107	19%	4.6	0.0966	-0.0534	0.15	0.0320
2108	19%	4.6	0.0966	-0.0535	0.15	0.0320
2109	19%	4.6	0.0966	-0.0535	0.15	0.0320
2110	19%	4.6	0.0966	-0.0536	0.15	0.0321
2111	19%	4.6	0.0966	-0.0536	0.15	0.0321
2112	19%	4.6	0.0966	-0.0536	0.15	0.0321
2113	19%	4.6	0.0966	-0.0537	0.15	0.0321
2114	19%	4.6	0.0966	-0.0537	0.15	0.0322
2115	19%	4.6	0.0966	-0.0537	0.15	0.0322
2116	19%	4.6	0.0966	-0.0538	0.15	0.0322
2117	19%	4.6	0.0966	-0.0538	0.15	0.0322
2118	19%	4.6	0.0966	-0.0538	0.15	0.0323
2119	19%	4.6	0.0966	-0.0539	0.15	0.0323
2120	19%	4.6	0.0966	-0.0539	0.15	0.0323

Year	Base Sat.	pH	$[NO_3^-]$ (eq m^{-3})	[ANC] (eq m^{-3})	molar Al/(Ca+Mg+K) ratio	$[Al^{3+}]$ (eq m^{-3})
2121	19%	4.6	0.0966	-0.0539	0.15	0.0324
2122	19%	4.6	0.0966	-0.0540	0.15	0.0324
2123	19%	4.6	0.0966	-0.0540	0.16	0.0324
2124	19%	4.6	0.0966	-0.0540	0.16	0.0324
2125	19%	4.6	0.0966	-0.0541	0.16	0.0325
2126	19%	4.6	0.0966	-0.0541	0.16	0.0325
2127	19%	4.6	0.0966	-0.0541	0.16	0.0325
2128	19%	4.6	0.0966	-0.0542	0.16	0.0325
2129	19%	4.6	0.0966	-0.0542	0.16	0.0326
2130	19%	4.6	0.0966	-0.0542	0.16	0.0326
2131	19%	4.6	0.0966	-0.0543	0.16	0.0326
2132	19%	4.6	0.0966	-0.0543	0.16	0.0326
2133	19%	4.6	0.0966	-0.0544	0.16	0.0327
2134	18%	4.6	0.0966	-0.0544	0.16	0.0327
2135	18%	4.6	0.0966	-0.0544	0.16	0.0327
2136	18%	4.6	0.0966	-0.0545	0.16	0.0327
2137	18%	4.6	0.0966	-0.0545	0.16	0.0328
2138	18%	4.6	0.0966	-0.0545	0.16	0.0328
2139	18%	4.6	0.0966	-0.0546	0.16	0.0328
2140	18%	4.6	0.0966	-0.0546	0.16	0.0328
2141	18%	4.6	0.0966	-0.0546	0.16	0.0329
2142	18%	4.6	0.0966	-0.0547	0.16	0.0329
2143	18%	4.6	0.0966	-0.0547	0.16	0.0329
2144	18%	4.6	0.0966	-0.0547	0.16	0.0330
2145	18%	4.6	0.0966	-0.0548	0.16	0.0330
2146	18%	4.6	0.0966	-0.0548	0.16	0.0330
2147	18%	4.6	0.0966	-0.0548	0.16	0.0330
2148	18%	4.6	0.0966	-0.0549	0.16	0.0331
2149	18%	4.6	0.0966	-0.0549	0.16	0.0331
2150	18%	4.6	0.0966	-0.0549	0.16	0.0331

Table 8.7 VSD Soil Solution Output for the Mixed Hardwood Site, using the Current Deposition Scenario

Year	Base Sat.	pH	$[NO_3^-]$ (eq m^{-3})	[ANC] (eq m^{-3})	molar Al/(Ca+Mg+K) ratio	$[Al^{3+}]$ (eq m^{-3})
1945	12%	4.8	0.0408	-0.0114	0.03	0.0055
1946	12%	4.8	0.0416	-0.0113	0.03	0.0054
1947	12%	4.8	0.0424	-0.0112	0.03	0.0054
1948	12%	4.8	0.0434	-0.0111	0.03	0.0053
1949	12%	4.8	0.0442	-0.0110	0.03	0.0053
1950	12%	4.8	0.0451	-0.0109	0.03	0.0053
1951	12%	4.8	0.0468	-0.0113	0.03	0.0054
1952	12%	4.8	0.0485	-0.0118	0.03	0.0056
1953	12%	4.8	0.0504	-0.0124	0.03	0.0059
1954	12%	4.8	0.0521	-0.0128	0.03	0.0061
1955	12%	4.8	0.0538	-0.0133	0.03	0.0063
1956	12%	4.8	0.0557	-0.0139	0.03	0.0065
1957	12%	4.8	0.0574	-0.0143	0.03	0.0068

Year	Base Sat.	pH	$[NO_3^-]$ (eq m^{-3})	[ANC] (eq m^{-3})	molar Al/(Ca+Mg+K) ratio	$[Al^{3+}]$ (eq m^{-3})
1958	12%	4.8	0.0591	-0.0148	0.03	0.0070
1959	12%	4.8	0.0610	-0.0154	0.03	0.0072
1960	12%	4.8	0.0628	-0.0159	0.03	0.0075
1961	12%	4.8	0.0637	-0.0157	0.03	0.0074
1962	12%	4.8	0.0646	-0.0156	0.03	0.0073
1963	12%	4.8	0.0654	-0.0153	0.03	0.0072
1964	12%	4.8	0.0663	-0.0151	0.03	0.0071
1965	12%	4.8	0.0671	-0.0149	0.03	0.0070
1966	12%	4.8	0.0688	-0.0155	0.03	0.0073
1967	12%	4.8	0.0706	-0.0162	0.03	0.0076
1968	12%	4.8	0.0724	-0.0169	0.03	0.0080
1969	12%	4.8	0.0741	-0.0176	0.03	0.0083
1970	12%	4.8	0.0760	-0.0183	0.03	0.0087
1971	12%	4.8	0.0777	-0.0190	0.03	0.0091
1972	12%	4.8	0.0796	-0.0197	0.04	0.0094
1973	12%	4.8	0.0814	-0.0205	0.04	0.0098
1974	12%	4.7	0.0832	-0.0212	0.04	0.0102
1975	12%	4.7	0.0850	-0.0219	0.04	0.0107
1976	12%	4.7	0.0847	-0.0219	0.04	0.0106
1977	12%	4.7	0.0843	-0.0218	0.04	0.0106
1978	12%	4.7	0.0838	-0.0217	0.04	0.0105
1979	12%	4.7	0.0833	-0.0215	0.04	0.0104
1980	12%	4.7	0.0828	-0.0214	0.04	0.0104
1981	12%	4.7	0.0823	-0.0213	0.04	0.0103
1982	12%	4.7	0.0819	-0.0212	0.04	0.0102
1983	12%	4.7	0.0815	-0.0210	0.04	0.0101
1984	12%	4.7	0.0810	-0.0209	0.04	0.0101
1985	12%	4.8	0.0804	-0.0207	0.04	0.0100
1986	12%	4.7	0.0807	-0.0208	0.04	0.0100
1987	12%	4.7	0.0811	-0.0209	0.04	0.0101
1988	11%	4.7	0.0814	-0.0210	0.04	0.0101
1989	11%	4.7	0.0817	-0.0211	0.04	0.0102
1990	11%	4.7	0.0820	-0.0212	0.04	0.0102
1991	11%	4.8	0.0806	-0.0206	0.04	0.0099
1992	11%	4.8	0.0790	-0.0199	0.04	0.0095
1993	11%	4.8	0.0775	-0.0192	0.04	0.0092
1994	11%	4.8	0.0759	-0.0185	0.04	0.0088
1995	11%	4.8	0.0743	-0.0178	0.04	0.0084
1996	11%	4.8	0.0727	-0.0170	0.04	0.0080
1997	11%	4.8	0.0710	-0.0163	0.04	0.0077
1998	11%	4.8	0.0694	-0.0155	0.03	0.0073
1999	11%	4.8	0.0693	-0.0152	0.03	0.0072
2000	11%	4.8	0.0693	-0.0152	0.03	0.0072
2001	11%	4.8	0.0693	-0.0152	0.03	0.0072
2002	11%	4.8	0.0693	-0.0152	0.03	0.0072

Year	Base Sat.	pH	[NO_3^-] (eq m^{-3})	[ANC] (eq m^{-3})	molar Al/(Ca+Mg+K) ratio	[Al^{3+}] (eq m^{-3})
2003	11%	4.8	0.0693	-0.0153	0.03	0.0072
2004	11%	4.8	0.0693	-0.0153	0.03	0.0072
2005	11%	4.8	0.0693	-0.0153	0.03	0.0072
2006	11%	4.8	0.0693	-0.0153	0.03	0.0072
2007	11%	4.8	0.0693	-0.0153	0.03	0.0072
2008	11%	4.8	0.0693	-0.0154	0.03	0.0072
2009	11%	4.8	0.0693	-0.0154	0.03	0.0072
2010	11%	4.8	0.0693	-0.0154	0.03	0.0072
2011	11%	4.8	0.0694	-0.0154	0.04	0.0073
2012	11%	4.8	0.0694	-0.0154	0.04	0.0073
2013	11%	4.8	0.0694	-0.0155	0.04	0.0073
2014	11%	4.8	0.0694	-0.0155	0.04	0.0073
2015	11%	4.8	0.0694	-0.0155	0.04	0.0073
2016	11%	4.8	0.0694	-0.0155	0.04	0.0073
2017	11%	4.8	0.0694	-0.0155	0.04	0.0073
2018	11%	4.8	0.0694	-0.0155	0.04	0.0073
2019	11%	4.8	0.0694	-0.0156	0.04	0.0073
2020	11%	4.8	0.0694	-0.0156	0.04	0.0073
2021	11%	4.8	0.0695	-0.0156	0.04	0.0073
2022	11%	4.8	0.0695	-0.0156	0.04	0.0074
2023	11%	4.8	0.0695	-0.0156	0.04	0.0074
2024	11%	4.8	0.0695	-0.0157	0.04	0.0074
2025	11%	4.8	0.0695	-0.0157	0.04	0.0074
2026	11%	4.8	0.0695	-0.0157	0.04	0.0074
2027	11%	4.8	0.0695	-0.0157	0.04	0.0074
2028	11%	4.8	0.0695	-0.0157	0.04	0.0074
2029	11%	4.8	0.0695	-0.0158	0.04	0.0074
2030	11%	4.8	0.0695	-0.0158	0.04	0.0074
2031	11%	4.8	0.0695	-0.0158	0.04	0.0074
2032	11%	4.8	0.0695	-0.0158	0.04	0.0074
2033	11%	4.8	0.0696	-0.0158	0.04	0.0075
2034	11%	4.8	0.0696	-0.0159	0.04	0.0075
2035	11%	4.8	0.0696	-0.0159	0.04	0.0075
2036	11%	4.8	0.0696	-0.0159	0.04	0.0075
2037	11%	4.8	0.0696	-0.0159	0.04	0.0075
2038	11%	4.8	0.0696	-0.0159	0.04	0.0075
2039	11%	4.8	0.0696	-0.0160	0.04	0.0075
2040	11%	4.8	0.0696	-0.0160	0.04	0.0075
2041	11%	4.8	0.0696	-0.0160	0.04	0.0075
2042	11%	4.8	0.0696	-0.0160	0.04	0.0075
2043	11%	4.8	0.0696	-0.0160	0.04	0.0075
2044	11%	4.8	0.0696	-0.0160	0.04	0.0076
2045	11%	4.8	0.0697	-0.0161	0.04	0.0076
2046	11%	4.8	0.0697	-0.0161	0.04	0.0076
2047	11%	4.8	0.0697	-0.0161	0.04	0.0076

Year	Base Sat.	pH	$[NO_3^-]$ (eq m^{-3})	[ANC] (eq m^{-3})	molar Al/(Ca+Mg+K) ratio	$[Al^{3+}]$ (eq m^{-3})
2048	11%	4.8	0.0697	-0.0161	0.04	0.0076
2049	11%	4.8	0.0697	-0.0161	0.04	0.0076
2050	11%	4.8	0.0697	-0.0162	0.04	0.0076
2051	11%	4.8	0.0697	-0.0162	0.04	0.0076
2052	11%	4.8	0.0697	-0.0162	0.04	0.0076
2053	11%	4.8	0.0697	-0.0162	0.04	0.0076
2054	11%	4.8	0.0697	-0.0162	0.04	0.0077
2055	11%	4.8	0.0697	-0.0163	0.04	0.0077
2056	11%	4.8	0.0697	-0.0163	0.04	0.0077
2057	11%	4.8	0.0698	-0.0163	0.04	0.0077
2058	11%	4.8	0.0698	-0.0163	0.04	0.0077
2059	11%	4.8	0.0698	-0.0163	0.04	0.0077
2060	11%	4.8	0.0698	-0.0164	0.04	0.0077
2061	11%	4.8	0.0698	-0.0164	0.04	0.0077
2062	11%	4.8	0.0698	-0.0164	0.04	0.0077
2063	11%	4.8	0.0698	-0.0164	0.04	0.0077
2064	11%	4.8	0.0698	-0.0164	0.04	0.0077
2065	11%	4.8	0.0698	-0.0165	0.04	0.0078
2066	11%	4.8	0.0698	-0.0165	0.04	0.0078
2067	11%	4.8	0.0698	-0.0165	0.04	0.0078
2068	11%	4.8	0.0698	-0.0165	0.04	0.0078
2069	11%	4.8	0.0698	-0.0165	0.04	0.0078
2070	11%	4.8	0.0699	-0.0166	0.04	0.0078
2071	11%	4.8	0.0699	-0.0166	0.04	0.0078
2072	11%	4.8	0.0699	-0.0166	0.04	0.0078
2073	11%	4.8	0.0699	-0.0166	0.04	0.0078
2074	11%	4.8	0.0699	-0.0166	0.04	0.0078
2075	11%	4.8	0.0699	-0.0166	0.04	0.0079
2076	11%	4.8	0.0699	-0.0167	0.04	0.0079
2077	11%	4.8	0.0699	-0.0167	0.04	0.0079
2078	11%	4.8	0.0699	-0.0167	0.04	0.0079
2079	11%	4.8	0.0699	-0.0167	0.04	0.0079
2080	11%	4.8	0.0699	-0.0167	0.04	0.0079
2081	11%	4.8	0.0699	-0.0168	0.04	0.0079
2082	11%	4.8	0.0699	-0.0168	0.04	0.0079
2083	11%	4.8	0.0699	-0.0168	0.04	0.0079
2084	10%	4.8	0.0700	-0.0168	0.04	0.0079
2085	10%	4.8	0.0700	-0.0168	0.04	0.0080
2086	10%	4.8	0.0700	-0.0169	0.04	0.0080
2087	10%	4.8	0.0700	-0.0169	0.04	0.0080
2088	10%	4.8	0.0700	-0.0169	0.04	0.0080
2089	10%	4.8	0.0700	-0.0169	0.04	0.0080
2090	10%	4.8	0.0700	-0.0169	0.04	0.0080
2091	10%	4.8	0.0700	-0.0170	0.04	0.0080
2092	10%	4.8	0.0700	-0.0170	0.04	0.0080

Year	Base Sat.	pH	$[NO_3^-]$ (eq m^{-3})	[ANC] (eq m^{-3})	molar Al/(Ca+Mg+K) ratio	$[Al^{3+}]$ (eq m^{-3})
2093	10%	4.8	0.0700	-0.0170	0.04	0.0080
2094	10%	4.8	0.0700	-0.0170	0.04	0.0080
2095	10%	4.8	0.0700	-0.0170	0.04	0.0080
2096	10%	4.8	0.0700	-0.0171	0.04	0.0081
2097	10%	4.8	0.0700	-0.0171	0.04	0.0081
2098	10%	4.8	0.0701	-0.0171	0.04	0.0081
2099	10%	4.8	0.0701	-0.0171	0.04	0.0081
2100	10%	4.8	0.0701	-0.0171	0.04	0.0081
2101	10%	4.8	0.0701	-0.0172	0.04	0.0081
2102	10%	4.8	0.0701	-0.0172	0.04	0.0081
2103	10%	4.8	0.0701	-0.0172	0.04	0.0081
2104	10%	4.8	0.0701	-0.0172	0.04	0.0081
2105	10%	4.8	0.0701	-0.0172	0.04	0.0081
2106	10%	4.8	0.0701	-0.0173	0.04	0.0082
2107	10%	4.8	0.0701	-0.0173	0.04	0.0082
2108	10%	4.8	0.0701	-0.0173	0.04	0.0082
2109	10%	4.8	0.0701	-0.0173	0.04	0.0082
2110	10%	4.8	0.0701	-0.0173	0.04	0.0082
2111	10%	4.8	0.0701	-0.0174	0.04	0.0082
2112	10%	4.8	0.0701	-0.0174	0.04	0.0082
2113	10%	4.8	0.0701	-0.0174	0.04	0.0082
2114	10%	4.8	0.0702	-0.0174	0.04	0.0082
2115	10%	4.8	0.0702	-0.0174	0.04	0.0082
2116	10%	4.8	0.0702	-0.0175	0.04	0.0083
2117	10%	4.8	0.0702	-0.0175	0.04	0.0083
2118	10%	4.8	0.0702	-0.0175	0.04	0.0083
2119	10%	4.8	0.0702	-0.0175	0.04	0.0083
2120	10%	4.8	0.0702	-0.0175	0.04	0.0083
2121	10%	4.8	0.0702	-0.0176	0.04	0.0083
2122	10%	4.8	0.0702	-0.0176	0.04	0.0083
2123	10%	4.8	0.0702	-0.0176	0.04	0.0083
2124	10%	4.8	0.0702	-0.0176	0.04	0.0083
2125	10%	4.8	0.0702	-0.0176	0.04	0.0083
2126	10%	4.8	0.0702	-0.0176	0.04	0.0084
2127	10%	4.8	0.0702	-0.0177	0.04	0.0084
2128	10%	4.8	0.0702	-0.0177	0.04	0.0084
2129	10%	4.8	0.0702	-0.0177	0.04	0.0084
2130	10%	4.8	0.0703	-0.0177	0.04	0.0084
2131	10%	4.8	0.0703	-0.0177	0.04	0.0084
2132	10%	4.8	0.0703	-0.0178	0.04	0.0084
2133	10%	4.8	0.0703	-0.0178	0.04	0.0084
2134	10%	4.8	0.0703	-0.0178	0.04	0.0084
2135	10%	4.8	0.0703	-0.0178	0.04	0.0084
2136	10%	4.8	0.0703	-0.0178	0.04	0.0085
2137	10%	4.8	0.0703	-0.0179	0.04	0.0085

Year	Base Sat.	pH	$[NO_3^-]$ (eq m^{-3})	[ANC] (eq m^{-3})	molar Al/(Ca+Mg+K) ratio	$[Al^{3+}]$ (eq m^{-3})
2138	10%	4.8	0.0703	-0.0179	0.04	0.0085
2139	10%	4.8	0.0703	-0.0179	0.04	0.0085
2140	10%	4.8	0.0703	-0.0179	0.04	0.0085
2141	10%	4.8	0.0703	-0.0179	0.04	0.0085
2142	10%	4.8	0.0703	-0.0180	0.04	0.0085
2143	10%	4.8	0.0703	-0.0180	0.04	0.0085
2144	10%	4.8	0.0703	-0.0180	0.04	0.0085
2145	10%	4.8	0.0703	-0.0180	0.04	0.0085
2146	10%	4.8	0.0703	-0.0180	0.04	0.0086
2147	10%	4.8	0.0704	-0.0181	0.04	0.0086
2148	10%	4.8	0.0704	-0.0181	0.04	0.0086
2149	10%	4.8	0.0704	-0.0181	0.04	0.0086
2150	10%	4.8	0.0704	-0.0181	0.04	0.0086

8.4 Data availability at Great Smoky Mountain National Park for critical loads calculations

List of Parameters for Calculating Nitrogen Critical Loads at Great Smoky Mtns NP

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A. DEPOSITION ***A.1. Throughfall***	**Mandatory/ Optional?**	**High elevation Data x/ ?**	**Mid elevation Data x/ ?**	**Low elevation Data x/ ?**
pH	M	x	x	
conductivity	M	x	x	
Base cations (Na^+, K^+, Mg^{2+}, Ca^{2+})	M	x	x	
NH_4^+	M	x	x	
Anions (Cl^-, NO_3^-, SO_4^{2-})	M	x	x	x
Total Alkalinity (if annual median pH>5)	M			
Total N	M	x	x	x
Al^{3+}, Mn^{2+}, Fe^{3+}	O	x	x	
Heavy metals (Cu,Zn, Hg, Pb, Cd, Co, Mo	O	x		
Total P, PO_4^{3-}	O			
Total alkalinity (if any sample pH>5	O			
Total S	O	x	x	x
TOC, DOC	O	x		

A.2. Wet Deposition	**Mandatory/ Optional?**	**High elevation Data x/ ?**	**Mid elevation Data x/ ?**	**Low elevation Data x/ ?**
pH	M	x	x	x
Base cations (Na^+, K^+, Mg^{2+}, Ca^{2+})	M	x	x	x
NH_4^+	M	x	x	x
Anions (Cl^-, NO_3^-, SO_4^{2-})	M	x	x	x
Total Alkalinity (if annual median>5)	M			
Al^{3+}, Mn^{2+}, Fe^{3+}	O	x		
Heavy metals (Cu,Zn, Hg, Pb, Cd, Co, Mo	O	x		
Total P, PO_4^{3-}	O			
Total alkalinity (if any sample pH>5	O			
Total S, Total N	O	x	x	x

B. CLIMATE	**Mandatory/ Optional?**	**High elevation Data x/ ?**	**Mid elevation Data x/ ?**	**Low elevation Data x/ ?**
Precipitation volume	M	x	x	x
Air temperature	M	x	x	x
Air humidity	M	x	x	x

Annual evapotransporation rate	M	x		
Wind speed	O	x	x	x
Wind direction	O	x	x	x
Solar radiation	O	x	x	x
Barometric pressure	O		x	
UV-b radiation	O			x
Soil temperatures	O	x USGS	x	x
Soil moisture (matric potential, water content)	O	x USGS	?	?
Stand precipitation (throughfall and stem flow)	O	x	x	

C. ANALYSIS OF NEEDLES AND LEAVES	**Mandatory/ Optional?**	**High elevation Data x/ ?**	**Mid elevation Data x/ ?**	**Low elevation Data x/ ?**
N, S, P, Ca, Mg, K	M	x	x	x understory
Zn, Mn, Fe, B, Pb, Cu, Cd, C	O	x	x	

D. SOIL ANALYSIS (SOLID PHASE)	**Mandatory/ Optional?**	**High elevation Data x/ ?**	**Mid elevation Data x/ ?**	**Low elevation Data x/ ?**
Course fragment	M	x		
Bulk density	M	x		
Particle size distribution	M			
pH ($CaCl_2$)	M	x (buffer pH)	x	x
Organic C	M	x		
Total N	M	x	x	x
Extractable Ca, K, Mg, Al, Na	M	x all	x	x
Exchangeable acidity	M	x	x	
Base saturation	M	x	x	
Cation exchange capacity	M	x	x	x
pH (H_2O)	M	x	x	x
Acceptable N accumulation	M	?	?	?
Exchange constants (lg K AlBC, lg K HBC)	M	x	x	
C pool in rooting zone	M	x		
Organic layer weight	O	x	x	x
Carbonates	O			
Extractable P, Mn, Cu, Pb, Cd, Zn, Fe, Cr, Ni, S, Hg	O	x most	x most	x most
Oxalate extractable Fe, Al	O	x	x Al	x Al
Total elements (Ca, Mg, K, Al, Fe, Mn)	O	x	x	x
Full mineralogical analysis	O	x	x	

E. SOIL SOLUTION ANALYSIS	Mandatory/ Optional?	High elevation Data x/ ?	Mid elevation Data x/ ?	Low elevation Data x/ ?
pH	M	x	x	
Alkalinity	M	x?	x?	
DOC	M	x		
K, Mg, Ca, Na	M	x	x	
Al (Total)	M	x	x	
Al (Labile)	M	x		
NO_3-N, SO_4-S	M	x	x	
NH_4-N	M	x	x	
Cl	M	x	x	
pCO_2 (partial pressure of CO_2)	M			
Fe, Mn, Zn, Cu, Cr, Ni, Pb, Cd, Si	O	x		
Electrical conductivity	O	x	x	
total P	O			

F. FOREST HEALTH PARAMETERS - OPTIONAL				

G. GROWTH AND YIELD	Mandatory/ Optional?	High elevation Data x/ ?	Mid elevation Data x/ ?	Low elevation Data x/ ?
Species composition	M	x	x	x
If removal of biomass via harvesting or fire occurs on the site	M		x	x
DBH	M	x	x	x
Biomass removed by tree compartment (stem wood, stem bark, branches, foliage)	M			
Nutrient content by tree compartment (stem wood, stem bark, branches, foliage)	M	x	x foliage	x foliage

H. SURFACE WATER (FROM ICP WATER)	Mandatory/ Optional?	High elevation Data x/ ?	Mid elevation Data x/ ?	Low elevation Data x/ ?
Alkalinity	M	x	x	x
pH	M	x	x	x
Conductivity	M	x	x	x
Base cations (Na^+, K^+, Mg^{2+}, Ca^{2+})	M	x	x	x
NH_4^+	M	x	x	x
Al (labile)	O			
DOC or permanganate	O	x	x	x
Al (reactive)	O			

Al (non-labile)	O			
Total Al	O	x	x	x
TOC	O			
Water temperature	O	x	x	x
Flow	O	x		x
Total or soluble reactive PO_4^{3-}	O			
Dissolved Oxygen	O			
Fe, Mn, Cd, Zn, Cu, Ni, Pb, F	O	x no i or F	x	x
Silica (SiO_2)	O	x	x	x
Color	O			
Turbidity	O	some storm event data		

I. ADDITIONAL AIR QUALITY PARAMETERS	**Mandatory/ Optional?**	**High elevation Data x/ ?**	**Mid elevation Data x/ ?**	**Low elevation Data x/ ?**
O_3	O	x	x	x
Trace Gases (SO_2, CO, NO-NO_y)	O		x	x
Hydrocarbons	O		x	
Continuous Fine Mass (TEOM)	O		x	x
Dry deposition SO_2, SO_4^{2-}, HNO_3^-, NO_3^-, NH_4^+ (CASTNet)	O	x	x	x
Mercury deposition (MDN)	O	x		x
Cloud deposition (MADPro)	O	x		
IMPROVE ($PM_{2.5}$, PM_{10}, nephelometer, hi-res camera)	O	x	x	x

8.5 Historic Deposition

The VSD requires an initial calibration in order to calculate the selectivity coefficients for Al:BC and H:BC exchange (log K Al:BC and log K H:BC). It is preferable to use a period of time when deposition inputs are both low and not changing rapidly, so that the assumption that the soil exchange complex is at equilibrium with the deposition is met. We estimated historical deposition in order to calibrate the model (Figure 8.2).

We used modeled historical deposition from the SAMI project (Sullivan et al., 2001; Cosby pers. comm.) with a simple regression to extend the SAMI data from 1990 to 1999. We normalized the historical data from SAMI by dividing the deposition in each year by the deposition for the current period (1999-2004). In this way, we calculated the fraction of current deposition for each (historic) year (Table 8.1). In order to estimate historical deposition at each site, we multiplied the current deposition (for S, N, and BC) by the fraction in each year. The SAMI data included wet deposition for N and S. We assumed that the BC tracked with the S deposition for our estimation. The purpose of these estimations was to calibrate the model; the accuracy of these estimates is well within the certainty of the model. However, these estimates of historical deposition at these sites should not be used for other purposes or assumed to have a high level of certainty. The resulting historical patterns of deposition we used for each site are shown below (Figure 8.2).

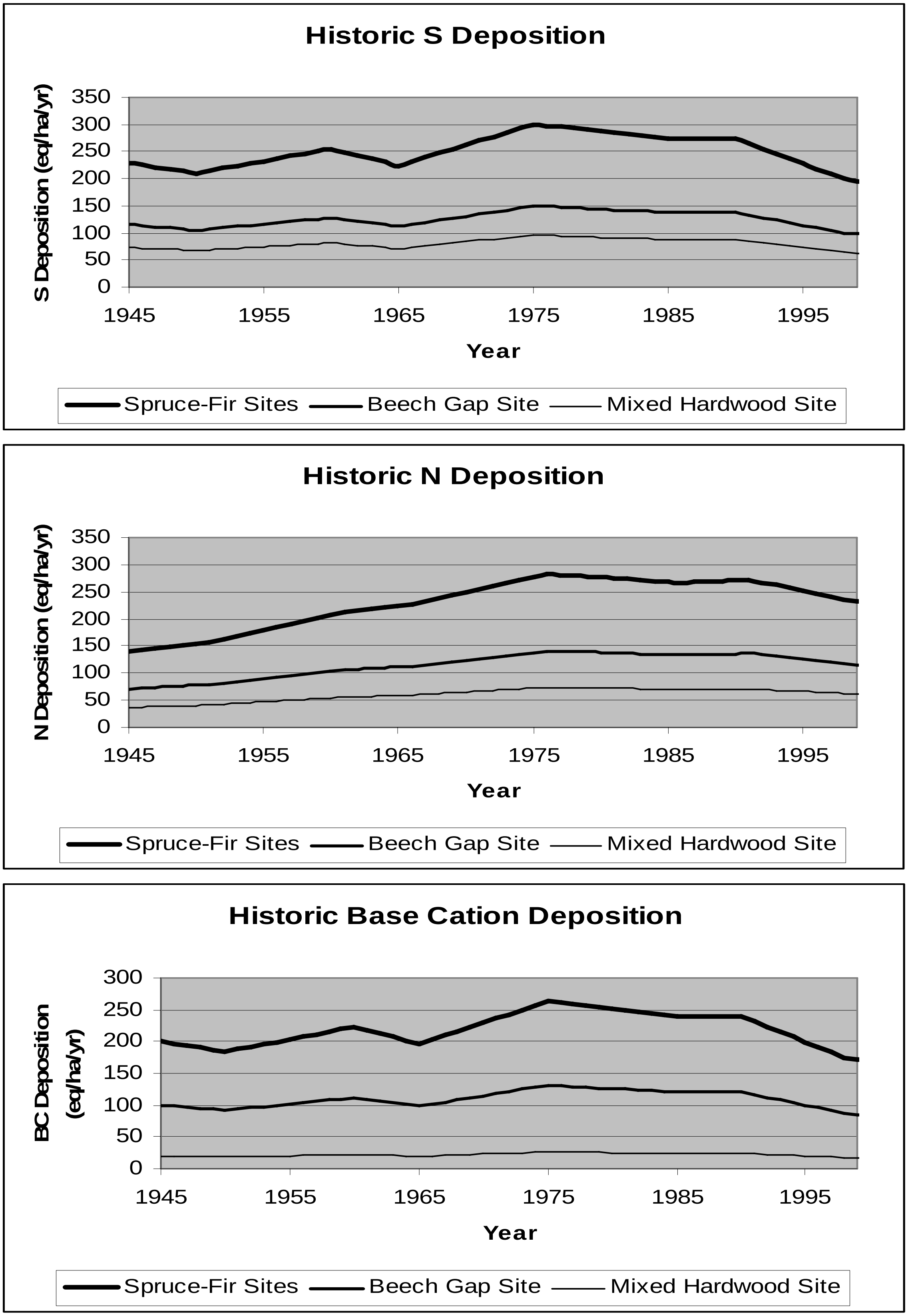

Figure 8.2 Historic S, N, and Base Cation Deposition for the GSMNP Sites.

Table 8.8 Fraction of current deposition (1999-2004) for each year from 1944-2004.

Year	S	N	BC	Year	S	N	BC
1944	1.12	0.60	1.12	**1972**	1.42	1.15	1.42
1945	1.17	0.62	1.17	**1973**	1.46	1.17	1.46
1946	1.15	0.63	1.15	**1974**	1.49	1.20	1.49
1947	1.13	0.64	1.13	**1975**	1.53	1.22	1.53
1948	1.11	0.65	1.11	**1976**	1.52	1.22	1.52
1949	1.09	0.67	1.09	**1977**	1.51	1.21	1.51
1950	1.07	0.68	1.07	**1978**	1.49	1.20	1.49
1951	1.10	0.70	1.10	**1979**	1.48	1.19	1.48
1952	1.12	0.73	1.12	**1980**	1.47	1.19	1.47
1953	1.14	0.75	1.14	**1981**	1.45	1.18	1.45
1954	1.17	0.78	1.17	**1982**	1.44	1.17	1.44
1955	1.19	0.80	1.19	**1983**	1.43	1.17	1.43
1956	1.21	0.82	1.21	**1984**	1.41	1.16	1.41
1957	1.23	0.85	1.23	**1985**	1.40	1.15	1.40
1958	1.26	0.87	1.26	**1986**	1.40	1.16	1.40
1959	1.28	0.90	1.28	**1987**	1.40	1.16	1.40
1960	1.30	0.92	1.30	**1988**	1.40	1.17	1.40
1961	1.27	0.93	1.27	**1989**	1.40	1.17	1.40
1962	1.24	0.94	1.24	**1990**	1.40	1.18	1.40
1963	1.21	0.96	1.21	**1991**	1.35	1.15	1.35
1964	1.18	0.97	1.18	**1992**	1.30	1.13	1.30
1965	1.15	0.98	1.15	**1993**	1.26	1.11	1.26
1966	1.18	1.00	1.18	**1994**	1.21	1.09	1.21
1967	1.22	1.03	1.22	**1995**	1.16	1.07	1.16
1968	1.26	1.05	1.26	**1996**	1.12	1.04	1.12
1969	1.30	1.08	1.30	**1997**	1.07	1.02	1.07
1970	1.34	1.10	1.34	**1998**	1.02	1.00	1.02
1971	1.38	1.12	1.38	**1999**	1.00	1.00	1.00

8.6 Literature Lists

The following lists are GSMNP publications and the additional references used in creating the Critical Thresholds Table. These references are in a ProCite database.

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