Multi-Agency Critical Loads Workshop

Sulfur & Nitrogen Deposition Effects on Freshwater and Terrestrial Ecosystems

MAY 23-25, 2006

FINAL REPORT

Workshop Organized by
US Environmental Protection Agency
US Forest Service
US Geological Survey
National Park Service

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Executive Summary

On May 23-25, 2006 a Multi-Agency Critical Loads Workshop for Sulfur and Nitrogen Deposition Effects on Freshwater and Terrestrial Ecosystems was convened by the US Environmental Protection Agency (EPA), the US Forest Service (USFS), the National Park Service (NPS), and the US Geological Survey (USGS). Approximately 75 participants gathered at the University of Virginia to share information, discuss scientific advances, and develop a broad federal strategy for advancing critical loads in the US. Scientists, conservation representatives, and state and federal agency officials met to discuss the science of critical loads during the first two days of the workshop, and a coordinating session limited to state and federal agency staff was held on day three.

The workshop goals as stated by the steering committee were:

1. to facilitate a broad sharing of information regarding critical loads terminology and definitions along with technical/science projects among the agencies and stakeholders,
2. to understand the history and science behind the development of critical loads in Europe and the US in order to provide context and background for future use of critical loads model outputs and empirical data, and
3. to develop a draft broad federal strategy for planning, executing, and evaluating critical loads projects, including integrating critical load science and technical issues with consideration of critical load use in a policy or management framework.

Through a series of scientific presentations, workshop participants explored three major critical loads research topics: (1) the strengths and weaknesses of simple mass balance and dynamic models for calculating critical loads, (2) the application of empirical methods for estimating critical loads, and (3) the state of air, water, soil, and forest monitoring data to support critical loads development. Summaries of the scientific presentations are provided in the workshop report.

Based on the scientific presentations, a research and monitoring agenda for advancing the science of critical loads emerged. The agenda encompasses atmospheric emissions and deposition, soils, surface waters, biological effects, and critical loads modeling. It emphasizes the need for improved nitrogen emission inventories and total deposition estimates for sulfur and nitrogen, hybrid approaches that combine models with empirical observations, and an improved understanding of relationships between chemical criteria and biological responses in aquatic and terrestrial ecosystems.

The workshop participants arrived at several important areas of agreement during the workshop, including a common definition of critical loads, general consensus that critical loads science in the US is strong enough to support management and assessment applications in some instances, and agreement that a comprehensive research and monitoring effort should be vigorously pursued to support the further development of critical loads.

The common definition of critical loads agreed upon by the group is the definition originally developed by the United Nations Economic Commission for Europe in 1988, and accepted by the US in 1989:

> *A critical load is a quantitative estimate of the exposure to one or more pollutants below which significant harmful effects on specific sensitive elements of the environment do not occur according to present knowledge* (UN ECE 1988).

The group also identified several questions in need of further discussion including stronger scientific consensus on the most appropriate biological indicators and associated chemical criteria, and the suitability of existing databases for national simple mass balance critical loads calculations. The workshop recommendations include several items to help resolve these questions.

Critical loads pilot projects that integrate science and policy were proposed and endorsed as one approach for encouraging the development and application of critical loads in the US. The workshop participants honed a set of specific goals and components for critical loads pilot projects.

PILOT PROJECT GOALS

Comprehensive critical loads pilot projects that integrate science and policy issues will:

1. build on existing capabilities and projects to further explore the development of critical loads for sulfur and/or nitrogen based on effects on sensitive aquatic and terrestrial ecosystems in the US;
2. evaluate the usefulness of critical loads for policymakers and managers at the state, regional, or national level; and
3. identify research and monitoring needs for future critical loads efforts (e.g., methods and models, data, monitoring, non-pollutant stressor interactions).

PILOT PROJECT COMPONENTS

Comprehensive critical loads pilot projects should be based on a well-defined project plan that delivers discrete products in 2-5 years. The project plan should include the following components:

1. REGION – the project should apply to a specific geographic area that can range from multi-site to regional or national scales (e.g., eastern or western US); the relative ecosystem sensitivity and representativeness of the area should be described.

2. ENVIRONMENTAL IMPACTS – the project should address sulfur and/or nitrogen deposition-related environmental issues (e.g., acidification, nitrogen saturation, and eutrophication) that are well-defined and supported by research and data for the selected project area.

3. METHODS/MODELS – the project should use appropriate methods and models that have been developed or could be adapted for the project area to calculate critical loads.

4. DATA AVAILABILITY – existing data should be available to support the effective application of the method or model selected for the project; including sensitivity and uncertainty analyses, and evaluation of results by ground-truthing or other scientifically valid means.

5. ENVIRONMENTAL INDICATORS - environmental indicators for tracking the chemical and/or ecological responses to sulfur and/or nitrogen deposition in the project area should be defined and supported by existing data and research.

6. MONITORING - satisfactory monitoring to measure or estimate atmospheric deposition and ecological response should be underway and continuing in the project area.

7. STAKEHOLDER INVOLVEMENT - stakeholders (e.g., Federal, State, Tribal, local representatives) should be engaged in discussions throughout the project to determine how the critical loads and related information could be used in policy, management, and assessment efforts.

The workshop culminated with a set of recommended next steps for advancing the development and application of critical loads for sulfur and nitrogen deposition in the US.

EXPAND THE SCIENTIFIC ENTERPRISE

1. Organize a scientific meeting or conference that produces scientific publications and perhaps a special issue of a journal. Proposed conference steering committee members include: J. Baron, J. Cosby, C. Driscoll, M. Fenn, and J. Galloway.
2. Pursue a research and monitoring agenda to support critical loads initiatives in the US.
3. Increase the publication of scientific papers in the peer-reviewed literature over the next 5 years.
4. Develop a scientific consensus regarding appropriate chemical criteria, biological indicators, and defensible thresholds linked to policy objectives.
5. Organize a focused session at the proposed scientific meeting, or a small-group workshop, aimed at resolving which indicators and thresholds best reflect the impacts of atmospheric deposition and are most strongly tied to a specific biological response.
6. Produce a review paper specifically focused on critical loads criteria, indicators, thresholds and linkages to biological response.
7. Compile information on existing critical loads projects that are underway, their objectives, and where they are located.
8. Develop written interpretation guidelines for national critical loads maps, conduct additional ground-truthing and uncertainty/sensitivity analysis, and integrate more observational data where possible.
9. Send US scientists to European critical loads workshops.

ENHANCE POLICY FRAMEWORKS & INTER-AGENCY COLLABORATION

1. Establish an inter-agency critical loads working group, perhaps as an NADP ad hoc committee.
2. Develop an Inter-Agency Policy Framework with a list of potential critical loads policy applications and associated information requirements in order to clarify how critical loads could most appropriately be applied to different policy and management issues.
3. Support research and monitoring needs for critical loads initiatives in the US.
4. Solicit, select, and implement pilot projects based on the defined project goals and components.

5. Incorporate critical loads science in the re-evaluation of secondary National Ambient Air Quality Standards.

GET THE WORD OUT THROUGH ORGANIZED COMMUNICATIONS ACTIVITIES

1. Develop a critical loads website that includes materials from this multi-agency workshop, as well as information and links to critical loads resources and projects in North America and Europe.
2. Organize joint briefings with scientists for staff and leadership of state, tribal, regional, and federal governments to increase understanding of critical loads, how they are developed and how they can be used.
3. Develop a critical loads fact sheet for policymakers and the public that describes the concept, history, science, and possible applications of critical loads.
4. Publish a summary of this multi-agency workshop in trade newsletters and publications to begin reaching larger audiences.

Chapter 1

Multi-Agency Critical Loads Workshop

Origin & Purpose

On May 23-25, 2006 a Multi-Agency Critical Loads Workshop for Sulfur and Nitrogen Deposition Effects on Freshwater and Terrestrial Ecosystems was convened by the US Environmental Protection Agency (EPA), the US Forest Service (USFS), the National Park Service (NPS), and the US Geological Survey (USGS). Approximately 75 participants gathered at the University of Virginia to share information, discuss scientific advances, and develop a broad federal strategy for advancing critical loads in the US. Scientists, conservation representatives, and state and federal agency officials met to discuss the science of critical loads during the first two days of the workshop, and a coordinating session limited to state and federal agency staff was held on day three.

The Multi-Agency Critical Loads Workshop builds upon previous efforts led by the USFS to enhance the understanding and application of critical loads in federal land management. Over the past 10 years, federal land managers have developed specific recommendations for using deposition analysis thresholds and critical loads in federal land management in the US (Porter et al. 2005). Between 2002 and 2005, the USFS convened a series of three meetings to review critical loads experiences in Europe and consider what additional steps could be taken to apply critical loads to the management of public resources in the US.

In addition to building on the continuing efforts of federal land managers, the Multi-Agency Critical Loads Workshop was intended to address the recommendations of the National Research Council (NRC) and the federal Clean Air Act Advisory Committee (CAAAC). In separate reports, the NRC and CAAC urged EPA to expand its ecosystem protection and ecological assessment capacity, including exploring issues such as the use of critical loads in the development of secondary National Ambient Air Quality Standards.

The NRC formed a Committee on Air Quality Management to examine the role of science and technology in the implementation of the Clean Air Act and to recommend ways in which the scientific and technical foundations for air quality management in the US can be enhanced. In their findings and recommendations to EPA, the NRC Committee pointed out the need for alternative air quality standards to protect ecosystems and recommended investigating the use of critical loads as a potential mechanism to address this need (NRC 2004). The recommendation to examine critical loads as a useful tool for protected ecosystems was echoed by CAAAC in their 2005 report to EPA (CAAAC 2005).

The NRC report specifically states: *The CAA currently directs the administrator to protect ecosystems from criteria pollutants through the promulgation and enforcement of ambient-concentration-based standards (that is, the secondary NAAQS). However, concentration-based standards are inappropriate for some resources at risk from air pollutants, including soils, groundwaters, surface waters, and coastal ecosystems. For such resources, a deposition-based standard would be more appropriate. One approach for establishing such a deposition-based standard is through the use of so-called "critical loads." …[T]his approach has been adopted to protect ecosystems from acid rain by the European Union with some success (National Research Council 2004).*

The heightened interest in critical loads generated by the activities of federal land managers and the recommendations of the NRC and CAAC prompted an effort to summarize and update what is known about critical loads methods, application, and research needs in the US. This was the purpose of this Multi-Agency Critical Loads Workshop focused on sulfur and nitrogen deposition. The workshop goals as stated by the steering committee were:

4. to facilitate a broad sharing of information regarding critical loads terminology and definitions along with technical/science projects among the agencies and stakeholders,
5. to understand the history and science behind the development of critical loads in Europe and the US in order to provide context and background for future use of critical loads model outputs and empirical data, and
6. to develop a draft broad federal strategy for planning, executing, and evaluating critical loads projects, including integrating critical load science and technical issues with consideration of critical load use in a policy or management framework.

THE CONCEPT AND HISTORY OF CRITICAL LOADS

A critical load is a quantitative estimate of the exposure to one or more pollutants below which significant harmful effects on specific sensitive elements of the environment do not occur according to present knowledge.

-- From the 1988 UN ECE Protocol Concerning the Control of Nitrogen Oxides or Their Transboundary Fluxes. Accepted by the US in July 1989.

Critical loads are based on the premise that the emission and deposition of atmospheric pollutants can be managed based on their ecological impacts. Critical loads have been most widely applied to sulfur and nitrogen pollution which cause ecosystem acidification, eutrophication, nitrogen saturation, and biotic community change (Porter et al. 2005).

Critical loads provide a science-based tool for managers and policymakers to evaluate the impact of potential new emissions sources in protected areas, to manage sensitive natural resources where air pollution and other disturbances occur, and to assess the progress made by federal air emissions reduction programs.

Critical loads were first developed and applied in Europe to address the impacts of acid deposition associated with sulfur dioxide (SO_2) and nitrogen oxides (NO_x) emissions. The United Nations Economic Commissions for Europe (UNECE), Convention on Long-Range Transboundary Air Pollution (LRTAP) was signed in 1979. Critical loads were adopted in 1988 as part of the protocol process to address the effects of air pollution on ecosystems, human health, and cultural resources.

In North America, the concept of critical loads was applied in the 1960s with the first Great Lakes Water Quality Agreement which set lake phosphorus loading limits to reduce eutrophication. The first critical load for air pollution was set by Canada in the 1980s when the Canadian government established a critical load for wet sulfate deposition as part of a US-Canada memorandum on transboundary air pollution. Although the US was a signatory to the memorandum, a critical load was not established in the US. In the 1980s, the US Forest Service applied the critical loads concept as a deposition threshold that provided a screening tool to protect air quality in Class I areas.

Over the past five years there has been renewed interest in critical loads in the US. Recent critical loads initiatives include the Conference of New England Governors and Eastern Canadian Premiers project to map forest sensitivity to sulfur and nitrogen deposition, the Federal Land Managers Air Quality Report which articulated a commitment to fostering the development of critical loads, a series of meetings known as the "Riverside Meetings" convened by the US Forest Service, and this Multi-Agency Critical Loads Workshop.

THE PROCESS OF DEVELOPING CRITICAL LOADS

The process of developing critical loads varies with specific management or policy objectives, the ecosystem or geographic area of interest, data availability, and the methods and models applied. In general, the critical loads process follows the 10 basic steps outlined below.

Once a critical load has been calculated, policymakers can determine whether to use this value for policy and management purposes or to develop a target load. "Target load" has been defined as "the level of exposure to one or more pollutants that results in an acceptable level of resource protection based on policy, economic, or temporal considerations" (Porter et al. 2005). The target load can be higher, lower, or equal to the critical load and may change over time.

Sample Steps for Determining Critical Loads

Modified from presentations by P. Ringold, D. Jeffries, C.T. Driscoll, and B.J. Cosby, 2006.

1. Determine the geographic area of interest:
    - Nation – the US
    - Region – the Northeastern or Western US
    - Area - Class I Areas, sensitive ecosystems
2. Define the ecosystem disturbance of concern:
    - Acidification
    - Eutrophication
    - Nitrogen saturation
3. Identify the mode of exposure (e.g., atmospheric concentration or deposition) and relevant pollutants:
    - SO_4, NO_3, NH_4, NO_x, SO_2
4. Select receptors that are subject to the disturbance:
    - Surface waters - northeastern lakes, alpine lakes
    - Forests - sugar maple/northern hardwood forests
    - Other - coastal sage scrub ecosystem, alpine meadows
5. Identify the biological indicators/resources of concern within the receptor area, such as:
    - Nutrient status - primary productivity
    - Organism - brook trout, sugar maple, species richness
    - Community structure - diatoms, non-native grasses
6. Define the chemical or biological criteria that control the response of the biological indicator to pollutant loading.
7. Determine the critical threshold for the chemical or biological variables at which damage to the biological indicator occurs.
8. Chose a timeframe for recovery, if the receptor is already damaged and if dynamic methods are available for calculating critical loads.
9. Use models or empirical methods to calculate the critical load of pollutants at which the chemical or biological variables reach the critical threshold. Determine the need for target loads.
10. Periodically update critical load estimates based on advances in knowledge.

Chapter 2

The Science and Application of Critical Loads

Summaries of Presentations Given on May 23-24, 2006

Environmental Science Perspectives on the Development and Meaning of Critical Loads

Session Chair: Rick Haeuber, PhD, US Environmental Protection Agency, Clean Air Markets Division

Speakers: James Galloway, PhD, Dept. of Environmental Sciences, University of Virginia

Myron Mitchell, PhD, SUNY-ESF

Greg Lawrence, PhD, US Geological Survey

SUMMARY

The emission and deposition of sulfur and nitrogen contribute to ecological impacts such as surface water and soil acidification, nitrogen saturation, eutrophication, and vegetation shifts in ecosystems throughout the US. While emissions of sulfur have declined in recent years, they remain high compared to natural background conditions. Scientists suggest that deposition of nitrogen may actually increase in the future in some regions in response to rising global emissions. Under these conditions atmospheric nitrogen deposition could account for a larger proportion of total reactive nitrogen inputs in North America.

Critical loads can be used to assess the impacts and manage the inputs of atmospheric pollutants such as sulfur and nitrogen. Importantly, sulfur and nitrogen have different biogeochemical cycles which control their response to changing emissions, and should guide the process of critical loads development.

Chemical indicators can be used to map critical loads and evaluate ecosystem responses to changing deposition. A matrix of indicators for terrestrial and aquatic ecosystems that are linked to biological responses and are not confounded by natural factors is particularly useful for developing critical loads.

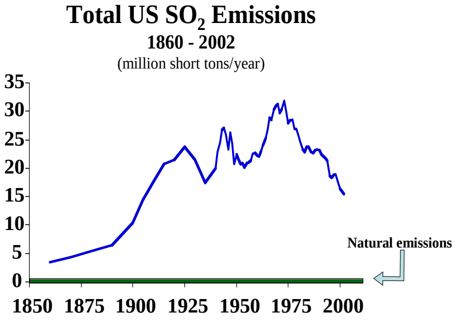
EMISSIONS AND DEPOSITION

Most gaseous sulfur emissions in the US and globally are anthropogenic in origin. Sulfur is released to the environment primarily by fossil fuel combustion which emits sulfur dioxide (SO_2) to the atmosphere. In the US, total SO_2 emissions declined from 32 million short tons in 1970, to 15 million short tons in 2002 but are still 10 times higher than natural background emissions (Figure 1). Reductions in SO_2 emissions have led to a decrease in sulfur deposition in the US, but surface water pH has not increased to the degree expected.

Both wet and dry deposition are important in estimating total sulfur loading, but major uncertainties in dry deposition still exist.

Figure 1: Total US SO_2 Emissions

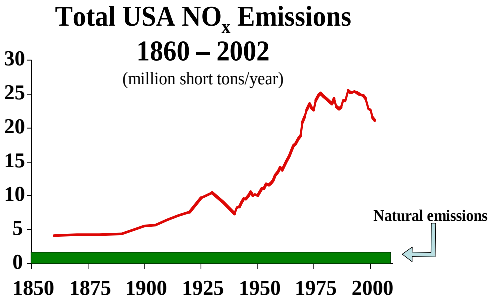
Source: Galloway, J. from EPA 2000 and 2002.



Nitrogen is released to the environment through many natural and anthropogenic processes that convert elemental nitrogen to reactive nitrogen forms. The dominant nitrogen inputs in 1860 consisted of small scale agriculture and natural biological nitrogen fixation. Today, the rate of conversion from elemental to reactive nitrogen is much higher than background levels due to the vast growth in food, feed, and energy production in the US and worldwide. These changes at global and national scales generate increased nitrogen fertilizer production and use, enhanced biological nitrogen fixation in agricultural crops, greater nitrogen imports in food, and higher emissions of nitrogen oxides from fossil fuel combustion. The result is the release of substantial nitrogen oxide and ammonia emissions to the atmosphere and direct reactive nitrogen inputs to the landscape from diverse, and often dispersed, sources.

Figure 2: Total US NO_x Emissions

Source: Galloway, J. from EPA 2000 and 2002.



Atmospheric nitrogen emissions and deposition currently constitute 15 to 20 percent of total annual reactive nitrogen inputs in North America. Scientists predict that nitrogen deposition in North America will increase substantially between 1993 and 2050 (Galloway et al. 2004), and that the proportion contributed via the atmosphere may reach 50 percent or more. For these reasons, critical loads are an important tool for managing and assessing atmospheric nitrogen pollution.

Approximately two-thirds of the nitrogen emissions to the atmosphere in North America occur as nitrogen oxides (NO_x), with the other third emitted as ammonia. Total nitrogen oxide emissions in the US dropped from a peak of 25 million short tons in 1993, to 21 million short tons in 2002 (Figure 2). This value is still 10 times greater than the background emissions. Wet nitrate deposition in the eastern US shows a commensurate decrease from 1993 to 2002, but wet nitrate concentrations at many sites in the western US are increasing.

Ammonia emissions in the US are not well characterized. The limited available data show a slight decrease from 5 million short tons in 1994 to 4 million short tons in 2002. However, wet ammonium deposition increased in some parts of the US during the same time period. Like sulfur, large uncertainties exist in estimates of dry nitrogen deposition; and measurements of organic nitrogen and ammonia are currently lacking.

BIOGEOCHEMICAL CYCLING

The differences and similarities in the cycling of nitrogen and sulfur affect the calculation of critical loads. There is generally a strong relationship between atmospheric deposition of sulfur and sulfate lost through discharge. This relationship is strongest under high sulfur loadings, but weakens with decreased loading due to the increasing importance of mineral weathering and organic sulfur mineralization. Sulfate adsorption relationships have a major influence on spatial patterns of sulfur retention and loss both within and among sites.

The relationship between atmospheric deposition of nitrogen and nitrate loss through discharge is more variable and generally does not occur below a certain threshold of nitrogen deposition. The spatial and temporal patterns of nitrate loss are affected by land use history (e.g., harvesting and fire), the form of nitrogen atmospheric inputs (e.g., ammonium versus nitrate), and vegetation type (due to the influences on nitrogen mineralization and nitrification rates). Nitrate dynamics are linked to other factors including soil freezing (e.g., disrupting fine root uptake) and carbon dioxide availability. Nitrate leaching from soil is also highly sensitive to climatic factors including overall temperature effects and snow cover.

Research has shown that both nitrogen and sulfur undergo substantial biological cycling before being released into drainage waters and that these processes become especially important at lower nitrogen and sulfur loadings. Biotic regulation is generally more important for nitrogen than for sulfur and illustrates the need to consider the impact of tree species, soil organic matter dynamics, nutrient demand, and other biotic factors when assessing the cycling and impacts of nitrogen loading in ecosystems.

ECOSYSTEM EFFECTS

Once in the environment, sulfur and nitrogen have wide-ranging effects on the atmosphere, terrestrial ecosystems, and aquatic ecosystems (Figures 3 and 4). Scientists expect that as SO_2 emissions decline, sulfur-related impacts on the atmosphere will decrease rapidly due in part to the relatively conservation cycling of sulfur. If emissions reductions are adequate, terrestrial and aquatic effects will also likely be ameliorated over time, although recovery may take decades or centuries where sulfur and nitrogen have accumulated to high levels in soils.

The nitrogen cascade describes the process by which a single nitrogen atom can contribute to a series of atmospheric, terrestrial, and aquatic effects (Galloway et al. 2003). The nitrogen cascade suggests that critical loads may be more complicated for nitrogen, since the impacts at various loading rates could be quite different for different ecosystems (e.g., forested uplands versus coastal estuaries).

Figure 3: The Sulfur Cascade
Source: Galloway 2003

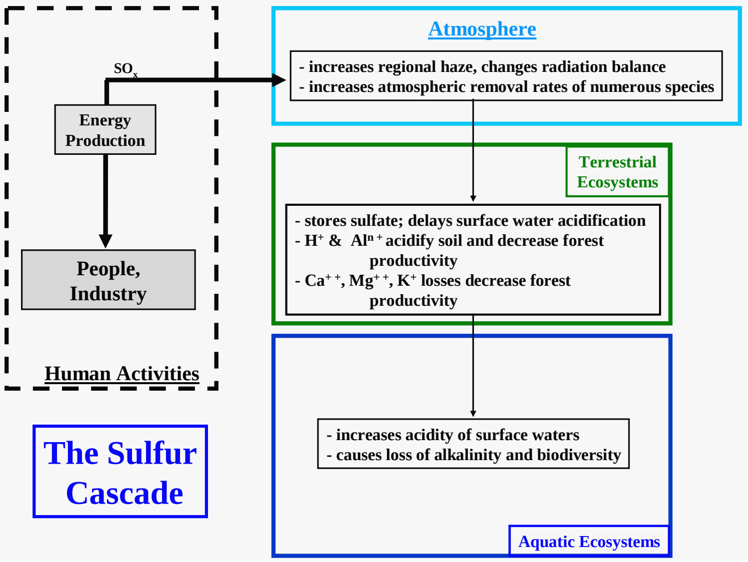
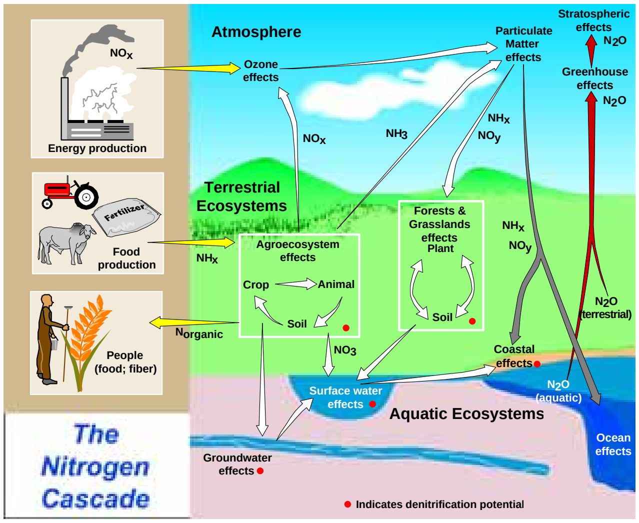


Figure 4: The Nitrogen Cascade
Source: Galloway et al. 2003



ENVIRONMENTAL INDICATORS

Effects of atmospheric deposition of sulfur and nitrogen on terrestrial and aquatic ecosystems are generally assessed through measurements of environmental change. Environmental indicators can be used to describe this response. Indicators can be defined for specific geographic areas (e.g., eastern and western US) and for both terrestrial and aquatic ecosystems (Table 1).

Discussions are occurring within the scientific community regarding which environmental indicators are most appropriate for critical loads development. In the eastern US, where the primary concern for surface waters is acidification, pH and ANC_G (acid-neutralizing capacity determined by Gran titration) are the most commonly used chemical indicators for critical loads based on acidification. In the western US, where excess nitrogen loading is typically the primary concern, the most commonly used chemical indicator is nitrate concentration in surface waters.

The selection of chemical indicators should account for the possible complication of natural factors. For example, pH and ANC_G can be substantially influenced by the presence of organic acids that are naturally derived from decaying plant matter. To assess acidification effects, it may be more useful to focus on the mobilization of inorganic aluminum (Al), a fundamental problem in both terrestrial and aquatic acidification.

DEFINITIONS

pH = measure of acidity

ANC = acid-neutralizing capacity

Ca/Al = calcium to aluminum ratio

Table 1: Critical Loads Receptors, Indicators, and Thresholds

Modified from presentations by T. Sullivan, G. Lawrence, C.T. Driscoll and B.J. Cosby, 2006

Disturbance	**Receptor type**	**Pollutant**	**Possible biological indicators**	**Examples of critical indicator responses**	**Possible chemical variables**	**Examples of chemical thresholds**
Acidification						
	Terrestrial	SO_4, NO_3, NH_4	Sugar maple, Norway spruce, Red spruce	Crown condition, mortality, seedling death	Soil % base saturation, soil Ca/Al ratio, exchangeable Mg, exchangeable Al, foliar nutrients	Soil base saturation = 20% Soil Ca/Al = 1.0
	Aquatic	SO_4, NO_3, NH_4	fish,, zooplankton, invertebrates	Presence/absence, species richness, species loss	Surface water ANC_G, pH, inorganic Al	ANC = 0-100 µeq/L
Nitrogen saturation and eutrophication						
	Terrestrial	NO_3, NH_4	Native grasses, native shrubs	Relative species abundance, total biomass	Soil C/N, extractable soil N, nitrification rates	Soil C/N = 20
	Aquatic	NO_3, NH_4	Diatom assemblages	Species composition	Surface water NO_3, chlorophyll a, N:P	Lake NO_3 = 10 µmol/L

Using Steady-State and Dynamic Models to Calculate Critical Loads

Session Chair: Rick Haeuber, PhD, US Environmental Protection Agency, Clean Air Markets Division

INTRODUCTION

Critical loads are typically calculated for specific sites (e.g., an alpine lake) based on empirical observations or dynamic models, or they may be estimated for large regions (e.g., the Northeast) using simple mass balance methods or empirical observations from probability-based surveys. Methods are being developed to link information from site-specific dynamic models with regional data to expand the geographic application of these detailed process-based models.

Site-specific calculations can be developed using empirical observations or dynamic models that measure or predict ecosystem change over time. These methods generate a set of critical load numbers that represents a specific ecosystem. Dynamic models are particularly effective because they incorporate temporal considerations and representing key ecosystem processes that account for delays in the impact or recovery from changing pollution loading. Where an ecosystem is already impacted by sulfur and/or nitrogen loading, dynamic models can be used to establish target loads based on a specific recovery timeline (e.g., 10 years, 20 years, 50 years). In general, most scientists maintain that dynamic models more completely represent ecosystem conditions and processes, but acknowledge that the data requirements of dynamic models make them largely site-specific at present.

Simple mass balance models can be used to overcome the data requirements of dynamic models and to estimate critical loads for larger regions. Simple mass balance models usually produce critical load maps that show a range of critical load values across the landscape. Critical loads maps are useful for applying spatially explicit data for which time series information is not available, and for showing differences in relative sensitivity to acidic and/or nitrogen inputs across the landscape. Simple mass balance models are also useful for mapping existing or projected future critical load exceedences over a large area. This approach allows policymakers to compare the spatial effect of various target load options, however the projections assume steady-state conditions and do not account for time-dependent processes that may influence the results.

The following case studies provide an overview of a range of tools for calculating critical loads based on several ecosystem types, indicators, and methods.

Estimating Critical Nitrogen and Sulfur Loads for Forest Soil Acidity Across the Lower 48 US States Using a Simple Mass Balance Equation

Model name:	Simple Mass Balance (SMB) Model
Model type:	Steady-state
Investigators:	S. McNulty (speaker), E. Cohen, H. Li, J. Moore Myers
Where applied:	continental US
Ecosystem type:	terrestrial forest soils
Indicators:	terrestrial indicators of acidity (e.g., ANC leaching, soil base cation:Al)
Threshold:	soil base cation:Al = 1 for conifers and 10 for deciduous forests
Timeframe:	NA
Strength:	provides a national overview of relative differences in soil sensitivity to acidic deposition based on present knowledge
Limitation:	limited to wet deposition, does not account for denitrification, most appropriate for eastern US ecosystems where acidification is a major concern, coarse scale, may overestimate critical loads for sensitive sites

The Simple Mass Balance critical loads model developed by S. McNulty and colleagues uses regional and national databases to estimate critical loads for acidity in forest soils over the entire continental US under steady state conditions. In its current configuration, the model is not intended for generating site-specific critical loads for regulatory and management purposes. Rather, it is being applied to identify areas needing more detailed study, to compare the relative differences in critical loads estimates and exceedences across large areas, and to evaluate model sensitivity to a range of input parameters.

This particular Simple Mass Balance model uses national data for wet deposition of major anions and cations, climate, forest cover, and basic soil characteristics. The model also estimates ecosystem processes such as base cation weathering, nutrient uptake and leaching of acid neutralizing capacity. The resulting values are combined using the following equation to estimate critical loads for forest soil acidity.

<u>Simple Mass Balance Equation for Acidic Deposition</u>

$$CL(S+N) = BC_{dep} - Cl_{dep} + BC_w - BC_u + N_i + N_u + N_{de} - ANC_{le(crit)}$$

BC_{dep} = base cation deposition
N_i = nitrogen immobilization
Cl_{dep} = chloride deposition
N_u = nitrogen uptake
BC_w = base cation weathering
N_{de} = nitrogen denitrification
BC_u = base cation uptake
$ANC_{le(crit)}$ = acid neutralizing capacity leaching

The equations for estimating base cation weathering and the critical acid neutralizing capacity are based on Werner and Spranger 1996. The weathering equation uses the soil type-texture approximation method. The equation for determining the leaching of ANC is based on a base cation to aluminum ratio of 1 for conifers and 10 for deciduous species. The gibbsite constant used in this model is variable and is a function of soil organic matter content.

Measured data and calculated values are combined in the mass balance equation to produce a map of estimated critical loads of acidity for forest soils in the continental US, as well as a map of exceedence values. Initial model outputs suggest that 7 percent of US forests exceed the estimated critical loads for acidity in forest soils by more than 250 eq/ha/yr.

Sensitivity and uncertainty analyses have been conducted for this Simple Mass Balance model. Since most of the factors in the equation are linear, sensitivity analysis was only needed for three factors: average annual air temperature, Gibbsite equilibrium constant, and soil BC/Al ratio. The order of sensitivity ranking of the components is: BC_u, N_u, ANC, BC_w, N_i, BC_{dep}, and Cl_{dep}. A four-part uncertainty analysis suggests that the factors BC weathering class, BC/Al ratio and soil depth had the largest uncertainty; and the components BC weathering and ANC had the largest uncertainty.

MAGIC Model Calculations of Critical Loads of Acidic Deposition for the Protection of US Surface Waters

Model name: MAGIC
Model type: dynamic
Investigators: T. Sullivan (speaker), J. Cosby
Where applied: approx. 100 streams and 10 lakes in the Southeast and western US
Ecosystem type: freshwater aquatic ecosystems
Indicators: aquatic indicators of acidity (e.g., ANC, zooplankton)
Thresholds: various including ANC = 0, 20 and 50 µeq/L
Timeframe: various including 2020, 2040, 2100
Strength: integrates key ecosystem processes, accounts for change over time
Limitation: model is data intensive, results are site-specific, focused on acidification, does not explicitly simulate nitrogen processes

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The MAGIC model (Model of Acidification of Groundwater in Catchments) is a dynamic model of watershed acid-base chemistry that calculates critical loads of acidic deposition of sulfur and nitrogen for lakes and streams in the US. MAGIC critical load calculations have been applied to multiple chemical endpoints using several target values and evaluation years. MAGIC yields a matrix of calculated critical loads for each aquatic ecosystem, and the results are provided to policymakers and managers for decision-making.

MAGIC has been applied to more than 100 lakes in the US. As demonstrated by the results for two sites in Colorado, the chemical threshold and timeframe chosen have a substantial impact on the critical load calculations (Table 2). MAGIC has also been used to show the difference in critical loads for sulfur in systems with different bedrock types in Shenandoah National Park. The results of this particular analysis underscore the significant influence soil conditions have on determining critical loads.

Additional MAGIC results for Monongahela National Forest illustrate the need to establish target loads for impaired systems where recovery cannot be achieved. Here, the model predicts that even if sulfur deposition were eliminated, an ANC of 50 µeq/L cannot be reached in 85 percent of the study streams by 2040. Under these circumstances a target load for sulfur deposition can serve as an interim deposition goal.

Table 2: MAGIC Critical Loads Results for Loch Vale and Andrews Creek, Colorado
Source: Sullivan et al. 2005

Simulated critical load of S or N required to reduce the ANC of The Loch and Andrews Creek to 0, 20, or 50 µeq/L by the year 2046.

	Critical Load (kg/ha/yr of S or N)					
	ANC Limit=0 µeq/L		ANC Limit=20 µeq/L		ANC Limit=50 µeq/L	
Deposition	The Loch	Andrews Creek	The Loch	Andrews Creek	The Loch	Andrews Creek
Nitrogen	20.6	12.2	14.7	7.8	5.8	NR*
Sulfur	11.1	8.1	7.8	4.6	2.8	NR*

NR - Ecological endpoint (ANC =50 µeq/L) could not be achieved (no recovery) by 2046 even if deposition of N or S was reduced to zero.

Calculating Critical Loads of Acidic Deposition in the Adirondack Region of New York

Model name:	PnET-BGC (and the Very Simple Dynamic Model - VSD)
Model type:	dynamic
Investigators:	C. Driscoll (speaker), W. Wu, J. Zhai, R. Warby, C. Johnson, B. MacNeil, K. Roy, M. Mitchell, T. Sullivan, J. Cosby, L. Pardo, N. Duarte
Where applied:	44 EMAP lakes in the Adirondacks of New York
Ecosystem type:	forested watershed ecosystems
Indicators:	aquatic and terrestrial indicators of acidity – ANC, pH, fish species richness, percent soil base saturation
Thresholds:	median concentrations for pre-industrial conditions
Timeframe:	2100
Strength:	regionalizes tested dynamic model, integrates aquatic and terrestrial indicators, accounts for change over time, can be used for hindcasting historical conditions
Limitation:	the model is data intensive, results are site-specific

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The dynamic model PnET-BGC has been applied to 44 EMAP (USEPA Environmental Monitoring and Assessment Program) lake-watersheds in the Adirondacks of New York. PnET-BGC was used to predict the acid-base chemistry of soils and surface waters, and to assess the fisheries status during pre-industrial conditions (~1850) and under three future acidic deposition scenarios. Efforts are underway to use PnET-BGC to develop critical loads calculations and to compare the results with estimates derived from the Very Simple Dynamic (VSD) model.

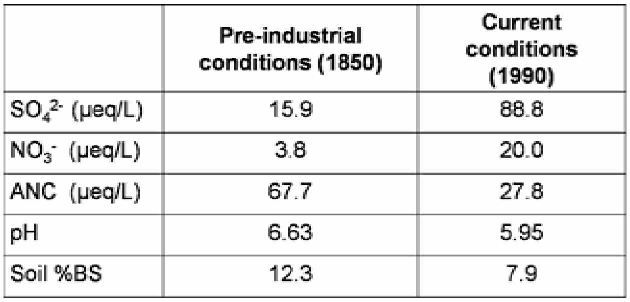
Model hindcasts using PnET-BGC indicate that acidic deposition has greatly altered surface waters and soils in the Adirondacks over the past 150 years (Table 3)(Zhai et al. 2006 and Sullivan et al. 2006). The limited available soil data show that a marked loss of exchangeable calcium has occurred in parallel with a marked increase in exchangeable aluminum; and that some ecosystems are continuing to acidify despite decreases in sulfur deposition.

The model was applied to three future emissions scenarios: base case, moderate reductions, and aggressive reductions. A case study for Indian Lake in the Adirondacks illustrates that the larger the reduction in sulfate deposition, the greater the decreases in sulfur and base cations in stream water, and the greater the recovery in pH and ANC. Within the full population of lake-watersheds, some lakes showed decreasing ANC and pH values from 1990 to 2050 even under the moderate and aggressive reduction scenarios. By 2100, however, nearly all lakes experience increasing ANC and pH (Table 4)(Zhai et al. 2006 and Sullivan et al. 2006).

Soil base saturation increased very slowly over the modeled time period, compared to changes in surface water chemistry. For 95 percent of the lake-watersheds studied, soil bass saturation remained below 20 percent in 2100 under all emissions scenarios.

Table 3: PnET-BGC Hindcast Mean Results for 44 EMEP Lakes, Adirondacks, NY

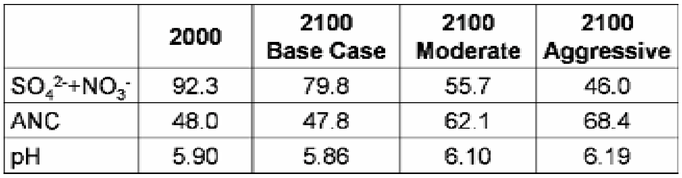
Source: Zhai et al. 2006 and Sullivan et al. 2006



	Pre-industrial conditions (1850)	Current conditions (1990)
SO_4^{2-} (µeq/L)	15.9	88.8
NO_3^- (µeq/L)	3.8	20.0
ANC (µeq/L)	67.7	27.8
pH	6.63	5.95
Soil %BS	12.3	7.9

Table 4: PnET-BGC Emissions Scenario Mean Results for 44 EMEP Lakes, Adirondacks, NY

Source: Zhai et al. 2006 and Sullivan et al. 2006



	2000	2100 Base Case	2100 Moderate	2100 Aggressive
SO_4^{2-}+NO_3^-	92.3	79.8	55.7	46.0
ANC	48.0	47.8	62.1	68.4
pH	5.90	5.86	6.10	6.19

Simulating Deposition Effects to Ecosystems with DayCent-Chem

Model name:	DayCent-Chem
Model type:	dynamic
Investigators:	J. Baron (speaker), M. Hartman, D. Ojima
Where applied:	Andrews Creek, Rocky Mountain National Park (5 other sites across US underway)
Ecosystem type:	diverse watershed ecosystems
Indicators:	aquatic and terrestrial indicators of acidity – ANC, soil percent base saturation
Thresholds:	ANC = 0, 20, and 50 μeq/L
Timeframe:	2048
Strength:	incorporates biology and ecological processes, uses a daily time step, can be used for hindcasting historical conditions
Limitation:	data intensive, does not perform as well in dry conditions

DayCent-Chem is a dynamic model that combines the daily version of the ecosystem Century model with the geochemical equilibrium model, PHREEQC (Figure 5). DayCent-Chem was initially designed for and tested in the alpine/subalpine Loch Vale Watershed in Colorado. It has recently been parameterized and run at six other sites across the US. Initial results show that the model outputs compared well with measured discharge, net primary productivity, and nitrogen mineralization. Stream chemistry model outputs showed the best correspondence for sites with detailed input data for wet and dry atmospheric deposition, soil properties, and mineral weathering. The model does not perform as well at very dry sites or during periods of low discharge.

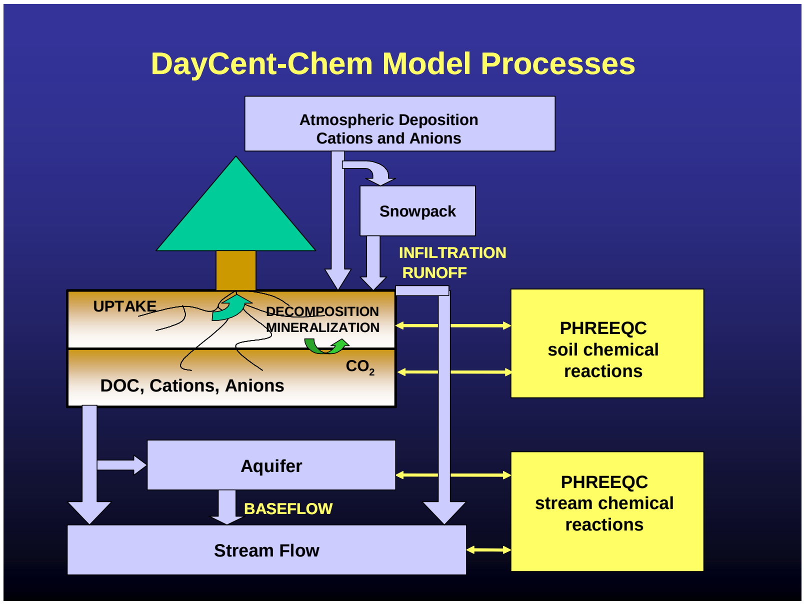
The DayCent-Chem model results indicate that ANC and soil base saturation have decreased at Andrews Creek by 26 μeq/L and 8 percent, respectively since 1900. Forecasts of increasing nitrogen deposition scenarios suggest that the onset of chronic acidification of Andrews Creek is likely to occur when deposition reaches 7.0 to 7.5 kg N/ha/yr.

DayCent-Chem makes several enhancements to critical loads models by incorporating creative ecological parameters such as microbial indicators, changes in carbon:nitrogen, and percent nitrogen in soils and foliage across many types of ecosystems.

In the next study phase, the DayCent-Chem model will be used to forecast ecosystem and stream chemistry responses to changing nitrogen and sulfur deposition using future scenarios including current emissions and deposition, deposition resulting from the Clean Air Interstate Rule, and zero emissions. These scenarios will be evaluated under current climate conditions, and with a doubling of carbon dioxide.

Figure 5: DayCent-Chem Model Schematic

Source: J. Baron presentation 2006



Assessing Forest Sensitivity to Acid Deposition in Northeastern North America

Model name:	Forest Sensitivity Steady-State Mass Balance Critical Load Model
Model type:	steady-state mass balance
Investigators:	E.K. Miller (speaker), R.D. Ziegler, P. Ryan, and the NEG-ECP Forest Mapping Working Group
Where applied:	the Northeastern US
Ecosystem type:	diverse watershed ecosystems
Indicators:	nutrient base cations (Ca, Mg, K)
Thresholds:	sustainable base cation supply (see equation)
Timeframe:	NA
Strength:	accounts for interaction between acid deposition and timber harvesting, incorporates impacts of elevation at regional scale
Limitation:	input values depend on submodels, more ground-truthing needed

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A Forest Sensitivity Steady-State Model for New England was developed with the New England Governors and Eastern Canadian Premiers. The goal of the model is to estimate the extent, location and severity of risk to the forest resource posed by sulfur and nitrogen deposition. The model uses measured data and modeled values to estimate the critical load for sulfur and nitrogen deposition that will support a sustainable supply of nutrient base cations.

Sustainable Supply of Base Cations

$BC_{we} + BC_{ad} >= BC_{rem} + BC_{le}$

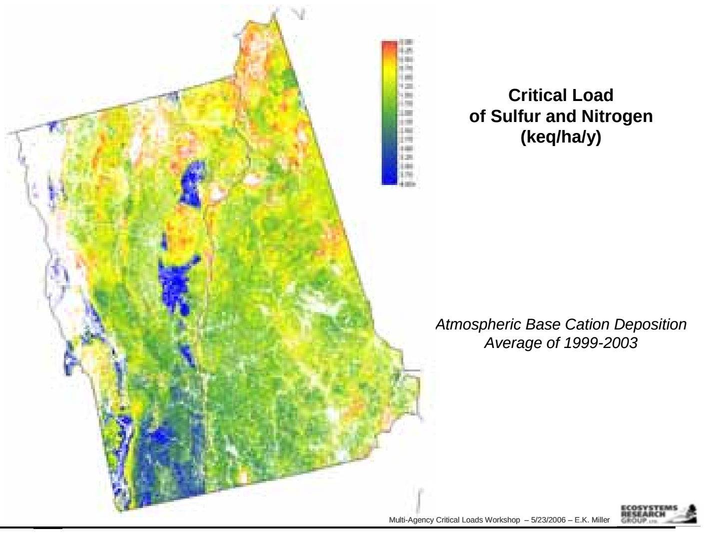
BC_{we} = base cation weathering
BC_{rem} = base cation removal
BC_{ad} = base cation atmospheric deposition
BC_{le} = base cation leaching

In the equation for the sustainable supply of base cations, atmospheric deposition of sulfur, nitrogen, and nutrient base cations for 1999 to 2003 is based on measured data and a high-resolution deposition model. Nutrient weathering rates are estimated using soil mineralogy (e.g., percent Ca-plagioclase and percent Hornblende). The model produces a map of critical loads (Figure 6), and the "deposition index" which shows the difference between cation supply and cation depletion under steady-state conditions with current levels of atmospheric deposition.

The results for each state indicate that 4 to 52 percent of forestlands in New England states are losing base cations at a faster rate than they are supplied, and are therefore deemed sensitive. Connecticut has the lowest percentage of sensitive forests, and Rhode Island has the highest. The most sensitive forest type in Vermont is sugar maple/northern hardwood (27% sensitive), followed by northern hardwood forests (24% sensitive).

The forest sensitivity model estimates that the sensitive forest area has declined in New Hampshire from 24 percent in 1984-1988, to 18 percent in 1999-2003; and from 37 to 30 to percent in Vermont over the same time periods. An additional 50 percent reduction in total sulfur and nitrogen deposition in Vermont is projected to further reduce the sensitive forest area in that state to 12.7 percent. The forest sensitivity model was also used to compare the impact of acidic deposition and forest harvesting on base cation loss in New Hampshire. The results suggest that for 1999-2003, leaching losses associated with acidic deposition exceeded removals from harvesting for all forest types by an average factor of 3.4.

Figure 6: Critical Loads for Forest Ecosystems Based on Sustainable Base Cation Supply



Critical Loads for Nutrient N: Calculated and Empirical

Model name:	Simple Mass Balance for Nutrient Nitrogen
Model type:	steady-state mass balance & empirical observations
Investigators:	L. Pardo
Where applied:	the Northeastern US, including Direct Delayed Response Project (DDRP) sites
Ecosystem type:	diverse watershed ecosystems
Indicators:	terrestrial and aquatic indicators of acidity and excess N such as stream water nitrate, crown dieback
Thresholds:	stream water nitrate = 0.2 mg N/L, >15 percent crown dieback
Timeframe:	NA
Strength:	accounts for interaction between acid deposition and timber harvesting, project includes a review of previous studies
Limitation:	currently limited to nitrogen

The Simple Mass Balance critical loads project for nutrient N by L. Pardo and colleagues uses calculated and empirical methods to estimate critical loads for nutrient-N and for acidity in the Northeastern US. The calculation of critical loads for nutrient N is based on the equation below.

Critical Load for Nutrient N

CL N nutrient = N soil accum + N biomass rem + N denit + N leaching

Assumptions for Calculation of Critical Load for Nutrient – N

Denitrification	0 N kg/ha/yr
N accumulation	1 N kg/ha/yr
Acceptable stream nitrate	0.2 mg N/L*
N uptake	Calculated per site**

*Posch et al. 1993.

**Based on the USDA tree chemistry database and information on annual biomass extraction rates and harvestable biomass.

The Simple Mass Balance approach for nutrient N has been applied to 2536 sites in the Northeast from the New England Governors and Eastern Canadian Premiers Forest Mapping Project and the Direct Delayed Response Project sites. The preliminary critical loads estimates for nitrogen range across the region from 2 to 10 N kg/ha/yr (assuming an N immobilization rate of 1 kg/ha/yr). Deposition at 90 percent of the sites exceeds the critical load. If the N immobilization rate is assumed to be 5 kg N/ha/yr, the critical load shifts to 5 to 14 kg N/ha/yr with deposition at only 40 percent of sites above the critical load. These results demonstrate the significant effect of the initial assumptions made in calculating critical loads.

The exceedence values for the study sites were compared with stream water nitrate concentrations and crown dieback in forests to evaluate the relationship between exceedences and aquatic and terrestrial effects. The initial results show no trend between exceedence values and nitrate in stream water. However, where data are available, the percentage of trees with crown dieback greater than 50 percent increases in areas where the critical load exceedence values are greater than approximately 250 eq/ha/yr.

In addition to the calculated critical loads approach described here, this project will include a review of empirical studies for nitrogen effects that could be used to estimate critical loads for specific ecosystems or regions. A synthesis of similar studies in Europe produced a comprehensive assessment to support critical load estimates.

Using Empirical Observations of Ecosystem Change to Estimate Critical Loads

Session Chair: Tamara Blett, National Park Service

INTRODUCTION

Empirical methods for developing critical loads rely on historical data or results from pollution-addition experiments to identify the loading that produces a measurable ecosystem change. Empirical methods are generally applied to specific sites or a group of sites. The indicators chosen to track change over time can include both chemical and biological indicators.

Critical loads are often determined by identifying the loading rate that corresponds to marked change in the environmental indicators. As described below, these methods have been used to understand ecological responses to nitrogen deposition at several sites throughout the western US.

Empirical Determination of Nitrogen Critical Loads for Alpine Vegetation

Approach:	Empirical estimates of N critical loads
Method:	coupled observations and N-addition experiments
Investigators:	B. Bowman (speaker), J. Gartner, K. Holland, M. Wiedermann
Where:	Front Range of the Colorado Rocky Mountains
Ecosystem type:	alpine dry meadow
Indicators:	ecological = plant species composition, plant community change; chemical = nitrate leaching
Thresholds:	detectable change in plants, and point of inflection for soil nitrate
Timeframe:	NA
Strength:	based on 8 years of measured data, compares biotic and chemical response
Limitation:	limited to specific research sites

Empirical observations of biological and chemical change were used to estimate critical loads for nitrogen in the alpine dry meadows of the Colorado Front Range. These ecosystems have chronically low rates of nitrogen cycling and tend to exhibit a low capacity to sequester anthropogenic nitrogen inputs. Community-level responses to nitrogen additions are often marked by changes in plant species composition, transitioning from slow-growing insensitive species to fast-growing sensitive species.

A nitrogen-addition experiment was conducted with 20, 40, or 60 kg N/ha/yr and monitored for 8 years along with an ambient control site that receives 6 kg N/ha/yr total deposition. Change in plant species composition associated with the treatments occurred within 3 years of the initiation of the experiment, and were significant at all levels of nitrogen addition (Figure 7). Using individual species abundance changes and ordination scores, the critical loads for total nitrogen deposition were estimated for 1) change in individual species = 4 kg N/ha/yr and 2) for overall community change = 10 kg N/ha/yr (Figure 8)(Bowman et al. 2006). In contrast, increases in nitrate leaching, soil solution inorganic nitrate, and net nitrification were detectable at levels above 20 kg N/ha/yr (Bowman et al. 2006). The results of the nitrogen-addition experiment indicate that changes in vegetation composition may be detectable at lower nitrogen deposition rates than traditionally used soil indicators of ecosystem responses to nitrogen deposition, and that changes in species composition are probably ongoing in alpine dry meadows of the Front Range of the Colorado Rocky Mountains.

Figure 7:
Source: Bowman et al. 2006

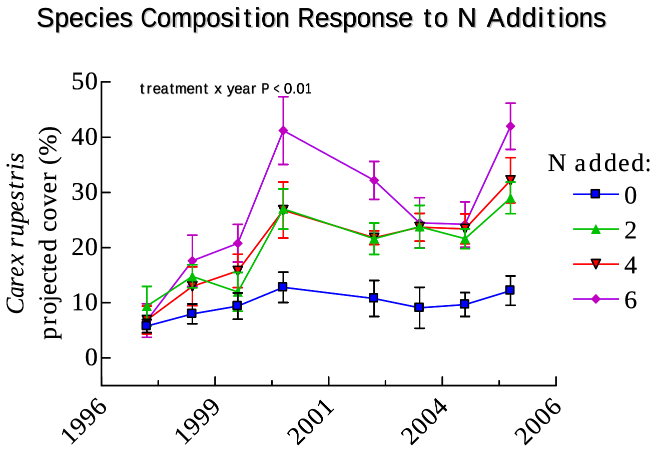
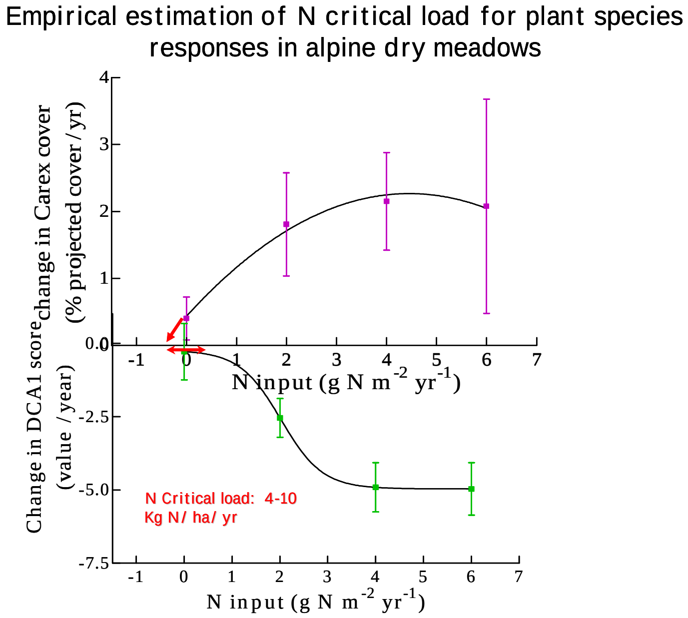


Figure 8:
Source: Bowman et al. 2006



Critical Loads of Nitrogen Deposition for Southern California Desert and Coastal Sage Scrub: An Empirical Approach

Approach: Empirical estimates of N critical loads
Method: coupled observations and N-addition experiment
Investigators: E. Allen
Where: Southern California
Ecosystem type: desert and coastal sage scrub
Indicators: native species diversity, grass biomass
Thresholds: exotic grass biomass/fire threshold = 0.5 to 1.0 T/ha
Timeframe: NA
Strength: based on measured data, incorporates biological change
Limitation: application is currently limited to desert and coastal sage scrub communities

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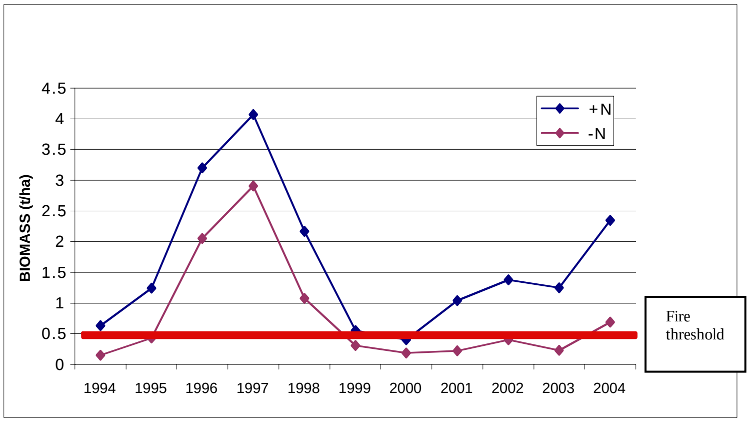
Models to predict critical loads are often based on changes in soil chemistry. However, soil chemistry changes (other than elevated soil nitrogen) are small to non-existent across nitrogen deposition gradients in southern California deserts and shrublands. Instead, as extractable soil nitrogen increases, these ecosystems experience increases in exotic annual species, increased fire frequency, and conversion of native vegetation to exotic annual grassland. These changes can be used to establish nitrogen critical loads.

To test the impacts of N deposition empirically, N-addition experiments were conducted along existing nitrogen deposition gradients in coastal sage scrub and desert ecosystems. The coastal sage scrub vegetation was fertilized with 60 kg N/ha/yr beginning in 1994. The desert vegetation was fertilized with 5 and 30 kg N/ha/yr beginning in 2002.

The results from these experiments show that, in general, the desert ecosystem responded faster and at lower levels of nitrogen fertilization than the coastal sage scrub ecosystem. Exotic annual grasses increased in the desert after three years of fertilization with 5 kg N/ha/yr. In the coastal sage scrub community, exotic grasses increased after 9 years of fertilization with 60 kg N/ha/yr. Decreases in the diversity of native plants paralleled increases in exotic grass biomass. In the desert ecosystem, native forb cover decreased after three years of fertilization with 5 kg N/ha/yr, whereas native forb cover decreased after 11 years of fertilization in coastal sage scrub ecosystems (Figure 9). The difference in responses between these two ecosystem types may be related to the responsiveness to nitrogen of native vs. exotic plant species in desert and coastal sage scrub, as well as the degree to which soil nitrogen limits plant growth in the two vegetation types.

The critical load of nitrogen for desert and coastal sage scrub ecosystems can be determined by the nitrogen deposition levels that promote elevated grass biomass, losses in native species diversity, and fire. Elevated exotic grass biomass above a threshold value of 0.5 to 1.0 T/ha has been shown to increases fire frequency. For deserts, the grass/fire-based nitrogen critical load may be as low as 5 kg N/ha/yr because nitrogen accumulates over time in dry soils, while for coastal sage scrub it may be closer to 10-15 kg N/ha/yr.

Figure 9: Exotic Grass Biomass in a Coastal Sage Scrub Ecosystem
Source: Allen, E. 2004 and unpublished data



Diatom Shifts in Alpine Lakes of the Southern and Central Rocky Mountains

Approach:	empirical estimates of N critical loads
Method:	analysis of lake sediments
Investigators:	J.E. Saros (speaker), A.P. Wolfe, S.J. Interlandi, T. Blett, J. Baron, C. Williamson, L. Graumlick, J. Stone
Where:	western US
Ecosystem type:	alpine lakes
Indicators:	diatom assemblages
Thresholds:	detectable change
Timeframe:	NA
Strength:	based on historic records of change that capture pre-industrial conditions, regional scope
Limitation:	link between diatom changes and biological impacts needs further study

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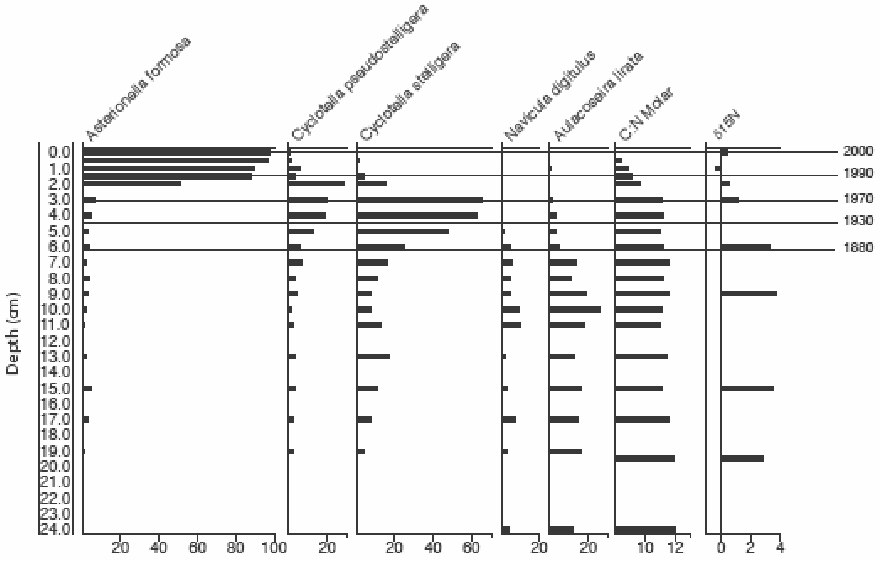
Changes in diatom community structure are frequently the first indication of ecological perturbations to lakes. Alpine lakes may be more sensitive to nitrogen deposition than temperate lakes since alpine lakes have low buffering capacities and the growth of algae in these lakes is often limited by nitrogen. A common shift in diatom assemblages has occurred in alpine lakes of the western US, with *Asterionella formosa* Hassall and *Fragilaria crotonensis* Kitton replacing typical alpine diatom taxa. The timing of this shift varies, with changes beginning in the 1950s in the southern Rocky Mountains and in the 1970s or later in the central Rocky Mountains (Figure 10).

In order to understand the basis of historic diatom community shifts, the distribution patterns and resource requirements of these taxa were explored in alpine lakes of the central Rocky Mountains. Nutrient enrichment experiments were conducted along with batch culture experiments in which the nitrogen, phosphorus, and silica growth kinetic parameters were measured. In addition, the distribution of diatom taxa in a suite of lakes was explored in relation to a variety of physicochemical parameters, which included dissolved and particulate nutrient concentrations as well as seston nutrient ratios. These results suggest that *Asterionella* and *Fragilaria* are excellent phosphorus competitors that become abundant under higher nitrogen loading. In conjunction with nitrogen isotope data from the sediment cores, these results indicate that enhanced atmospheric nitrogen deposition is driving these changes in diatom community structure. Current research is focused on establishing the timing of these diatom shifts in sediment records across several national parks, and to use this information to estimate nitrogen critical loads. Recently, J. Baron used existing diatom records to test the DayCent-Chem model and determined a critical load of 1.5 kg N/ha/yr. Research will expand upon this application by combining existing data with additional records from Sequoia, Glacier and Northern Cascades National Parks to develop a critical nitrogen load model for alpine lakes in the western US.

Figure 10: Diatom Assemblage Sediment Patterns Emerald Lake, Wyoming

Source: Saros et al. 2003



International Experiences with Critical Loads Implementation

Session Chair: Doug Burns, US Geological Survey

CRITICAL LOADS IN EUROPEAN AIR POLLUTION ABATEMENT STRATEGIES

Till Spranger, German Federal Environmental Agency

The United Nations Economic Commissions for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (LRTAP) has successfully reduced air pollution in Europe due, in part, to an "effects-based approach". The approach optimizes emission reduction strategies using critical loads as long-term goals. Critical loads; emissions transport and deposition models; and abatement technologies are combined in integrated assessment models (IAM) to devise pollution reduction strategies. These models yield national emission limits for ammonia, nitrogen and sulfur oxides for tropospheric ozone, acidification, and terrestrial eutrophication.

The results of LRTAP negotiations to date include national emissions ceilings for European countries and projected emissions reductions for SO_2 (-60%), NO_x (-40%), and NH_3 (-17%) by 2010. The IAM results also show that critical loads exceedences are greater in magnitude and more extensive for eutrophication than for acidification, and the exceedences are dominated by ammonia emissions from intensive animal husbandry.

Many remaining problems in the European environment relate to atmospheric nitrogen emissions from agriculture and mobile sources. Consequently, nitrogen effects are a main focus of the activities under LRTAP, including the International Cooperative Programme on Modeling and Mapping Critical Loads.

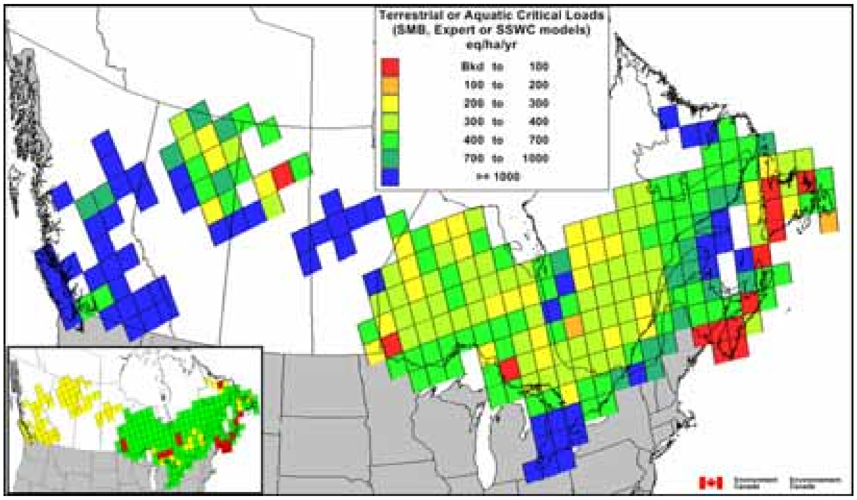
The European experience demonstrates that effects-based emission abatement policies are cost-effective. Additional research and policy development is needed to link biodiversity and climate change policies to critical loads in order to reduce uncertainties in critical load estimates and optimize management and abatement strategies.

ACIDIC DEPOSITION: THE CANADIAN EXPERIENCE USING CRITICAL LOADS

Dean Jefferies, Environment Canada

The development of the Canadian SO_2 emissions reduction policy to address acid deposition was developed using critical and target loads. Southeastern Canada is presently the area of concern for acid deposition, but sensitive areas of western and northern Canada are being investigated as well. The 2004 Canadian Acid Rain Assessment updated critical loads estimates using combined critical loads for aquatic systems and upland forests, resulting in a critical loads map and map of exceedences for the entire country (Figure 11). The process is described in Appendix E. It should be noted that prior to the 2004 Assessment, critical loads (and the policy "target load") were expressed as kg/ha/yr wet SO_4 deposition. To include both S and N, critical loads are now expressed as eq/ha/yr such that 1 kg SO_4/ha/yr = 20.8 eq/ha/yr. Critical loads are also now expressed in terms of total deposition including both wet and dry deposition.

Figure 11: Critical Loads for Acidity in Terrestrial and Aquatic Ecosystems
Source: Jeffries and Ouimet 2004, Ouimet et al. 2006



Environmental Monitoring and Critical Loads

Session Chair: Rich Fisher, US Forest Service

Speakers: Gary Lear, US Environmental Protection Agency

Kathie Weathers, PhD, Institute of Ecosystem Studies

John Stoddard, PhD, US Environmental Protection Agency

Scott Bailey, PhD, US Forest Service

Borys Tkacz, US Forest Service

Rich Hallett, PhD, US Forest Service

ATMOSPHERIC DEPOSITION

Atmospheric deposition of sulfur and nitrogen occurs in three forms: wet (rain and snow), dry (gases and particles), and cloud/fog (also rime ice). Accurate measurements and estimates of atmospheric deposition are important for determining the loading at which chemical or biological changes occur, and for accurately estimating critical load exceedences.

Wet Deposition

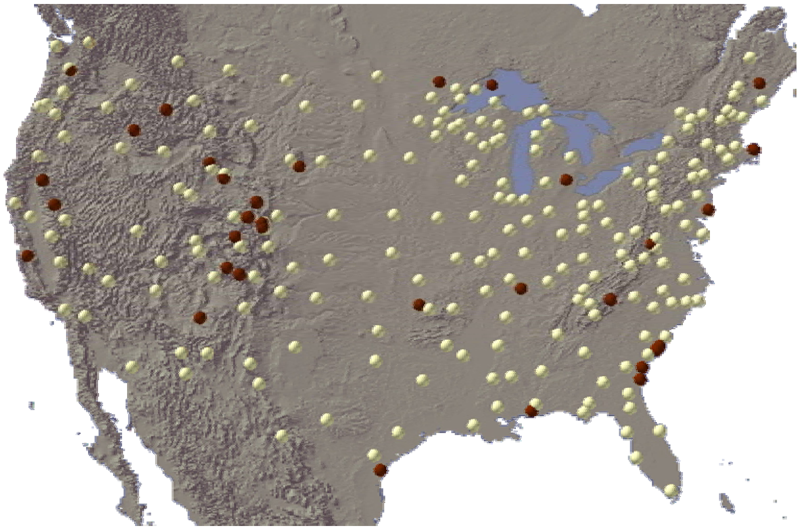
Wet deposition in the US is measured by the National Atmospheric Deposition Program (NADP). The NADP includes the National Trends Network (NTN) and the Atmospheric Integrated Research Monitoring Network (AIRMON). For complete program descriptions go to: http://nadp.sws.uiuc.edu/.

The National Trends Network measures major ion concentrations in precipitation weekly through a network of 252 wet-only Aerochem deposition collectors. The NTN is characterized by broad geographic and ecosystem coverage, sites located away from local sources, regionally representative locations, consistent and comparable measurements, and a comprehensive quality assurance program.

AIRMON also measures wet deposition, but on a daily time step at only 8 sites designed to capture the effects of precipitation events on deposition chemistry.

Wet deposition is generally well-described by NTN and AIRMON monitoring data, and has been effectively extrapolated nationally. However, it is widely recognized that the Aerochem collector used at NTN sites has poor collection efficiency in snow. As a result, several sites routinely fail completeness criteria for the network (Figure 12).

Figure 12: NADP/NTN sites in red meet completeness criteria less than 50% of all years
Source: NADP



Dry Deposition

CASTNET uses filter packs to collect gas and particle concentrations in air on a weekly basis at a network of 89 sites. The filters are extracted and concentration data are then used to estimate dry deposition. An inferential model is used to estimate dry deposition rates for ozone, SO_2, HNO_3, and particles. CASTNET sites are located in rural areas and thus provide regionally representative data. For a complete program description go to: http://www.epa.gov/castnet/.

The current model used to infer dry deposition using CASTNET data is the Multi-Layer Model (MLM) which uses estimated deposition velocities that are based on surface conditions. EPA is testing a new model called the Multi-Layer Biochemical (MLBC) model that incorporates plant growth and ammonia, and appears to better match observed measurements.

At the present time, CASTNET generally underestimates dry deposition in complex terrain. Many sites with heterogeneous terrain do not meet the model criteria and are therefore excluded from the dry deposition estimates. Consequently, CASTNET dry deposition values provide modeled approximations that apply best to homogenous surfaces, and are useful for reference, but should not be used for extrapolations or interpolations.

Total deposition

In order to estimate total deposition, NADP/NTN and CASTNET data are combined (Figures 13 & 14). The results suggest that total sulfur and nitrogen deposition are highest in the Eastern US and that dry deposition constitutes 50 percent or more of total deposition in some locations. As a result of the limitations inherent in the Aerochem collector and current dry deposition estimates and the need to exclude data that do not meet network criteria, wet + dry deposition estimates are not extrapolated beyond CASTNET sites. Thus total deposition to heterogeneous/complex landscapes is not well-characterized in many areas.

Figure 13: Estimated Total Sulfur Deposition

Source: USEPA/CASTNET; NADP/NTN

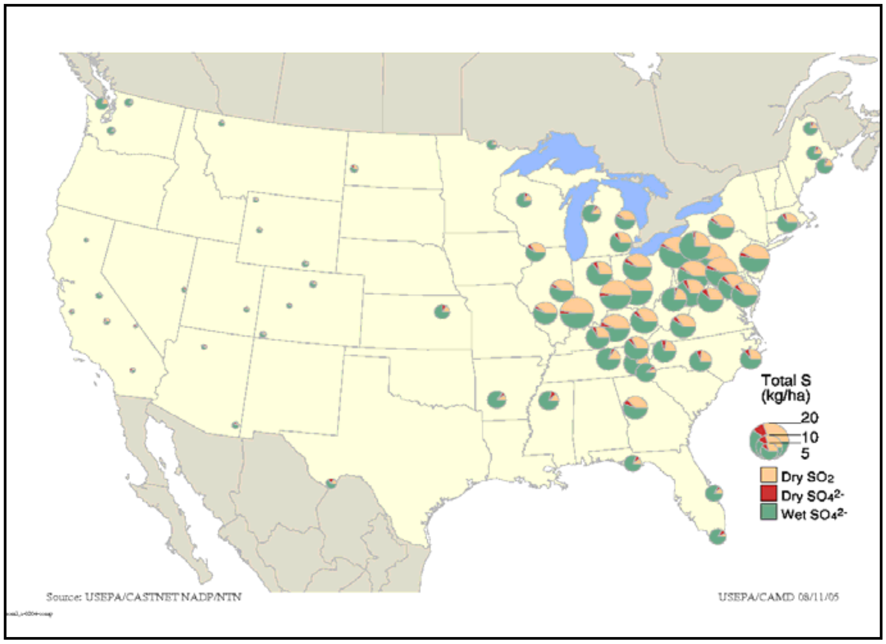
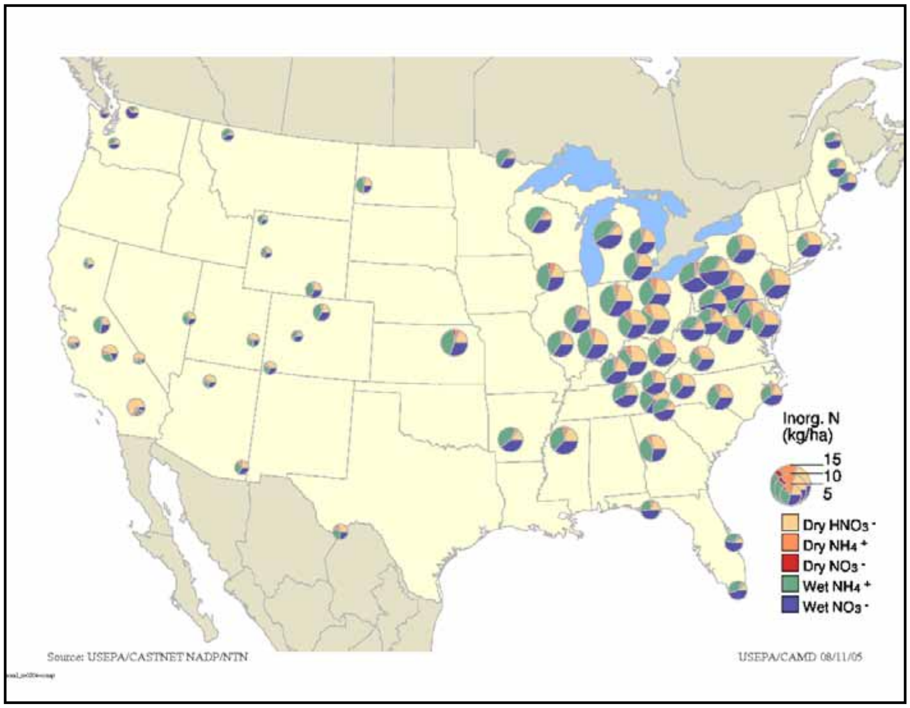


Figure 14: Estimated Total Nitrogen Deposition

Source: USEPA/CASTNET; NADP/NTN



Empirical Deposition Models

Efforts have been made to regionalize total deposition data by accounting for elevation and other features in Nanus et al. (West), Holland et al. (global), Ollinger et al. (NE US), Miller et al. (NE), and Weathers et al. (NE). However, in most of these cases the extrapolation did not include collection of additional deposition data. A new empirical deposition model combines network data and additional field measurements to predict deposition patterns in complex terrain (Weathers et al. 2006).

The empirical deposition model uses field measurements (e.g., throughfall) and GIS data layers (e.g., elevation, aspect, vegetation cover) to develop statistical models and maps of atmospheric deposition. The models were developed for Acadia National Park in Maine (Figure 15), and Great Smoky Mountains National Park in Tennessee and North Carolina. Additional models are being developed for the Catskill Mountains of New York.

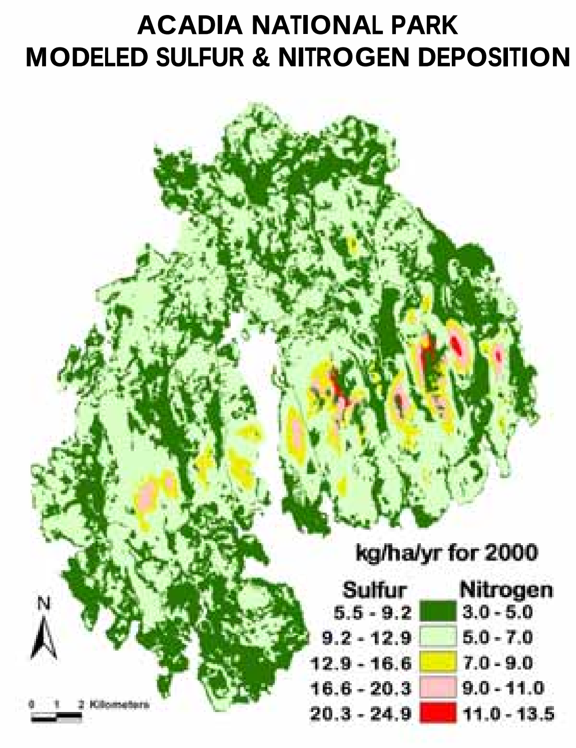
The results suggest that these empirical deposition models capture several important drivers (e.g., landscape features) of atmospheric deposition in complex terrain.

Weathers et al. (2006) estimate that total nitrogen and sulfur deposition is 40 to 70 percent higher at the study sites than values derived from NADP plus CASTNET.

Vegetation type (coniferous, deciduous or mixed) and elevation are the primary independent landscape factors that control deposition in complex terrain. Hotspots of deposition exist in high elevation conifer forests and coldspots (regions of low deposition) occur in low elevation areas with open (or deciduous) vegetation types. The model does not yet fully account for local-scale variability in deposition and should be tested in other mountainous environments.

The results from the Weathers et al. empirical model suggest that critical load exceedences may vary widely over a relatively small area in complex terrain; and may therefore not be accurately depicted by estimates of total deposition based solely on NADP/CASTNET data. However, the existence of the monitoring data is essential to scale-up deposition estimates to the landscape.

Figure 15: Total Sulfur and Nitrogen Deposition



Weathers et al. 2006

SURFACE WATER CHEMISTRY

Surface water monitoring is critical to understanding the impacts of acid deposition and assessing the effect of emissions reductions. Two major lake and stream water monitoring programs exist at the federal level: the Long-Term Monitoring Network (LTM) and the Temporally Integrated Monitoring of Ecosystems Network (TIME). Water quality data collected through these networks can be used in a critical loads context to calibrate and improve existing critical loads models, and to regionalize critical loads estimates.

LTM sites have been sampled intensively (quarterly to monthly, with episodes) since the early-mid 1980s. The LTM network is focused entirely on chemistry and the data are used to assess trends in seasonal and episodic acidity. Many sites have sufficient watershed characterization data to allow critical loads calculations.

The TIME network consists of repeated probability surveys of lakes in the Adirondacks and New England, as well as streams in the Mid-Atlantic region. The TIME lake network began as part of EMAP in 1991. It includes approximately 80 lakes with ANC <60 µeq/L that are sampled annually. The TIME Stream network began as part of EMAP in 1993 and includes roughly 50 streams with ANC <50 µeq/L sampled annually.

The TIME data support regional temporal trend analysis and assessments of population change by geographic region. For example, with TIME data it is possible to describe the status of each region at the time the Clean Air Act Amendments were enacted: approximately 13 percent of Adirondack lakes and 12 percent of the stream length in the northern Appalachians were chronically acidic. In 2006 about 8 percent of Adirondack lakes and 8 percent of the stream length in the northern Appalachians are chronically acidic.

By combining TIME and LTM data, probability results can be extended based on seasonal water chemistry patterns such as acid-neutralizing capacity (Figure 16). For example, a comparison of summer and spring acid-neutralizing capacity illustrates that spring ANC is lower by a predictable amount in combined data for New England and Adirondack lakes, and Appalachian streams. These data show that, from a critical loads perspective, if protecting these lakes and streams from acidification in the spring is a goal, then the critical ANC to protect is approximately 40 µeq/L. Surface water data demonstrate that several ecosystem processes are not well described or explained by models, including: nitrate trends, base cation behavior and its relationship to ANC, and the role of organic acids.

At the present time, dynamic and steady state models often produce widely differing critical load results. For example, sulfate critical loads calculated for Northeast lakes are consistently higher using the MAGIC model than the values produced by steady state models in the region (Figure 17). It may be possible to calibrate simpler models to help extrapolate from site-specific to regional critical loads using monitoring data. For example, using more realistic F factors (change in base cations/change in acid anions) based on LTM data significantly improves the relationship between calculated sulfate critical loads produced by dynamic and steady-state models.

Figure 16: Integrating TIME and LTM Datasets

Source: Stoddard, J. presentation 2006, unpublished data

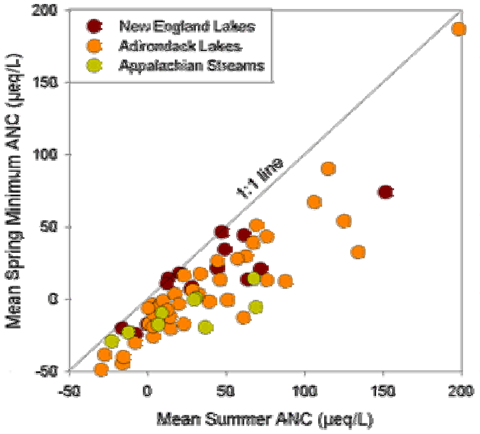
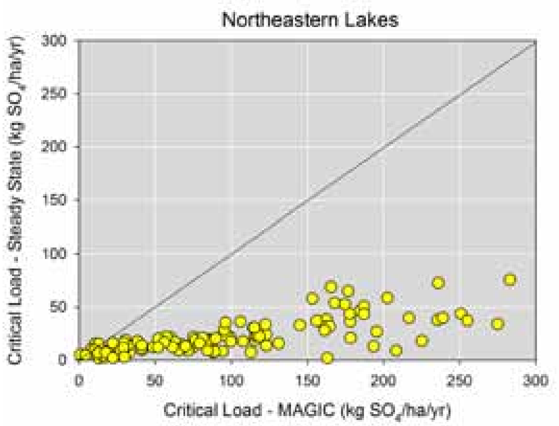


Figure 17: Regionalization – A Simple Example

Source: Stoddard, J. presentation 2006, unpublished data



SOILS

Evaluating soil quality is critical to determining impacts caused by acid deposition, and therefore to estimating critical loads for aquatic and terrestrial ecosystems. Soil determines the quality of drainage waters as well as the nutrition of terrestrial organisms. Much of the evidence for soil changes caused by acid deposition is indirect, derived from modeling or watershed mass balance studies. Direct evidence of soil change from retrospective soil monitoring is rare due to a lack of studies initiated prior to the acid deposition era, a lack of archiving and documentation in early soil studies, and difficulties caused by spatial variability in soils.

Resampling of soil profiles thirty years after initial sampling on the Allegheny Plateau, PA demonstrated an order of magnitude reduction in exchangeable calcium and magnesium, with concomitant increases in exchangeable aluminum (Bailey et al. 2005). This and other retrospective studies illustrate that detection of chemical changes in forest soils is possible over decadal time scales; base cation depletion is observed in areas subject to acid deposition; and changes are deeper than expected and can occur in soils developed in well buffered (calcareous) parent materials.

Research has been conducted to relate soil changes to biological impacts. Extensive research on sugar maples offers two soil chemical thresholds linked to greater susceptibility to forest decline in the unglaciated Allegheny Plateau under conditions of repeated insect defoliation: 2 percent Ca saturation and 0.5 percent magnesium saturation in the upper B horizon. These thresholds may be useful in the development of critical loads for terrestrial ecosystems (Bailey et al. 2004).

Field observations of forest soils suggest several challenges in verifying critical loads models, including: difficulty in defining the depth of the rooting zone, a preponderance of lateral and upward flow-paths in many landscapes, incomplete understanding of the mechanisms of nutrient storage, and difficulty in translating soil chemical data from a concentration to a pool basis. These real world observations need to be taken into account when designing and interpreting critical load studies.

Documentation of soil dynamics is fundamental to an understanding of the impacts of acid deposition, yet soil monitoring in the United States is severely lacking. With careful design it is possible to detect soil change over relatively short time periods.

FOREST HEALTH

Federal and State agencies have been working together since 1991 on a national program for monitoring and reporting on the status and trends of forest health. The Forest Health Monitoring (FHM) program can be used to assess sulfur and nitrogen deposition impacts on forest ecosystems, and to set thresholds or breakpoints for the analyses of detection monitoring data. For complete program details see http://fhm.fs.fed.us.

TheFHM program gathers data from ground plots and surveys, aerial surveys, and other biotic and abiotic data sources and develops analytical approaches to address forest health issues that affect the sustainability of forest ecosystems. The objectives of the FHM program are to establish a monitoring system throughout the forests of the United States to determine detrimental changes or improvements that occur over time; provide baseline and health trend information that is statistically precise and accurate; and report annually on status and changes to forest health.

The FHM program covers all forested lands of the US through a partnership involving the USDA Forest Service, State Foresters, and other state and federal agencies and academic groups. The three major components of the FHM program are: detection monitoring, intensive site monitoring, and evaluation monitoring.

Projects such as the Delaware River Basin Collaborative Environmental Monitoring and Research Initiative (CEMRI) offer an example of how forest monitoring data can be integrated with hydrology, water quality, soils, atmospheric deposition, and remote sensing datasets to link atmospheric sulfur and nitrogen loading to forest health and water quality. Similar projects could be implemented to determine critical loads for terrestrial ecosystems over large geographic areas.

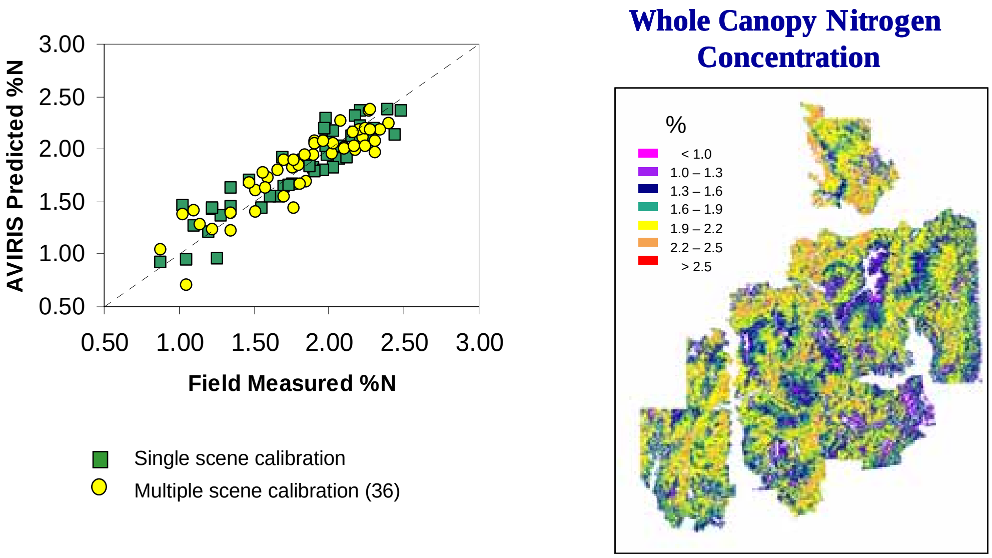
REMOTE SENSING

Hyperspectral remote sensing imagery is a digital technology that covers the visible and near infrared spectrum in many narrow spectral bands. It produces data intensive images that cover large geographic areas. Hyperspectral remote sensing has been used to map foliar chemistry, forest productivity, species composition, and tree health at the landscape scale (25,000 acres to 840,000 acres). This level of detail is not obtainable using traditional remote sensing techniques. For example, an in-depth study of the White Mountains in New Hampshire produced a map of percent canopy nitrogen that showed strong agreement with field measurements of canopy nitrogen ($r2=0.84$)(Figure 18)(Smith et al. 2002).

These data products can be integrated with other spatially explicit indicators of ecosystem function to create base line maps of ecosystem health; assess ecosystem sensitivity to deposition; provide spatially continuous input parameters to critical loads models; or detect changes in tree health over time to assist with validation and mapping of ecosystem health. For example, predicted soil C:N was mapped for the White Mountains and remotely sensed data were combined with field measurements to develop an estimated nitrification threshold of soil C:N = 22.

Hyperspectral imagery can provide information about the landscape that is similar in detail to plot-based empirical studies and is spatially continuous at the landscape scale, including: species mapping, foliar chemistry (nitrogen and calcium), forest productivity, and forest health.

Figure 18: AVIRIS Canopy Percent Nitrogen Prediction – White Mountain National Forest, NH
Source: Smith et al. 2002



Reflectance data calibrated using PLS regression to measured foliar N ($R^2 = 0.84$).

Chapter

3

Workshop Findings & Recommendations

The participants in the Multi-Agency Critical Loads Workshop developed a set of findings and recommendations to help advance critical loads in the US. The results are summarized below.

Critical Loads – Common Ground

Several areas of agreement as well as topics that need further consideration emerged through workshop discussions.

AREAS OF AGREEMENT

1. A critical load is defined as: *a quantitative estimate of the exposure to one or more pollutants below which significant harmful effects on specific sensitive elements of the environment do not occur according to present knowledge* (UNECE 1988).
2. Despite reductions in sulfur and nitrogen emissions in the US, deposition rates still exceed pre-industrial levels and acidification and eutrophication effects remain widespread. Critical loads can be used to better understand impacts of atmospheric deposition, assess the effectiveness of emissions programs, and guide natural resource management.
3. The development of critical loads is a process that is subject to continued development and improvement as knowledge advances.
4. Adequate information exists to move forward with the development and limited application of critical loads in some regions and ecosystems in the US.
5. An intensive research and monitoring agenda should be pursued to support the development and refinement of critical loads in the US.
6. Critical loads should be based on a matrix of biological and chemical indicators for aquatic and terrestrial ecosystems that account for acidification, nitrogen saturation, and eutrophication effects and are relevant to the geographic area or ecosystem of concern.
7. Adequate information exists to establish harmful effect thresholds for some indicators based on specific protection and recovery objectives defined by policymakers and managers.
8. Dynamic models provide the most accurate site-specific information and account for time-dependent processes, but are generally too data intensive to be applied across large geographic areas at present. Simple mass balance models can be applied to current conditions in large geographic areas, but in some instances do not adequately highlight some sensitive areas because they tend to average conditions across the landscape. Hybrid approaches that link observational datasets with dynamic and steady state models represent a useful approach for regionalizing site-specific information.

QUESTIONS NEEDING FURTHER DISCUSSION

1. What are the appropriate applications of critical loads estimates to policy and management issues given current knowledge? For applications where buy-in to an incremental process does not exist, greater investment in critical loads methods may be needed before this application can be pursued.
2. How strong is the relationship between specific indicators, thresholds, and biological responses?
3. What are the suitable interpretations and uses of existing databases for the development of national simple mass balance critical load models?

RECOMMENDATIONS FOR ADDRESSING DISCUSSION QUESTIONS

2. Develop an Inter-Agency Policy Framework with a list of critical loads applications and associated information requirements in order to clarify how critical loads could most appropriately be applied.
3. Prepare a review paper focused on critical loads indicators, thresholds, and linkages to biological response; organize a focused session at the proposed critical loads scientific meeting; convene a small-group workshop under the auspices of the National Center for Ecological Analysis and Synthesis (NCEAS), or some other entity, aimed at resolving the questions of which indicators and thresholds best reflect the impacts of atmospheric deposition and are most strongly tied to biological response.
4. Develop written interpretation guidelines for national maps, conduct additional ground-truthing, and uncertainty/sensitivity analysis, and integrate more observational data where possible.

Critical Loads Research and Monitoring Needs

Workshop participants identified several research and monitoring needs to support critical loads development in the US.

ATMOSPHERIC EMISSIONS AND DEPOSITION

1. Update nitrogen and sulfur emissions inventories on a state-by-state basis back to the 1900s to correspond with methods used in current emissions inventories.
2. Develop ammonia emissions inventory.
3. Improve dry deposition estimates for sulfur and nitrogen.
4. Improve total sulfur and nitrogen deposition estimates.
5. Measure gaseous ammonia concentrations.
6. Add ammonia deposition measurements to current networks.
7. Improve estimates of total deposition in complex terrain.
8. Develop nitrogen and sulfur deposition maps for North America.

SOILS

1. Improve spatial coverage and representativeness of soil chemistry databases, particularly in sensitive terrain.
2. Increase soil monitoring.
3. Improve estimates of mineral weathering rates.
4. Develop soil archiving and well characterized reference samples to promote cross-laboratory comparisons.
5. Expand research on the nature and size of soil nutrient pools.
6. Conduct research on threshold values of soil quality for biologic responses.
7. Determine nitrogen supply rates in different soil types.
8. Investigate nitrogen soil accumulation rates in arid lands and implications for critical loads.

9. Assess relationship between nitrogen deposition and soil nitrogen levels.
10. Enhance understanding of the fate of deposited nitrogen (e.g., is it stored or denitrified?).

SURFACE WATERS

1. Incorporate TIME and LTM surface water monitoring programs into a larger network with better geographic coverage (e.g., the West and Southeast).
2. Improve spatial coverage and representativeness of surface water chemistry databases, particularly in sensitive and complex terrain.
3. Integrate fixed-site monitoring with regional probability monitoring design
4. Continue to monitor major drivers of acidity.
5. Build critical loads considerations (e.g., validation, improvement, regionalization) into monitoring from the start by combining chemistry, hydrology, deposition and biology, and integrating site-specific models and measurements into regional contexts.
6. Expand research to understand what is driving dissolved organic carbon (DOC) changes in the East.
7. Analyze the impact of groundwater transport on recovery times.

BIOLOGICAL EFFECTS

1. Develop better understanding of the link between chemical indicators and biological response (e.g., quantify the minimum nitrogen level at which plankton communities shift).
2. Conduct additional research on the sequential impacts of nitrogen and relationship between nitrogen deposition and ecosystem impacts.
3. Integrate critical load estimates with biodiversity and climate change interactions.
4. Undertake more research on biological change and “harmful effects” to help establish appropriate critical loads thresholds (e.g., in arid lands, what level of productivity of exotic invasive species will cause the reduction versus the extinction of native species?).
5. Collect sediment cores from lakes that vary in rates of N deposition to track changes in diatom assemblages.

CRITICAL LOADS MODELS

1. Improve representation of nitrogen dynamics in models.
2. Expand models to include ammonia.
3. Improve explicit consideration of changing base cations and dissolved organic carbon.
4. Conduct ground-truthing of forest sensitivity and other models.
5. Integrate water flowpaths into nutrient cycling models since lateral and vertically upward flowpaths are common.
6. Understand and quantify uncertainties in models.
7. Conduct site level model comparisons of dynamic and simple mass balance models.
8. Integrate observational databases with steady-state and dynamic models.
9. Incorporate capacity to understand and evaluate climate change interactions.

Guidelines for Critical Loads Pilot Project

During the workshop, comprehensive inter-agency critical load pilot projects were put forward as an action item that would help advance critical loads by applying current knowledge to specific locations based on defined policy and management objectives. The workshop participants responded to a draft set of pilot project criteria and developed the following project goals and components.

PILOT PROJECT GOALS

Comprehensive critical loads pilot projects that integrate science and policy issues will:

1. build on existing capabilities and projects to further explore the development of critical loads for sulfur and/or nitrogen based on effects on sensitive aquatic and terrestrial ecosystems in the US;
2. evaluate the usefulness of critical loads for policymakers and managers at the state, regional, or national level; and
3. identify research and monitoring needs for future critical loads efforts (e.g., methods/models, data, monitoring, non-pollutant stressor interactions).

PILOT PROJECT COMPONENTS

Comprehensive critical loads pilot projects should be based on a well-defined project plan that delivers discrete products in 2-5 years. The project plan should include the following components:

8. REGION – the project should apply to a specific geographic area that can range from multi-site to regional or national scales (e.g., eastern or western US); the relative ecosystem sensitivity and representativeness of the area should be described.

9. ENVIRONMENTAL IMPACTS – the project should address sulfur and/or nitrogen deposition-related environmental issues (e.g., acidification, nitrogen saturation, and eutrophication) that are well-defined and supported by research and data for the selected project area.

10. METHODS/MODELS – the project should use appropriate methods and models that have been developed or could be adapted for the project area to calculate critical loads.

11. DATA AVAILABILITY – existing data should be available to support the effective application of the method or model selected for the project; including sensitivity and uncertainty analyses, and evaluation of results by ground-truthing or other scientifically valid means.

12. ENVIRONMENTAL INDICATORS - environmental indicators for tracking the chemical and/or ecological responses to sulfur and/or nitrogen deposition in the project area should be defined and supported by existing data and research.

13. MONITORING - satisfactory monitoring to measure or estimate atmospheric deposition and ecological response should be underway and continuing in the project area.

14. STAKEHOLDER INVOLVEMENT - stakeholders (e.g., Federal, State, Tribal, local representatives) should be engaged in discussions throughout the project to determine how the critical loads and related information could be used in policy, management, and assessment efforts.

Critical Loads – Recommended Next Steps

Several potential next steps were articulated by workshop participants during the three day meeting. They are organized here into three categories: (1) expand the scientific enterprise, (2) enhance policy frameworks and inter-agency collaboration, and (3) get the word out through organized communications activities.

EXPAND THE SCIENTIFIC ENTERPRISE

1. Organize a scientific meeting or conference that produces publications and perhaps a special issue of a journal. Proposed conference steering committee members include: J. Baron, J. Cosby, C. Driscoll, M. Fenn, and J. Galloway.
2. Pursue a research and monitoring agenda to support critical loads initiatives in the US.
3. Increase the publication of scientific papers in the peer-reviewed literature over the next 5 years.
4. Develop a scientific consensus regarding receptor ecosystems, appropriate indicators, and defensible thresholds linked to policy objectives.
5. Organize a focused session at the proposed scientific meeting, or a small-group workshop, aimed at resolving which indicators and thresholds best reflect the impacts of atmospheric deposition and are most strongly tied to a specific biological response.
6. Produce a review paper specifically focused on critical loads indicators, thresholds and linkages to biological response.
7. Compile information on existing critical loads projects that are underway, their objectives, and where they are located.
8. Develop written interpretation guidelines for national critical loads maps, and conduct additional ground-truthing, and uncertainty/sensitivity analysis, and integrate more observational data where possible.
9. Send US scientists to European critical loads workshops, including the Bulgaria meeting in April 2007.

ENHANCE POLICY FRAMEWORKS & INTER-AGENCY COLLABORATION

1. Establish an inter-agency critical loads working group, perhaps as an NADP ad hoc committee (see recommendations in Appendix F on pages 46-47).
2. Develop an Inter-Agency Policy Framework with a list of critical loads applications and associated information requirements in order to clarify how critical loads could most appropriately be applied to different policy and management issues.
3. Support research and monitoring needs for critical loads initiatives in the US (see pages 27-28).
4. Solicit, select, and implement pilot projects based on the defined project goals and components.
5. Incorporate critical loads science in the re-evaluation of secondary National Ambient Air Quality Standards.

GET THE WORD OUT THROUGH ORGANIZED COMMUNICATIONS ACTIVITIES

1. Develop a critical loads website that includes materials from this multi-agency workshop, as well as information and links to critical loads resources and projects in North America and Europe.
2. Organize joint briefings with scientists for the staff and leadership of state, tribal, regional, and federal governments to increase understanding of critical loads, how they are developed and how they can be used.
3. Develop a critical loads fact sheet for policymakers and the public that describes the concept, history, science, and possible applications of critical loads.
4. Publish a summary of this multi-agency workshop in trade newsletters and publications to begin reaching larger audiences.

Multi-Agency
Critical Loads Workshop
Sulfur & Nitrogen Deposition Effects on
Freshwater and Terrestrial Ecosystems

Appendices

Appendix A: Workshop Goals, Charge, and Outcomes

Prior to the workshop, the Steering Committee developed a series of goals and an overall charge for the event. They also articulated a list of outcomes that the workshop should strive to achieve.

WORKSHOP GOALS

1. Facilitate a broad sharing of information regarding critical load terminology and definitions along with technical/science projects among the agencies and stakeholders.
2. Understand the history and science behind the development of critical loads in Europe and the US in order to provide context and background for future use of critical loads model outputs and empirical data.
3. Develop a draft broad federal strategy for planning, executing, and evaluating critical loads projects, including integrating critical load science/technical issues with consideration of critical load use in a policy/management framework.

WORKSHOP CHARGE

To achieve these goals, participants will:

1. Present an overview of critical load projects, scientific research, and stakeholder perspectives.
2. Evaluate the state of the science, identify strengths and weaknesses, and outline gaps to be filled.
3. Clarify critical loads terminology, methods, indicators, thresholds, and target ecosystems.
4. Discuss ways to move forward with the science, policy, and management aspects of critical loads.

The federal agencies will work together on day three of the workshop to:

1. Define “pilot project” and develop a strategy for selecting and implementing these projects.
2. Outline ways to enhance communication within and among federal agencies regarding the use of critical loads and the status of critical loads projects.
3. Plan efforts to catalyze new peer-reviewed research.
4. Discuss the potential for a critical loads monitoring and research network.

WORKSHOP OUTCOMES

Participants will leave the meeting with the groundwork laid for:

1. A critical loads synthesis report or workshop report.
2. Comprehensive critical loads science & policy pilot projects.
3. A scientific meeting to catalyze new research and monitoring.
4. A system for intra- and inter-agency communication and cooperation.

Appendix B: Workshop Agenda

Multi-Agency Critical Loads Workshop: Sulfur and Nitrogen Deposition Effects on Freshwater and Terrestrial Ecosystems

May 23, 2006

8:30 – 8:35 **Welcome and Overview – Jim Galloway, *University of Virginia***

8:35 – 8:45 **Workshop Goals, Charge, and Outcomes – Sean Casey, *ICF International***

8:45 – 9:15 **U.S. Critical Load Efforts: Past and Present – Paul Ringold, *U.S. Environmental Protection Agency (EPA/ORD)***

9:15 – 10:15 **Session 1: Critical Loads – What do they Mean? Environmental Science Perspectives on Development and Meaning of CLs – Session Chair: Rick Haeuber**

- Biogeochemical Perspective on Critical Loads – Linkages between Emissions, Deposition, and Biogeochemical cycles – Jim Galloway, *University of Virginia*
- Ecological Perspectives on Critical Loads – Linkages between Biogeochemical Cycles and Ecosystem Change – Myron Mitchell, *SUNY-ESF*
- Environmental Indicators that Link Terrestrial and Aquatic Ecosystem Responses to Atmospheric Deposition of Sulfur and Nitrogen – Greg Lawrence, *U.S. Geological Survey*

10:15 – 10:30 **Discussion**

- Do we have sufficient knowledge, data, etc. regarding ecosystem indicators and pollution-effects thresholds to move forward with development of CLs for selected areas?

10:30 – 11:00 BREAK

11:00 – 12:00 **Session 2: Calculating CLs – Modeling Approaches to Developing Critical Loads – Session Chair: Rick Haeuber**

- Forest Service CL National Mapping Project – Steve McNulty, *U.S. Forest Service*
- Calculations of critical loads of acidic deposition for the protection of acid-sensitive U.S. surface waters using the MAGIC model – Tim Sullivan, *E&S Environmental Chemistry*
- Effects of acidic deposition and calculating critical loads of acidic deposition in the Adirondack region of New York – Charley Driscoll, *Syracuse University*

12:00 – 1:00 LUNCH

1:00 – 2:00 **Session 2: Calculating CLs – Modeling Approaches to Developing Critical Loads (continued)**

- Using DayCent-Chem to explore ecological and biogeochemical responses to changing atmospheric nitrogen and sulfur deposition for diverse ecosystems – Jill Baron, *U.S. Geological Survey*

- NEG-ECP Northeast US Mapping Project – Eric Miller, *Ecosystems Research Group*
- Critical loads for nitrogen: calculated and empirical – Linda Pardo, *U.S. Forest Service*

2:00 – 3:00 **Discussion – Calculating Critical Loads**

- ➢ Which modeling approaches seem most promising? Pluses and minuses of different models?
- ➢ How do steady-state and dynamic approaches compare? Are there roles for both modeling approaches?
- ➢ What level of accuracy and precision is "good enough" for the stated objectives?
- ➢ Do we have the data necessary to implement modeling approaches over a regional to national scale?
- ➢ Modeling aquatic effects vs. terrestrial effects
- ➢ Modeling acidification vs. nutrient fertilization

3:00 – 3:30 BREAK

3:30 – 4:30 **Session 3: Empirical CL Approaches – Critical Loads based on Observation of Temporal or Spatial Ecosystem Changes – Session Chair: Tamara Blett**

- Empirical determination of N critical loads for alpine vegetation – Bill Bowman, *University of Colorado – Boulder*
- Critical Loads of Nitrogen Deposition for Southern California Desert and Coastal Sage Scrub: an Empirical Approach – Edith Allen, *University of California – Riverside*
- Linking Diatom Fossil Records to Patterns of Atmospheric Nitrogen Deposition in the Rocky Mountains – Jasmine Saros, *University of Wisconsin – La Crosse*

4:30 – 5:30 **Discussion – Developing Critical Loads**

- ➢ How can site-specific calculations for fertilization be used to supplement modeled CLs?
- ➢ How can observed changes in ecosystem condition best be linked to monitored deposition loads to determine CLs?
- ➢ How do CL approaches for eastern US vs. western US differ?
  - o Northeast – Southeast differences
  - o High elevation – low elevation differences
- ➢ Can empirical approaches be used in conjunction with modeling approaches to make long-term predictions?
- ➢ Can CLs be defined using error-bounds or a risk assessment?

5:30 – 7:30 **Happy Hour – Clark Hall (Mural Room)**

May 24, 2006

8:30 – 8:40 **Day One Revisited – Lingering Issues – Sean Casey, *ICF International***

8:40 – 9:40 **Session 4: Critical Loads – What are they Good for? International Experiences with CL Implementation – History, Use, Uncertainties, & Future Directions – Session Chair: Doug Burns**

- Application of Critical Loads in European Air Pollution Abatement Strategies – Till Spranger, Chair, *ICP Modeling and Mapping Task Force*
- Reducing Acidic Deposition: the Canadian Experience Using Critical Loads – Dean Jeffries, *Environment Canada*

9:40 – 10:00 BREAK

10:00 – 11:00 **Session 5: Perspectives on CLs – Roundtable and Discussion of Linkages and the Future – Moderator: Sean Casey**

- Tamara Blett, *National Park Service*
- Rich Fisher, *U.S. Forest Service*
- Rick Haeuber, *U.S. Environmental Protection Agency*
- Dan Johnson, *Western States Air Resources Council*
- Kevin McDonald, *Maine Department of Environmental Protection*

11:00 - 11:30 **Discussion: Ideas for moving forward in exploring development and application of a CL approach in the U.S.**

11:30 - 12:30 LUNCH

12:30 – 1:50 **Session 6: CL Validation – How do we Track Improvement or Decline in Ecosystem Condition over Time using CLs? Session Chair: Rich Fisher**

- Deposition Monitoring (NADP & CASTNet) – Gary Lear, *U.S. Environmental Protection Agency* Deposition Mapping – Kathie Weathers, *Institute of Ecosystem Studies*
- Surface Water Monitoring (EPA's TIME/LTM Network) – John Stoddard, *U.S. Environmental Protection Agency*
- The role of soil monitoring in critical loads modeling – Scott Bailey, *U.S. Forest Service*

1:50 – 2:15 BREAK

2:15 – 3:15 **Session 6: CL Validation (continued)**

- Monitoring the health of the forests of the United States – Boris Tkacz, *U.S. Forest Service*
- National Ecological Observatory Network – Bruce Hayden, *University of Virginia*
- Hyperspectral Remote Sensing Imagery: What is it? What can it do? – Rich Hallett, *U.S. Forest Service*

3:15 – 3:45 **Discussion**

- ➢ Do we have the monitoring that we need in the places that we need it in order to validate CLs and observe ecological response to emissions and deposition changes over time?
- ➢ If not, what is needed to fill the gaps?

3:45 – 4:15 **Next Steps: Future Meetings and CL Projects**

May 25, 2006

Federal and State Agencies Coordinating Session
(Federal and State employees only, to comply with FACA rules)

Coordinating Session Goal:

- Develop strategy between Federal and State participants for future cooperation and coordination on CL research/application efforts and pilot project development.

Facilitators – Sean Casey, *ICF International*; Kathy Fallon-Lambert, *Ecologic: Analysis and Communications*

8:30 – 9:00 **Review key points of agreement from discussions in Workshop**

9:00 – 9:30 **Review additional items from Workshop needing resolution in this session**

9:30 – 10:30 **Session 1: Planning and Executing CL Projects**

- How can we work together on developing and implementing CL projects? General goals:
    - Explore and advance resolution of scientific, technical, and application issues remaining in the use of CLs in a US context;
    - Develop clear objectives explaining what CL issues (science, technology, application) the projects will address;
    - Avoid duplication of effort between agencies;
    - Facilitate communication between multiple CL projects.
- Can we develop draft ideas/proposals now for integrated CL projects (including management and/or regulatory components) that we will pursue together?

10:30 – 11:00 BREAK

11:00 – 12:00 **Session 2: Reporting and Evaluating CL Projects**

- What steps must be taken to evaluate completed CL projects to determine which ones are most useful and effective as policy/management assessment tools?
- What processes (if any) should be put in place to deal with conflicting CL developed by different groups?
- Should CL summary products (e.g., reporting many efforts together as an integrated package) be developed and, if so, how and by whom?
- What future workshops, conferences, or other venues can we use to report on CL projects and other efforts to resolve scientific, technical, and applied CL issues? Who should develop or coordinate these activities?

12:00 – 1:00 **Session 3: Integrating CLs into Policy and Management**

- What steps would be necessary to integrate CLs (once they are developed) into State or Federal air regulatory and assessment processes?
- What steps are needed to integrate CLs into Federal Land Manager natural resource management and assessment processes?

1:00 – 1:30 **Wrap-Up and Review of Action Items and Next Steps**

Appendix C: Agency Roundtable Discussion

Moderator:	Sean Casey, ICF Consulting
Participants:	Tamara Blett, National Park Service Rich Fisher, US Forest Service Dan Johnson, Western States Air Resources Council Kevin MacDonald, Maine Department of Environmental Protection Rick Haeuber, US Environmental Protection Agency

The panelists in the roundtable discussion were asked to respond to three questions. The questions and a summary of responses are provided below.

Do you see ways in which you and staff from similar organizations could use critical loads?

1. Maine - critical loads are being considered as a tool that could be used for conducting integrated assessments or for modeling the potential impact of proposed new emission sources.
2. USFS - critical loads are used in programs as a way to include air quality in forest plans, and to make informed decisions regarding energy development.
3. NPS - critical loads provide a tool for looking at how ecosystems have changed over time and for restoring and protecting sensitive and protected park resources.
4. WESTAR - critical loads are a tool that should be moved beyond the science and into regulation in order to achieve greater emissions reductions.
5. Clean Air Markets Division of EPA - critical loads represent a tool that may help meet accountability goals by providing an expanded approach for assessing programs and by helping to answer the question, "Do the benefits justify the economic costs?" Critical loads could also be used to determine what more is needed if current emissions reductions do not adequately protect ecosystems.
6. EPA ORD - critical loads represent an area of scientific advancement that ought to be considered in the upcoming air quality standards review. Critical loads could be particularly important in determining whether the primary standards set for human health are adequate to satisfy the secondary standards that are intended to protect "public welfare", which includes the environment.

Note: during questions from the audience it was noted that there are not policy levers in place to address ammonia emissions; and yet ammonia emissions are increasing in the western US.

Are there places (sites or areas) that you feel might provide good case studies for exploring a critical loads approach?

1. Experimental Forests – case studies should build on the work done to date, such as the USFS pilot projects at experimental forests in Fernow, West Virginia and in the San Bernardino Mountains of California.
2. The Northeast – case studies should be targeted in areas where extensive research is already underway. In the Northeast, dynamic models have been applied, extensive surface water monitoring networks exist, states are interested in using critical loads, and there are opportunities to apply methods and models at a regional scale.
3. Tribal lands – case studies should be conducted in areas such as tribal lands where lakes are affected by acidic and nitrogen deposition and are an important public resource.

4. West and Southeast – case studies should focus on highly impacted regions such as the West and Southeast. In these regions, it would be necessary to scatter sites in order to fully capture regional variability.
5. Criteria – case studies should incorporate chemical and biological impacts to terrestrial and aquatic ecosystems; and should be developed in areas where it is possible to determine critical loads based on pre-impact conditions and where soils information is available.

What are the two most important things to keep in mind in developing critical loads pilot projects and exploring critical loads implementation strategies over the next two years?

The responses below are augmented by written answers provided by all of the workshop participants summarized in the table on pages 39 and 40.

1. Feedback between science and policy – when developing critical loads, more communication and interaction is needed between scientists and policymakers.
2. Regionalize critical loads – critical loads methods and applications need to evolve beyond a site by site approach.
3. Develop some successes in areas where there is high impact and great public interest.
4. Pay attention to what the Europeans have done, many of the methods and approaches are applicable in the US.
5. Don’t be too narrow, need to consider a multi-pollutant approach (including ammonia, CO_2, mercury) to avoid being “surprised” by cumulative effects.
6. Need an integrated North American map of deposition to support critical loads initiatives.
7. The importance of considering and communicating the differences between critical loads developed on a national scale, and the site specific critical loads developed for sensitive ecosystems.

IMPORTANT THINGS TO KEEP IN MIND

The workshop participants offered the following responses to the question: “The most important thing for those of us in the room to keep in mind about critical loads (CL) over the next two years is: __________”.

Name	Response
Paul Stacey	It is only one cause and effect relationship of a complexity of media and receptor that needs to be considered.
Tamara Blett	Need loose organization of folks to shepherd process and continue communication.
Kevin Macdonald	It represents a shift in the way we are accustomed to looking at things.
Dan Johnson	To establish a policy framework for future studies.
Rich Fisher	Policy will drive the efficient development and implementation of CLs.
Doug Burns	That we need to have accurate nationwide maps of exceedence areas before we can proceed.
Gary Lovett	That developing CLs is a <u>process</u> and will be subject to continued development and improvement.
Rick Haeuber	It can be a useful tool, but it will take a large collective effort to bring to fruition.
Hobie Perry	There is a pressing need for action and we need to move forward with “present knowledge.
No name	Multiple approaches and continued redefinition of methods will be needed to increase our capacity to determine realistic CLs with confidence.
Ellen Porter	If you build it they will come – policy will follow science.
Suzanne Fisher	We need to start, to organize a group, define CL, and detect areas to determine CL for.
Edith Allen	Need more precise and long term data on rates of deposition and environmental impacts.
Annabelle Allison	To consider collaboration (i.e. tribes) and to expand to include other air pollutants.
Jay Lee	Overcome institutional barriers and inertia to concerted action based on experience-to-date and existing relationships.
Shaun Watmough	That it is a developing process, but has been used successfully elsewhere so start.
Julian Aherne	That it’s time to implement.
Borys Tkacz	Base CL levels on sound science and monitoring regarding ecosystem effects.
Rich Hallett	How to measure impacts to the resource or resources we are trying to protect.
Scott Bailey	They are tied to measurable impacts.
Tim Larson	To expand efforts to engage state/local/tribal natural resource and air permitting agencies in CL efforts to increase understanding and explore applications.
Susan Johnson	Creating a “public relations” campaign to build support and therefore the likelihood of success in policy process for using CL in all ways discussed.
Wei Wu	CL should be viewed as a function with critical threshold as dependent variable instead of a single number and pollutants as an independent variable.
Myron Mitchell	To develop an integrated and agreed upon procedure for developing CLs for the US.
Pamela Padgett	Need to inform the public and gain public buy-in.
Andrea Stacy	Communication and collaboration between scientist and policymakers.
Ann Mebane	We need to move forward while accounting for ecosystem differences in resource sensitivity and impacts.
Karen Rice	To develop a holistic approach for monitoring pollutants.
Vicki Sandiford	It is an evolving method and we need to remain flexible.
Cindy Huber	Evaluate.
Jill Baron	There will be a range of CLs for multiple pollutants across regions and ecosystems.
Tim Sullivan	Tools are available, so get in gear and just do it!
Paul Ringold	To get started with a comprehensive long-term perspective and approach and be prepared to update it incrementally.
Thomas Meixner	The continuing necessary conversation between science and policy.
Steve McNulty	Collaboration must be mutually beneficial because additional funding for this work is highly unlikely.
Dean Jeffries	How the information will be used.
David Gay	We need a multi-pollutant approach and better dry deposition estimates (i.e. inputs to the models).

Gary Shenk	The ecological end points must be relevant to the public and not just scientifically interesting.
Ginger Tennant	Needs to involve both science and policy concerns to be broadly useful.
Till Spranger	1) US is signatory to CLRTAP, 2) implement CLs in multi-pollutant abatement, 3) get started!
Linda Pardo	Coordination and synthesis of on-going and new projects and incorporation and awareness of previous work.
Kathie Weathers	The development is a process and should include multiple linked pollutant (e.g., S, N, Hg, P) response.
Lewis Linker	To make clear links to living resources in some meaningful way on a regional basis.
Art Bulger	Flexibility in choice of biological receptors.
Timothy E. Lewis	We can do it now with what we've got.
Randy Waite	That CLs have broad application for many pollutants and ecosystems.
Jasmine Saros	What are we trying to protect in each region.
Charles Driscoll	Is to integrate observational datasets (monitoring, effects relationships) with models (steady state, dynamic).
Mark Watson	Beginning to use a critical loads approach is better than delaying due to lack of data.
Harald Sverdrup	It is a whole process and that you need to have a plan.
David LaRoche	That it's a tool to help us better inform policy decisions.
Rick Webb	The need to account for spatial variability in response characteristics in determining CL and evaluating success in attaining them.
Amelia Atkin	Another valuable assessment tool that should be including in protection policies.
David Clow	How to accurately estimate CLs for N eutrophication and acidification.
David R. DeWalle	That we need support for research to provide data and critical load experiments.
Sherry Skipper	To keep moving forward with the effort.
Bill bowman	It provides a means for unifying environmental impacts and policy.
Karen M. Roy	Where the US will be with respect to oil prices.
Greg Lawrence	Research continues to improve our ability to measure and predict environmental effects of air pollutants.
Eric Miller	Work with what we have, but work very hard on improving data, models, and thresholds.
Paul Schaberg	Their relevance to biological response, especially relative to sensitive species and habitats.
Jack Cosby	It is the most robust tool we have to inform policy decisions concerning air pollution effects.
Robin Dennis	How we can best mine current efforts and also create a rough national scope of CLs to compare against 2020 projections.
Steve Kahl	Appropriate ecosystem response goals, and the fact that they may be a moving target through time.
John Stoddard	We can argue forever about how best to calculate, or we can start now.
Paul Miller	What are they? And do current programs address them already?
Jim Galloway	To keep the momentum going through additional meetings at the national and international forum.

APPENDIX D: Summary of Group Discussion

Over the course of the first two days of the workshop, participants responded to several overarching questions as summarized below.

A. Do we have knowledge, data, etc. regarding ecosystem indicators and pollution affects thresholds to move forward with the development of critical loads for selected areas?

1. Group response

Yes = most
No = 2
I don't know = 5

2. Discussion

When selecting indicators it is important to keep in mind whether they apply to terrestrial and/or aquatic ecosystems, and which pollutant loading issue they reflect.

Numerous chemical indicators have been shown to be useful for acidification, eutrophication, and nitrogen saturation. But some indicators, such as pH are complicated by natural factors. For others, the link to biological response is unclear. Others have a temporal dimension that may complicate their use (e.g., inorganic Al). In addition, in western ecosystems, biological indicators may show change before measurable changes are observed in known chemical indicators.

A useful strategy may be to develop a set of biological and chemical indicators for terrestrial and aquatic ecosystems that can be applied separately for acidification and eutrophication, and then combined to determine an appropriate critical load. This approach would make the most of the data that are currently available while also acknowledging the limitations of existing information.

B. Do we have the data necessary to implement models over a regional or national scale?

1. Group response

Yes = 5
No = 10
I don't know = most

2. Why "yes"?

Where well-calibrated models exist, such as the Adirondacks, it is possible to apply the results for dynamic models to the region. In other locations, existing data is adequate to take the first step and then refine as more information becomes available.

3. Why "no"?

The importance of soil conditions and weathering rates suggests that more information is needed on these processes before accurate critical loads can be developed. There does not seem to be policy support for an incremental process in the US as there is in Europe, so it will take more time to develop data and methods at the outset.

4. Why "don't know"?

To answer this question, it is necessary to ask, "For what purpose?". Adequate information exists to test tools and hypotheses. Current methods and data may also support the use of critical loads to depict relative landscape sensitivity to sulfur and nitrogen loading, and the relative impact of emissions reductions scenarios. It may also be far enough along to assess the relative impacts of deposition versus other disturbances (such as timber harvesting) or evaluate progress made by emissions reductions programs that have been implemented. However, it is probably not far enough along in the US at this point to be used to set new federal regulations.

C. What type of model should be used to develop critical loads – steady-state, dynamic, or both? And what modeling seems most promising?

The model to be used should be determined by the specific critical load application. For example, if a park manager is interested in a critical load for a specific lake, a site-specific empirical calculation or dynamic model could be most appropriate. If a federal agency is interested in the percentage of surface waters likely to achieve a specific recovery level under a designated emission reductions program, then a steady-state model or dynamic model linked to probability-based surveys would be needed. National and continental-scale modeling should be used with caution and with the understanding that they sometimes do not fully depict local sensitivity. In most cases, a hybrid modeling approach will have broad application.

In summary, the group suggested that models used to develop critical loads should be:

- mixed models that use a mix of indicators,
- empirically based, data driven, mechanistically correct, efficient,
- based on the specific policy or management application of the results, and
- compatible with Canada to address transboundary issues.

Appendix E: Critical Loads in Canada - Method and Results

1. Aquatic critical loads were estimated on a lake-by-lake basis using:
   - the Expert Model (threshold was pH 6).
   - the Steady-State Water Chemistry Model (threshold was ANC 40 μeq/L).
   - for a given lake, the lesser of the 2 values was taken as the critical load.
   - results were mapped on a grid basis (5th percentile value was used as the critical load for the cell).

The results for aquatic systems show (see note on units below):

- the policy-based target load (20 kg/ha/yr) is encompassed by the four lowest CL classes.
- 21% of eastern grid cells are in the lowest CL class; most of them occur in the Atlantic provinces.
- provincial critical loads range from “background” (~60 eq/ha/yr) in Newfoundland, Nova Scotia and New Brunswick to 1620 eq/ha/yr in Manitoba.
- the availability and distribution of the data affects the resulting critical load.

2. Upland forest soil critical loads were estimated for polygon map units using:
   - the Simple Mass Balance Model (threshold was soil water C_b:Al = 10 and gibbsite dissolution constant = 109).
   - forest harvesting and fire were not considered.
   - soil polygons were mapped (in southeastern Canada only).

The results for upland forests show:

- lowest critical load classes reflect shallow, coarse-textured upland soils derived from felsic or granitic bedrock (Canadian Shield plus other areas).
- highest critical load classes have calcareous soils.
- provincial forest soil critical loads were generally <400 eq/ha/yr

3. Combined aquatic-terrestrial critical load maps were developed on a grid basis (Figure 13):
   - point-based aquatic and polygon-based soil critical load values were combined and the easiest compromise was to grid the soil map.
   - the soil polygon critical load map was “re-sampled” within a grid overlay to determine the 5th percentile value for each grid cell.
   - The lower of the aquatic and soil 5th percentile values was taken as the cell critical load for the combined maps.
   - there were many grid cells in eastern Canada where only soils values were available.
   - only aquatic values were available for western Canada.

   The results for the combined critical loads show:

   - the lowest critical load cells were usually contributed by the aquatic analysis.
   - there were many cells where the soil value was lower than the aquatic value.
   - grid cells with critical loads less than the old policy target of 20 kg/ha/yr occur throughout south eastern Canada (also in northern Saskatchewan and Alberta).
   - extremely low regional critical loads were predominantly defined by lakes whose catchments have very thin soils. Critical loads in regions with thicker soils were predominantly defined by forest soil estimates.

4. Critical load exceedences were calculated using estimates of total (wet and dry) S and N deposition from the mid-90s (Figure 14):

- the current or "N-leaching" exceedence used total S deposition plus measured or estimated NO_3 export as the estimate of acidifying deposition.
- the steady-state or "N-saturated" exceedence used total S and N deposition (available for southeastern Canada only).
- 95th percentile exceedence value was mapped for each grid cell.

Critical load exceedence results show:

- ~0.5 million km^2 of the mapped area currently experience CL exceedences, most areas are in southern Nova Scotia, southwestern Quebec and south-central Ontario. If ecosystem N-saturation develops, the exceedence area could expand to 1.8 million km^2. Either way, further reductions in acidic deposition is needed to reduce the exceedences.

Note: To include both sulfur and nitrogen, the Canadian approach expresses critical loads as equivalents per hectare per year.

Appendix F: Multi-Agency Break-out Sessions

BREAK-OUT SESSION #1 – STRUCTURING A CRITICAL LOADS INITIATIVE

Rapporteur: Tamara Blett
Question: What should be the structure of a critical loads initiative moving forward?

Brainstorm:

- Should it be a big group or small?
- What are the goals of a coordinating group?
- What is the role of the planners / working group?

Goals:

- Develop clear **PLAN** of incremental steps
- Communication! Involve states
- Avoid duplication of effort
- Facilitate comparison of analytical tools
- Coordinate & leverage funding
- Oversee pilot projects
- Provide both policy and technical leadership – work together
- Tap existing data resources
- Serve as policy group to help oversee next scientific meeting
- Organize workgroups
- Facilitate <u>tangible</u> progress
- Keep larger group informed
- Track progress toward products
- Facilitate information sharing
- Keep the size manageable
- <u>Develop a strategy!</u>

How do we do this?

- Newsletters
- WEBSITES – agency or independent? (.edu)
- Existing meetings

Proposed structure:

- Create a working group such as an NADP – critical loads subcommittee
- Designate agency reps. to form decision-making body above level of workgroups
- Include current steering committee – policy managers, decision-makers & scientists
- Do we need a <u>formal</u> structure? Keep independent entity on its own

Members:

- Leader is elected, rotates, <u>works</u>
- Steering committee is constant, workgroups can change

- Committed members at staff level
- States and all agencies represented
- Steering committee will put together proposal

BREAK-OUT SESSION # 2 – COMMUNICATING CRITICAL LOADS

Rapporteur: Doug Burns

Question: Is it time to go public?

- Critical loads (CL) are already being discussed in different venues and applied to some degree.
- This bottom-up approach seems to be appropriate for now and provides the opportunity to develop some key messages for informing and educating natural resource managers and policymakers.
- At the present time, messages should emphasize: “CL provide one useful tool for assessing impacts” and de-emphasize linking CL to regulations.
- Another important message is the global change context – fact sheets and other materials should include this context in an opening paragraph.
- Don’t pursue a strategy that would force EPA to decide at this point whether to support/not support CL as a policy tool at this point.
- Concerns were expressed about national maps because of the uncertainties inherent to them, and the potential for average out areas of concern in the west.
- It <u>is</u> time for the science to be visible and above the radar – time to get the details and information published in scientific journals and to provide as much of this information as possible to managers and policy-makers at all levels.
- Tact at this point in time should be on information-sharing and educating, and describing pilot projects.

Question: Critical loads – who needs to know?

- States
    - Attorneys General
    - Air division directors
- Regulated community
- NGOs (environmental) – The Nature Conservancy (re landscape classification)
- NGOs (think tanks) – RFF, RPOs, MJO, NESCAUM, WESTAR
- Policy – those involved in assessment
- Canadians – US/Canada – Mexico – COMABIO, Border 21, SW Consortium
- Federal land managers – park supervisors, chief scientists

Appropriate communication tools:

- Fact sheets
- Briefings
- Scientific publications
- Not – op-eds and news releases, at this point

Next steps for critical loads initiative:

- A second meeting
- Some way of continuing multi-agency and stakeholder dialogue in routine setting – perhaps NADP ad hoc working group
- Pilot projects
- Publications
- Website/listserve

APPENDIX G: Critical Loads Resources

CRITICAL LOADS WEBSITE

http://www.fs.fed.us/ne/durham/4352/critical_loads/Critical_loads_webs/home.htm

The following resources are available on the website:

Approaches for Estimating Critical Loads of N and S Deposition for Forest Ecosystems on U.S. Federal Lands (draft). This paper describes the basic mass balance approach for calculating critical loads, presents the various critical thresholds, and explains the assumptions inherent in the calculation and data selection procedure.

Protocol for Calculating Critical Loads of Nitrogen and Sulfur Deposition for Forest Ecosystems in Forest Service Class 1 Areas (draft).

Data Availability for Forest Service Class 1 Areas (draft). A summary of data available for critical loads models of Forest Service class 1 areas.

Ecosystem Descriptions for Forest Service Class 1 Areas (in progress). This document contains four tables summarizing climate, vegetation, and soil attributes associated with EcoMap Sections and Subsections.

Critical Loads Database – Data Management Protocol (draft). The Data Management Protocol contains instructions for preparing data for simple mass balance calculations of critical loads.

Critical Loads Database Parameters. A one page graphic of database parameters and structure.

Instructions for Calculating Critical Loads. This document discusses model input, intermediate calculations, background data and data for additional analysis.

Data Required for Critical Loads Calculations. This is a one page table indicating required and additional parameters for calculating critical loads.

European Data Requirements. This is a list of mandatory and optional parameters for calculating critical loads from the ICP Forests and ICP Waters manual.

Summary of Critical Loads in the United States. List of publications with critical loads data.
Database Parameters. A one page graphic of parameters and structure in the Critical Loads Summary database.

Site Selection Criteria for Critical Loads Demonstration Plot.

Demonstration Plot Design. ICP Forests plot design from ICP Forest Manual.

Assessment of Forest Sensitivity to Nitrogen and Sulfur Deposition in New England and Eastern Canada. Conference of New England Governors' and Eastern Canadian Premiers' Pilot Phase Report.

Protocol for Assessment and Mapping of Forest Sensitivity to Atmospheric S and N Deposition. The New England Governors' and Eastern Canadian Premiers' Forest Sensitivity Mapping Group.

Appendix H: Steering Committee, Speakers, and Participants

WORKSHOP STEERING COMMITTEE

Rona Birnbaum - US Environmental Protection Agency
Tamara Blett - National Park Service
Doug Burns - US Geological Survey
Rich Fisher - US Forest Service
Rick Haeuber - US Environmental Protection Agency
Steve McNulty - US Forest Service
Mark Nilles - US Geological Survey
Vicki Sandiford - US Environmental Protection Agency
Chris Shaver - National Park Service
Randy Waite - US Environmental Protection Agency
Suzanne Young - US Environmental Protection Agency

SPEAKER BIOS

Edith B. Allen, PhD
Professor, Plant Ecology and Natural Resources Extension
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Edith Allen's major focus is restoration ecology, and she has done research on restoration of grasslands, shrublands, deserts, boreal forest, and tropical forest, including disturbances such as mining, landfills, roads, grazing, fire, invasive species, and air pollution. Southern California has high levels of emissions of nitrogen oxides from automobiles, that in turn are deposited to plants and soils as nitrogen fertilizer. This causes an increase in growth of invasive plants, which increases the fire frequency and reduces the conservation value of wildlands. She is also working on ways to restore lands that have been impacted by high levels of nitrogen deposition.

Scott Bailey, PhD
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Scott Bailey is a Research Scientist with the USDA Forest Service, Northeastern Research Station. Although his position is classified as a geologist, the term geo-ecology better describes his work. He is broadly interested in the interactions between substrate (including soils, geologic parent-materials and landforms) with water and vegetation. Specific areas of current focus include (1) evaluation of watershed mass balance studies and retrospective soil studies to determine temporal dynamics of forest soil base cation supply, (2) the potential role of secondary minerals as nutrient reservoirs in forest soils, (3) site factors responsible for spatial variability in nutrient supply in sugar maple, and (4) the role of seepage and fractured-rock groundwater discharge in forest nutrient cycling and biodiversity.

Jill S. Baron, PhD
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Jill S. Baron is an ecosystem ecologist with the US Geological Survey, and a Senior Research Ecologist with the Natural Resource Ecology Laboratory at Colorado State University. Her recent interests include applying ecosystem concepts to management of human-dominated regions, and understanding the biogeochemical and ecological effects of climate change and atmospheric nitrogen deposition to mountain ecosystems. Baron has edited two books: *Rocky Mountain Futures: an ecological perspective* (Island Press 2002), which addresses the past present, and possible future human influences on ecosystems of the Rocky Mountains, and *Biogeochemistry of a Subalpine Ecosystem* (Springer-Verlag 1992) which summarized the first 10 years of long-term research to the Loch Vale Watershed in Rocky Mountain National Park. Dr. Baron received her PhD from Colorado State University in 1991, and has undergraduate and master's degrees from Cornell University and the University of Wisconsin. She has received a number of achievement awards for her work from the National Park Service, US Geological Survey, and USDA Forest Service, including the Department of Interior Meritorious Service Award in 2002. She has been a member of the Governing Board of the Ecological Society of America, serves on several Science Advisory Boards, has given testimony to Congress on western acid rain, and is an associate editor for Ecological Applications.

William D. Bowman PhD
Professor and Associate Chair for Graduate Studies,
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Bill Bowman's research has focused on the interaction between plants and their resources, broadly defined from plant adaptations to low resource availability to how plants influence soils and subsequently ecosystem function. Over the past decade his work has concentrated on the interaction between alpine plants and nutrients, examining the response of plants to low nutrient supply, as well as the influence that plants have on their nutrient environment. Because of the tremendous variation in soil resource availability associated with landscape topographic and microclimatic diversity, and the accompanying variation in biotic diversity, the alpine is an excellent system to address questions of plant-soil interactions. Over the past 10 years his lab has addressed questions of resource limitations to primary production in alpine communities, the role of competition in community composition, the role of symbiotic N_2-fixation in the alpine N cycle and its influence on species diversity, and plant species influences on N cycling.

Examples of some of the ongoing research his students and he are doing include determining the influence of plant secondary chemistry on nutrient cycling and on competitive interactions, the use of various forms of N (NO_3^-, NH_4^+, and small amino acids) by plants as a means of meeting growth requirements and avoiding competitive interactions, and the influence of soil age on P biogeochemistry in alpine landscapes.

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Charles T. Driscoll is the University Professor of Environmental Systems Engineering at Syracuse University. Dr. Driscoll received PhD in Environmental Engineering from Cornell University. A principal research focus of Dr. Driscoll's research has been the effects of disturbance on forest, aquatic and coastal ecosystems, including air pollution (acid rain, mercury), land-use change and elevated inputs of nutrients and trace metals. He is currently the principal investigator of the National Science Foundation's Long-Term Ecological Research project at the Hubbard Brook Experimental Forest, New Hampshire. In 1984, the National Science Foundation designated Dr. Driscoll as a Presidential Young Investigator. He has provided expert testimony to U.S. Congressional and State committees. Dr. Driscoll has served on many local, national and international committees, including the National Research Council Panel on Process of Lake Acidification and the Committee of Air Quality Management.

James Galloway, PhD
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James N. Galloway is Professor of Environmental Sciences at the University of Virginia. Dr. Galloway received the BA degree in Chemistry and Biology from Whittier College in 1966 and the PhD degree in Chemistry from the University of California, San Diego in 1972. Following a postdoctoral appointment with Gene Likens at Cornell University, he accepted a position as Assistant Professor of Environmental Sciences at the University of Virginia in 1976. He served as President of the Bermuda Biological Station for Research from 1988 to 1995, and as chair of Environmental Sciences, University of Virginia from 1996 to 2001. He is currently chair of the International Nitrogen Initiative, a program sponsored by SCOPE and IGBP, and is a member of the USA EPA Science Advisory Board. In 2002 he was elected a Fellow of the American Association for the Advancement of Science. His research on biogeochemistry includes the natural and anthropogenic controls on chemical cycles at the watershed, regional and global scales. His current research focuses on beneficial and detrimental effects of reactive nitrogen as it cascades between the atmosphere, terrestrial ecosystems and freshwater and marine ecosystems.

Richard Hallett, PhD
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Rich Hallett is a research ecologist for the USDA Forest Service, Northeastern Research Station stationed in Durham, NH. His research is focused on regional scale forest health issues and understanding impacts of stressors on ecosystem function. Part of this work involves working with a team to develop new ways to use hyperspectral remote sensing technology to create continuous maps of tree species, chemistry, and stress across the landscape. His current research is focused on sugar maple decline, hemlock woolly adelgid infestation, emerald ash borer infestation, and examining the role of Ca-oxalate in the forested ecosystem in relation to calcium depletion issues.

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Dean Jeffries received his BS and PhD (Geochemistry) from McMaster University in the 1970s. His research is presently conducted at the National Water Research Institute in Burlington, Ontario. It focuses on quantifying the factors that control chemical changes in lakes as they respond to atmospheric perturbations such as acid rain and climatic change/variation. In particular, he is the senior Environment Canada research scientist involved in the Turkey Lakes Watershed Study, a long-term (25+ year) study of a forested, Canadian Shield ecosystem north of Sault Ste Marie, Ontario (see www.tlws.ca) and has led production of the aquatic effects and critical load sections of three national acid rain assessments (the most recent released last year can be found at www.msc-smc.ec.gc.ca/saib/acid/acid_e.html).

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Greg Lawrence received his PhD from Syracuse University in 1987 where he began studying the effects of acidic deposition on forests, soils and surface waters. He has continued this work throughout his career, most of which has been done in the northeastern U.S., but has recently expanded to include research on acidification and climate change effects in Russia. To date he has authored or co-authored over 75 publications on topics related to acidification.

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Eric K. Miller is President and Senior Scientist at Ecosystems Research, Ltd. in Norwich, VT. Ecosystems Research Group, Ltd. conducts air-pollution and ecosystem research for federal, state and private clients. Some of Dr. Miller's current research projects include measurement of surface-atmosphere exchanges of mercury, regional modeling of atmospheric sulfur, nitrogen, and mercury deposition, and regional modeling of forest sensitivity to acid deposition. Dr. Miller earned his BA in Geology from Bucknell University in 1984. He completed his PhD in Earth Sciences at Dartmouth College in 1993. Dr. Miller's research is focused on the interactions between the atmosphere and ecosystems, including the effects of atmospheric pollutants on soils, plants and surface waters and the role of forest-atmosphere exchanges in biogeochemistry. He conducts field, laboratory and modeling investigations of micrometeorology, atmospheric deposition, canopy gas exchange, soil and water chemistry, mineral weathering, and ecosystem processes.

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Myron J. Mitchell is a Distinguished Professor at the College of Environmental and Science and Forestry, State University of New York (Syracuse, New York). He graduated from Lake Forest College (Lake Forest, Illinois) in 1969 where he received a BA in Biology and was also awarded the Stahl Award for Excellence in Biology. He was elected to Beta Beta Beta and Phi Beta Kappa. He graduated from the University of Calgary (Alberta, Canada) with a PhD in Biology in 1974 with support from an Izzak Walton Killam Memorial Scholarship. He currently heads the Council on Hydrologic Systems Science and directs the Graduate Program in the Faculty of

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From 1984 though 1988 he worked in the Office of the Executive Director of the National Acid Precipitation Assessment Program (NAPAP). In that office he served as a Senior Scientist, the Acting Executive Director, and the Associate Director. In 1988 he began work with EPA in the Office of Research and Development in Washington, DC. In collaboration with a number of other scientists and institutions he worked to develop a demonstration project to evaluate the critical loads approach. This project was supported by EPA, DOE and NOAA. He represented the technical findings to a variety of groups in the UN Economic Commission for Europe under the Long-Range Transboundary Air Pollution Convention. These groups included the Working Group on Effects, the Task Force on Mapping, and the Working Group on Strategies. In addition he worked on a number of activities under the Arctic Environmental Protection Strategy. In 1994 he left Washington DC and moved to EPA's Western Ecology Division in Corvallis, Oregon. In Corvallis he has been working with the EMAP surface waters program on riparian monitoring and the assessment of alien species.

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