FEDERAL LAND MANAGERS CRITICAL LOADS FOR SULFUR AND NITROGEN WORKSHOP

MARCH 30-APRIL 1, 2004,

DENVER, CO

WORKSHOP SUMMARY

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Workshop Background and Goals

Background

Aquatic and terrestrial ecosystems on federal lands are currently receiving deposition of atmospheric sulfur and nitrogen species. In some geographic areas, sensitive ecosystems are vulnerable to these atmospheric loads and are experiencing changes in ecosystem structure and function including acidification, fertilization, and eutrophication. During the late 1980's and 1990's, the European and Canadian communities developed procedures for estimating critical and target loads of atmospheric nitrogen and sulfur species that would protect vulnerable terrestrial/aquatic systems and permit the restoration of impaired systems. The application of the critical loading approach has been used by some Federal Land Managers (FLM) to estimate loading thresholds and limits of acceptable change for selected species (e.g., sugar maple, brook trout), or vulnerable processes (e.g., base cation exchange in granitic or non-karst geology watersheds). However, many features of the critical loads approach, such as selection of target biotic species or processes, selection of management endpoints, determination of critical versus target loads, and using this information in the decision making process, are not uniformly applied by FLMs. Greater consistency and comparability among FLMs would improve the critical load (CL) process. A workshop was designed to contribute to this improved CL process.

Goals

The workshop goals were to:

1. Discuss approaches for using critical loads and target loads in regulatory and policy recommendations, and management decisions in order to make the critical loads concept useful for FLMs to protect and restore ecosystems.
2. Develop common understanding of critical load terminology and definitions so that staff from all FLM agencies can communicate critical loads issues effectively.
3. Understand the history and science behind development of critical loads in Europe and the U.S. in order to give context and background for future use of critical loads model outputs, and empirical data by FLMs.
4. Develop strategies for selecting site specific critical and target loads from empirical data and modeling results where a range of critical loads and target loads are possible, to strive for consistency between parks, forests, regions, and agencies in the application of critical loads.
5. Determine where a consistent approach (between regions, parks, forests, agencies) is possible for selecting types of information needed to determine critical loads (which sensitive receptors, which deposition data, which modeling tools to use) in areas where these decisions have not yet been made.
6. Communicate specific critical loads data needs to researchers involved in critical loads modeling, and ecosystem effects of deposition, so that research and modeling results might meet manager's needs.

7. Consider developing a strategy (and subsequent report) for items 2-6 above, in order to document progress and agreement on critical loads issue by FLMs.

Introduction and Overview

Introduction

Tamara Blett, National Park Service (NPS), introduced the workshop, discussed the workshop goals, and described the overall workshop purpose – to build a common understanding and move toward a consistent approach in implementing the CL process. Some of the issues to be addressed included: lack of clarity about how to use CLs in the administrative and regulatory processes (NEPA, PSD); which tools are most useful to FLMs, considering their cost to use, applicable spatial/temporal scales, required site specific data, type and quantity of data; differences in terminology used to discuss the same issues; and how to use empirical and model output in establishing CL and target load (TL). This workshop was designed to turn some of these issues into opportunities in implementing the CL process.

Critical Loads Overview and Definitions

Ellen Porter, NPS, provided an overview of the CL approach and process The CL concept arose from a 1979 agreement signed by over 30 European countries to reduce long-range transboundary air pollution. Canada also uses CL to control air pollution. In the U.S. EPA's 1995 acid deposition feasibility study report to Congress, the recommendation was to not use CL or TL to control air pollution, but to use broad cap-and-trade emissions programs instead, based on information available at that time. CL and TL definitions were presented that are commonly used in the literature:

Critical Load: the threshold deposition of pollutants at which harmful effects on sensitive receptors begins to occur.

Target Load: the deposition of pollutants that will result in an "acceptable level" of resource protection above or below the critical load.

In general, CL is based on modeled or measured dose-response data, while TL can be based on political, economic, spatial, or temporal considerations in addition to scientific information. Spatial considerations (site, watershed, wilderness or other boundary), description of "sensitive receptors", and a definition of the "harmful effect" used in the critical loads assessment are all important in describing a specific CL or TL. A sensitive receptor is the resource, or part thereof, that is the most responsive to, or the most easily affected by the type of air pollution in question; a sensitive receptor indicator is a measurable physical, chemical, biological, or social (*e.g.*, odor) characteristic of a sensitive receptor.

CL and TL are concepts applicable to both terrestrial and aquatic ecosystems, and to areas designated both Class I and Class II under the Clean Air Act. These CL and/or TL can be defined based on biological, physical, and/or chemical indicators. Temporal considerations can be especially important in defining TL, because selecting acceptable timeframes to ecological or ecosystem recovery are often policy decisions. Spatial definitions are necessary because even adjacent watersheds may have substantially different chemical retention characteristics and/or buffering capacities. Given different sensitive receptors, sensitive receptor indicators, and different endpoints and ecosystem types, there may be a range of CL and TL used to describe a suite of characteristics for any given site. It may be useful to narrow the range, or choose a single value for the CL or TL, defining it for the sensitive receptor, sensitive receptor endpoint, timeframe, or area of interest.

Policy Overview

Rich Fisher, USDA Forest Service (FS), provided insight into management needs of FS FLMs. Managers need to work with researchers (and vice-versa) to determine what is needed to use CLs as a management tool. The primary tool currently available for new source review is the FLAG (Federal Land Manager's Air Quality Related Values Workgroup, 2000) document, which provides FLM guidance on evaluating qualitative impacts on sensitive resources. CLs will provide further quantitative information useful to land managers.

Some of the advantages of the CL approach are that it integrates air quality values with other management activities; is applicable for multiple pollutants; is science-based; is internationally accepted; can be refined with additional knowledge; and provides a gaming tool for evaluating alternative management options. Some of the disadvantages of the CL approach are that it is, in many instances, sufficiently complex to appear to managers as a "black-box" approach; is a different way of doing business that requires change; has not been embraced by EPA as a national tool for emissions reduction goals; and is data intensive.

In moving forward, a candidate North American model for critical loads needs to be developed. This candidate model needs to be tested for robustness, accuracy, and applicability. If necessary, this model should be refined and then adapted for use in management activities and demonstrated for FLMs. Finally, the CL approach needs to be integrated into the Forest Service National Inventory and Monitoring Protocols.

Chris Shaver, NPS Air Resources Division, provided insight into management needs of NPS FLMs. Chris used the analogy of a lighthouse. A critical load can be a lighthouse, providing a point of reference to FLMs for resource protection. For CL to be useful, all the terms must be defined and the techniques and methods tested and refined. FLMs must then develop a strategy for implementing CL. Multiple agencies can benefit from using CLs, including the FWS. Critical loads provide an objective approach for evaluating the effects of new or modified pollution sources on resources, including visibility. They also provide an approach for outreach and education that will benefit Resource Stewardship Plans, and Government Performance and Results Act (GPRA) goals.

Framing the Workshop Issues

Cindy Huber, FS, presented a Decision Matrix Table with four columns (Table 1). The first column identified what is needed to develop CLs. The second column listed the decisions about CLs that have already been made through FLAG or similar venues, and agreed upon by NPS, FWS, and FS, that do not need to be revisited. The third column listed the issues that needed to be addressed at this workshop, and the last column was to be used in providing responses or recommendations to the issues listed in the third column. The Decision Matrix Table provided a vehicle for synthesizing and summarizing the results of the CL workshop.

Table 1. Decision Matrix Table Framing the Issues.

CRITICAL LOAD: Threshold for ecosystem sensitivity to a pollutant that is derived from the best-available scientific knowledge. Usually expressed as kilograms per hectare of Nitrogen or Sulfur.			
What do we need to know or do to develop critical loads?	**We have made decisions on these and do not need to revisit**	**These are the issues we need to deal with in this meeting**	**Notes**
Select Sensitive Receptors and Indicators for the AQRVs	FS Example: AQRV - Water quality or Aquatic Integrity. Sensitive Receptor - Perennial Streams. Sensitive Receptor Indicator - ANC.	Terrestrial ecosystem sensitive receptors and indicators have not been selected for many areas. Terrestrial receptors and indicators may need to be aligned with model outputs (i.e. soil chemistry ratios?)	
Establish Protection Criteria.	Example: (From the Critical Loads paper) ANC$\geq$50 ueq/l to protect sensitive aquatic biota, ANC$\geq$20 ueq/l to avoid episodic acidification, ANC$\geq$0 to avoid chronic acidification.	Are these universally accepted resource protection criteria for aquatic effects? What resource protection criteria should we be using for terrestrial effects?	
	"Physical components are as essential as biological components" (FLAG).	Physical components may be "essential" but how can we use changes to them in setting critical loads? Do they need to be linked to biological effects to be used? Can we use them to set target loads?	
Estimate Total Deposition		What method will be used to estimate total (wet+dry+cloud) deposition? Can FLMs agree on what type of data is best used in which circumstances?	
Estimate Effects to Sensitive Receptors for a Range of Protection Criteria (Indicator Endpoints).	Example: Table 2 in the Critical Loads paper provides examples. (e.g. Indicator endpoint for ANC at 50 ueq/l to protect sensitive fish and invertebrate species).	Can FLMs develop strategy about how to determine ecosystem endpoints (desired future condition) we'd like CLs and TLs to be developed for?	
Selecting the Critical Load from a Range of Options.	Decision was made in FLAG to "protect the most sensitive ecosystem components" rather than those of average sensitivity.	What is the appropriate level of protection? See Table 2 in the critical loads paper for a range of protection criteria and associated Critical Loads for aquatic ecosystems.	
Know the Time to Recovery or Restoration where Damage has Already Occurred.		This has been done for a few of the Class I areas, but not all. MAGIC modeling can provide this information for aquatic ecosystems.	
Select an Appropriate Target Load.		Can FLMs develop a strategy to consistently determine appropriate target load in locations where Critical Load has been exceeded? What about for areas where CL is not yet exceeded.	
Determine how Critical Loads can be Used Directly in PSD, NEPA and Other Processes Used by FLMs.	Deposition Analysis Thresholds (DAT) have been used (on a case-by-case basis) by NPS as adverse impact thresholds where Critical Loads are clearly exceeded.	Determine how FLMs can use critical loads in their daily decision making and policy and management recommendations in a way that will better protect parks, wilderness areas, and refuges.	

Synopsis of Workshop Presentations

First day presentations were intended to provide a common understanding and foundation for CL and TL. The morning presentations summarized the current status of CL in the eastern and western U.S. and the current status of estimating deposition loads in the U.S. The afternoon presentations discussed the European International Cooperative Programme (ICP) experiences with CL, for both terrestrial and aquatic systems, with a summary of modeling approaches for estimating deposition effects on aquatic ecosystems. These presentations are briefly summarized here. Additional details about presentation contents or information references may be obtained from the speakers directly.

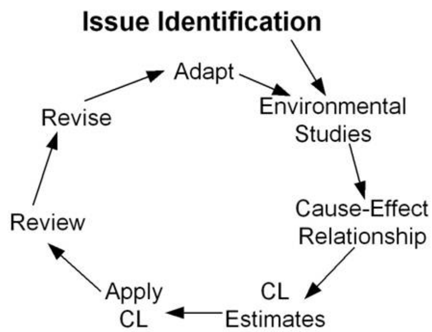
Western United States Deposition and Deposition Effects Research and Monitoring

Jill Baron, U.S. Geological Survey (USGS), discussed deposition loading and associated effects in western ecosystems. In general, the target ecosystems for research have been high elevation, nutrient-poor, slowly weathering terrestrial and aquatic ecosystems. While these have been the target ecosystems, there is some evidence that other ecosystems such as deserts and lower elevation dryland ecosystems might also be susceptive to nitrogen (N) deposition. Canadian scientists have found forest ecosystems encroaching or moving into grassland ecosystems in areas with increased N deposition. Shifts in vegetative communities as a result of N deposition have been observed in a variety of ecosystem types. The predominant deposition concern in the west is nitrogen deposition, although some areas also receive elevated sulfur (S) deposition loads. Nationally, a decreasing trend in sulfur deposition has been occurring because of requirements under the Clean Air Act to reduce sulfur, and consequently, acid rain; on the other hand, the trend in nitrogen deposition has been increasing. Empirical studies on nitrogen deposition effects occurring in the west have found a decrease in symbiotic soil fungi, endangerment of native butterfly species because of vegetative shifts that reduced native forbs, shift in diatom species community types, increase in non-native grasses, and increase in fire frequency. Lichen species also appear to be especially sensitive to nitrogen deposition.

Other types of studies that can help inform understanding of ecosystem thresholds are manipulation studies, spatial comparisons, and modeling analyses. Manipulation studies have been used to investigate some of the subtle ecosystem effects associated with excess nitrogen addition. These effects include both an increase in concentration, and productivity. Diatom species shifts have been shown to occur with increased nitrogen concentrations. In terrestrial systems, there is an increase in vegetative cover, a decrease in C:N ratios, and increased mineralization and nitrification rates. Comparative or spatial studies have also documented an increase in nitrogen mineralization rates with increased nitrogen deposition. Nitrogen deposition can also lead to acidification, but typically at nitrogen deposition loads higher than those occurring throughout much of the West. Ecosystem modeling has been used to investigate changes in soil chemistry and acid neutralizing capacity due to nitrogen deposition.

CL are another management tool that can be used to protect sensitive terrestrial and aquatic resources. To use CL effectively, however, we need to be able to establish thresholds for various sensitive resource indicators. Sensitive resource indicators are measurable physical, chemical, biological, or social (*e.g.*, odor) characteristics of a sensitive resource. Some suggested critical loads, based on empirical evidence for the central Rocky Mountains include ~ 2.5-3.5 kg N/ha-yr for episodic acidification, ~ 3.5-5.0 kg N/ha-yr for chronic acidification, ~ 1 mg N/L for abrupt shifts in algal species, C:N < 24 for increased soil nitrification rates, and C:N <29 for increased soil mineralization rates .

The use of CL as a management tool can be schematically described as:



Eastern United States Deposition and Deposition Effects Research and Monitoring
Helga Van Miegroet, Utah State University, discussed the effects of S and N deposition in the eastern U.S., emphasizing the effects on soils. There are significant gradients of both S and N in the eastern U.S., ranging from 12-32 kg-S/ha-yr and 8-27 kg-N/ha-yr. Elevation is a covariant with deposition. Glaciation is also a factor in assessing the effects of deposition on soils. In general, glaciated sites have younger parent material and soils with more weatherable Calcium (Ca) and lower N accumulation. In non-glaciated soils, the parent material and soils are older, there has been an historic depletion of Ca-bearing minerals due to long-term leaching by acidic deposition, and a longer period of N accumulation. The glaciation/non-glaciation observation has management implications because soil disturbance activities such as fire and farming, can set back the N accumulation clock, therefore postponing the time of N saturation and excessive nitrate leaching. Both N and S deposition can result in cation leaching, Aluminum (Al) mobilization, and soil/water acidification. N deposition can also result in N saturation and eutrophication of surface waters. Excess N addition has been associated with winter injury and growth decline in terrestrial vegetation and changes in species diversity. While the effects of N and S deposition have historically been studied independently, it is total deposition that affects both terrestrial and aquatic ecosystems so N and S deposition must be evaluated together. In the past two decades, there have been decreasing trends in S deposition because of specific requirements under the Clean Air Act to reduce sulfur dioxide emissions, but increasing trends in N deposition in the East.
The Bear Brook and Fernow Experimental Forest manipulation sites are areas of long-term research which have provided insight into the effects of deposition and prior land use on available cations. In the control watershed in Bear Brook, recovery of soil base saturation is being observed with the regional decrease in S deposition. In the experimentally treated watershed, the system was observed to “flip” from insensitive to sensitive to deposition loads. The new challenge is to consider impacts of the increasing N deposition loads and the combined effects of S and N deposition to these systems. For

N deposition, 7 kg-N/ha-yr appears to be a threshold for eastern systems with effects noted when N deposition > 7 kg-N/ha-yr. C:N and Ca:Al ratios are two useful soil indicators for assessing deposition loading. Dale Johnson, Desert Research Institute (now at the University of Nevada Reno), indicated a simple approach for establishing a N deposition CL for terrestrial systems might be CL_N = N deposition – Plant Uptake.

Deposition Monitoring and Modeling
Kristi Morris, NPS, discussed various approaches for estimating deposition loading in the U.S. Deposition loading estimates are typically obtained through a combination of deposition monitoring estimates combined with deposition modeling estimates. The types of deposition monitoring networks in the U.S. include National Atmospheric Deposition Program (NADP), Clean Air Status and Trends Network (CASTNet), throughfall, snow surveys, cloud (fog, occult) deposition monitoring and various research projects. Both NADP and CASTNet are national programs. However, NADP has a much greater density of sites throughout the U.S. than does CASTNet. CASTNet sites are sparse in the western U.S. NADP measures constituent concentrations in precipitation while CASTNet measures constituent concentrations in air and estimates deposition using deposition velocities. Throughfall and cloud deposition monitoring are typically site specific with a limited number of sites in the U.S. The Rocky Mountain Snowpack Survey measures snow pack concentrations of sulfate, nitrate, and ammonium. These estimates represent winter deposition to high elevation sites, but these estimates are limited primarily to the Rocky Mountain Region of the U.S.

Emission-based models include EPA's CMAQ (Community Multiscale Air Quality Model) and RADM (Regional Acid Deposition Model), and SAI's REMSAD (Regional Modeling System for Aerosols and Deposition). While there are other models available, these are the three most commonly used. The advantages and disadvantages of each of these approaches are described in her presentation.

A number of recommendations for estimating deposition loads were provided during the presentation including: 1) use the best available information, 2) use annual total deposition estimates, when available, 3) use the deposition estimate that the most sensitive resource experiences, 4) use methods for estimating total deposition based on a "preferred sequence", 5) compare CL to all past years of deposition data available to determine if CL has been exceeded and 6) support long-term monitoring of deposition and ecosystem effects. These recommendations were discussed by workshop participants and the revised recommendations were included in the workshop synthesis and Decision Matrix Table 2 (See Workshop Synthesis Section).

European International Cooperative Programme (ICP) Approaches for Terrestrial Ecosystems
Pam Padgett, FS, discussed the ICP approach to long-range transboundary air pollution. The European approach has been adopted by 49 European countries to abate air pollution. The ICP effort has an institutional framework that brings scientists and policy-makers together in resolving air pollution problems through cooperation and negotiation. The presentation focused primarily on ICP Forests. ICP Forests has two primary goals: to

monitor the effects of natural and anthropogenic stressors and factors on European forests; and to contribute to a better understanding of cause-effect relationships between forest condition and deposition. This was accomplished through two levels of monitoring. Level I monitoring includes national and international coverage and is intended to characterize spatial and temporal variation in forests. Level I monitoring is conducted on about 6,000 plots, distributed on a systematic 16 x 16 km grid. The primary indicators are for crown condition, soil, and foliar constituent concentrations. Level II monitoring represents site-specific, intensive monitoring to better understand cause-effect relationships. There are slightly over 850 plots distributed within important forest ecosystems. There are a consistent set of protocols and methods, but each country selects its own sites. Consistency in methodology among sites is needed in order to contribute to modeling and mapping activities to develop critical loads and develop target emission and deposition reductions to achieve those critical loads. In general, the ICP modeling estimates in the past have been based on empirical, steady-state models, rather than dynamic models. Part of the future goal for ICP terrestrial models is to improve the dynamic modeling capabilities.

Modeling Deposition Critical Loads in Terrestrial Ecosystems

Linda Pardo, FS, discussed three approaches for estimating critical loads on forest ecosystems: empirical, simple mass balance, and dynamic modeling. Although CL is discussed in the singular, as a single estimate, there will be multiple CL – one for acidification and one for excess nutrient N loading, for each sensitive resource indicator. The ICP empirical approach, for example, might provide one estimate for N for a sensitive resource indicator. This is similar to the current Forest Service approach to air quality, with red line/green line thresholds. Below the green line is acceptable whereas above the red line is unacceptable, with a cautionary zone in between the two lines. Empirical critical loads for forest ecosystems are not well developed in the U.S. The ICP also uses simple mass balance methods. These methods are applicable for either acidification or nutrient imbalances. ICP critical load indicators include Al concentrations, base cations (BC), Al:BC or Ca:Al ratios, or changes in % base saturation (%BS) for acidification. Critical thresholds include considerable uncertainty. Using ICP methods, an acidification threshold used in developing a critical load is generally a specific Al:BC ratio. For U.S. forests modeled as a part of the New England Governors'/Eastern Canadian Premiers' project, the threshold is "no significant change in %BS". The purpose of these thresholds is to "protect roots from toxicity" (the ICP objective) or "protect soils from cation depletion" (the Forest Service objective).

CL estimates for soils in terrestrial systems are affected by weathering rate estimates, and regional differences in soils. Differences in deposition in each area may add complexity to calculating deposition exceedances. A dynamic model that is currently being applied to U.S. forest soils is the VSD (very simple dynamic) model. Because it is dynamic, the VSD model can estimate both time to acidification and time to recovery. Specific input requirements and characteristics of the VSD model were presented. Input from FLMs in using these modeling approaches include identifying sensitive receptors and critical thresholds, scale of interest, and how representative various modeled plots are for the sensitive receptor.

European International Cooperative Programme (ICP) Approaches for Aquatic Ecosystems

Kent Thornton, FTN & Assoc., discussed the ICP approach for estimating CL for aquatic ecosystems. The CL is typically based on science while TL are based on other factors such as economic cost, technical feasibility, ease of implementation, and similar policy related issues. ICP Waters addresses only freshwater systems that are typically oligotrophic (or ultra-oligotrophic) seepage and drainage lakes, dune slackwater ponds, and small 1st to 2nd order streams. The specific sensitive receptors vary by country. The sensitive receptor indicators include acid-neutralizing capacity (ANC), brown trout or other salmonid species, softwater macrophytes, diatom species assemblages, and changes in species distributions. The specific indicator varies by country. Determining critical load maps is a two step process. First, the distribution of sensitive receptors is mapped and then critical loads are assigned to these sensitive receptors. Steady-state models, rather than dynamic models, have been used to establish CL in Europe. These models typically project a change in ANC. Recent studies have developed a relationship between ANC and the probability of brown trout occurrence so that changes in ANC can be related to an important biotic indicator. Since 1980, there has been about a 40% reduction in S deposition across the European countries. With decreasing deposition levels, interest is shifting toward recovery, so dynamic models such as the Model for Acidification of Groundwater In Catchments (MAGIC) are being used to evaluate revised CL estimates. Critical Load Functions (CLF) have been developed to express the myriad possible combinations of N and S deposition producing total deposition estimates. These CLFs indicate whether reductions in N or S or both are appropriate in targeting the next round of emission and deposition reductions in Europe.

Modeling Deposition Critical Loads in Aquatic Ecosystems

Tim Sullivan, E&S Environmental Chemistry, discussed estimating effects on surface waters using dynamic models. The primary sensitive receptor indicator is ANC, and critical values are often set at levels of 0, 20, and 50 μeq/L. The CL doesn't preclude the use of FLM developed thresholds like Limits of Acceptable Change (LACs), and can complement these values. A model-based approach is required to establish CLs. There are a number of dynamic models that have been or can be used to establish CLs, including MAGIC, PnET, NuCM, SAFE, SMART, MERLIN, and others. MAGIC has been most widely applied for aquatic ecosystems in the United States. The primary sensitive receptors have been lakes in the West and streams in the East. The modeled scenarios are usually question-based. A four box conceptual model (described in the Workshop Synopsis) provides a useful perspective in thinking about the issues of acidification and/or excess nutrient addition, for either terrestrial or aquatic ecosystems. The questions being asked determine the appropriate approach and/or model scenarios to evaluate. Site selection can be achieved statistically as a probability sample, or by targeting, focusing on a specific site or class of sites. Either approach can be appropriate, depending on the specific questions being asked. As indicated in previous presentations, the CL is science-based while the TL is policy-based. In addition, there are likely to be multiple CLs based on the sensitive receptors, sensitive receptor indicators, protection status (e.g., episodic acidification, chronic acidification, excess nutrient addition, etc.), and time period specified for resource protection. The general procedure for estimating CLs is to formulate the specific questions to be answered, identify the relevant time period, select the pollutant of concern and the model that incorporates that pollutant, determine the applicable criteria and critical values, and simulate the long-term deposition that is expected to result in the targeted conditions. Next steps are to determine the range of CL and the regional representation of those values, and estimate the uncertainty associated with the CL, including seasonal/episodic variability. Once the CL is estimated, the TL can be determined that incorporates legislative mandates or policy requirements and other policy-relevant factors that might influence the implementation of emission reductions to achieve the TLs and CLs. A number of examples of using the MAGIC model to establish CLs are included in his presentation.

Breakout Group Discussions

Case studies for the Shenandoah National Park (NP), Rocky Mountain NP, and Monongahela National Forest were used to focus the CL discussions on questions and issues relevant to land managers, for three systems where a variety of ecosystem effects and deposition loads are present. Three Breakout Groups discussed each case study simultaneously so that consensus among groups could be gauged. Only Federal employees were involved in these three discussion groups, and they focused on recommended approaches for land managers to address critical loads. A fourth Breakout Group consisted of a mixture of researchers from federal and non-federal groups and discussed additional research needed to support the CL process.

Synopsis of Thresholds for FLM Consideration

There were several effects thresholds mentioned in the Day One presentations or included in the poster session presentations that are published in the peer-reviewed literature. They are summarized below. Managers who may wish to consider their use as effects thresholds, or resource protection criteria for development of critical loads, should consult with researchers in their area to determine site-specific applicability. It is understood that any thresholds are unlikely to be applicable to all ecosystems, and that adaptive management approaches could be used to adjust and refine both resource effects thresholds and critical loads as site specific information becomes more available in the future.

Western U.S.

1. Organic Horizon N of 1.2% for increased mineralization.
2. Soil C:N Ratio of 29 as threshold for N mineralization.
3. Soil C:N Ratio of 24 as threshold for increased N nitrification.
4. Lake N of 1mg/L as threshold for algal community changes.
5. 0.02% N in lichen tissue for increases in weedy nitrophilous lichen species (Pacific Northwest)

Eastern U.S.

1. ANC$\geq$ 0 µeq/L for chronic acidification of surface waters
2. ANC$\geq$ 20 µeq/L for episodic acidification of surface waters
3. ANC$\geq$ 50 µeq/L for sensitive aquatic species

Workshop Synthesis

The workshop synthesis and summary was derived from the workshop discussions on the second and third days, and are also presented as answers to the questions in the Decision Matrix Table (Table 2). This synthesis represents points of general agreement of the FLM participants at the workshop.

The following are recommendations for specific definition wording, FLM policy approaches, and improved science approaches from the Breakout Group discussions:

Recommended Definitions

- Critical Load is the deposition of one or more air pollutants at which a specific harmful effect begins to occur to ecological condition [i.e., structure (e.g., species richness) and function (e.g., primary productivity)].
- Interim Target Load is the deposition of one or more air pollutants that is an interim management goal, in areas where the CL is exceeded, toward attainment of the desired Target Load or Critical Load.
- Target Load is the deposition of one or more air pollutants that provides a reasonable margin of safety below the critical load or that will result in an "acceptable level" or resource protection.

Recommendations for Improving Management Approaches to Critical Loads

- CL is expressed for the most sensitive Class I area receptor; Class II area receptors can include other considerations in addition to sensitivity.
- CL is based on science (data); TL is policy-based (influenced by other considerations such as socioeconomic, political, practical).
- CL should be accompanied by explanations about what sensitive receptor the CL applies to and over what spatial extent the CL is applicable (e.g. "a CL of 3 kgN/ha/yr for protection of high elevation lake chemistry to an ANC of 50ueq/l in the Red Mountains wilderness area)
- CL may be expressed as a range where a population of resources is being described, or to describe the uncertainty around CL calculations for a sensitive receptor.
- CL may be expressed as a range with the management option of selecting a single value from the range.
- The decision whether CL can be used in FLM policy or management approaches should be based on the "weight-of-evidence" available.
- Monitoring deposition and sensitive receptor indicators is needed to support development of additional CL.
- A consistent approach or process among agencies should be developed to provide sensitive receptor and protection criteria information used by scientists to determine specific CL.
- A national framework (with regional refinements) for establishing CL would be useful.

- The process used to select CL/TL must be thoroughly documented, including assumptions made in data and modeling analyses, identification of sensitive receptors and the spatial extent of relevance; for the TL, time period to ecosystem recovery should also be made explicit.
- Use of "adaptive management" principles for CL development is highly recommended. Review => Revise => Adapt => Reiterate.
- A range of natural variability might be the envelope beyond which "harmful" effects are considered to occur. Defining "natural variability" will likely be difficult.
- A four-box model is a useful conceptual framework for considering sulfur and nitrogen deposition to terrestrial and aquatic ecosystems because it can be used to improve communication about which scenarios are under discussion.

	Acidification	Excess Nutrient Effects
Aquatic	S,N	N
Terrestrial	S,N	N

FLM CL Summary of Recommendations: Decision Matrix Table (Table 2)
Information or answers for each of the questions raised in Table 1 are summarized below.

Table 2. Workshop recommendations as answers to Table 1 questions.

What do we need to know or do to develop critical loads?	Workshop Recommendations
Select sensitive receptors and indicators for the AQRVs	1. Select the most sensitive receptors in Class I areas. Class II areas might consider other factors in addition to sensitivity 2. Terrestrial receptor indicators for acidification are typically tied to soil indicators. FLMs could focus on changes in soil chemistry indicators to define CL in terrestrial ecosystems due to acidification. 3. Aquatic receptor indicators for acidification are typically tied to ANC thresholds. FLMs could focus on changes in surface water ANC to define CL changes in aquatic ecosystems due to acidification. 4. Excess nitrogen indicators are not as well developed as acidification indicators. Preliminary indicators for excess nitrogen addition might be: • C:N ratios for terrestrial soils • Trophic indices or metrics for aquatic ecosystems
Establish protection criteria	1. FLMs protection criteria for aquatic ecosystem acidification will vary by system sensitivity and management goals, but 20ueq/l (as protection from episodic acidification), 50ueq/l (as protective of aquatic biota), and "natural condition" have been proposed for some Class I areas. 2. Criteria must be based on specific sensitive receptors and selected endpoints. 3. Physical/chemical indicators, as elements of ecological condition, can be used to establish CL and TL. 4. Linking physicochemical indicators with biological effects and deposition is the desired approach.
Estimate total deposition	1. Total deposition consists of wet, dry, and cloud/fog components. 2. Wet deposition can be estimated from NADP measurements, corrected for elevation and snowpack. 3. Dry deposition measurement techniques should continue to be improved to reduce uncertainty. 4. Lower bound total deposition estimates can be obtained by adding NADP wet deposition estimates to CASTNet dry deposition estimates. 5. Upper bound total deposition estimates can be obtained by adding wet deposition estimates to dry deposition estimates and estimates of fog or cloud deposition. 6. Total deposition should also be estimated on the scale and at the location of the most sensitive receptor.
Estimate effects to sensitive receptors for a range of protection criteria	1. The workshop specified that the FLM role is to identify sensitive receptors and protection criteria and that scientists role is to use this information when estimating CL to ensure that CL are useful to FLMs.
Select the critical load from a range of options	1. CL are expressed for the most sensitive Class I receptors 2. CL for Class II receptors can include other considerations in addition to sensitivity.

What do we need to know or do to develop critical loads?	Workshop Recommendations
	3. CL can be expressed as a range with the management option to select a single value from the range. 4. CL numbers selected should be accompanied by specific description of what sensitive receptor in which ecosystem the loading applies to.
Know the time to recovery or restoration where damage has already occurred	1. Dynamic models are required to estimate the time to recovery or restoration. 2. Development of a Descriptive Tool Box could include selection criteria to consider in choosing a dynamic model for use. 3. Selecting desired time frames to recovery is a policy decision, therefore loading to achieve these goals are TLs
Select an appropriate target load	1. The workshop discussed approaches for selecting appropriate target loads, and agreed that selection of target loads is a site specific process based on FLM policy considerations. 2. A separate work group might be established to further develop procedures for selecting appropriate target loads
Determine how critical loads can be used directly in PSD, NEPA, and other processes used by FLMs	1. Presentation by Fisher and Shaver discussed current and future approaches for FLMs to use CLs in their management processes. 2. FLMs will work with state and federal air regulators to determine if/how CL/TL could be incorporated into air quality regulatory processes. 3. After CLs are established for a few areas, FLMs might reconvene to discuss how they are being used, and to develop strategy for additional options.

Recommendations for Improving Science Approaches to Critical Loads

- "Eutrophication" is not the preferred term for nitrogen loading to aquatic ecosystems because effects are noted long before the system is considered eutrophic. "Excess nitrogen addition" is the preferred term.
- CL should be based on the best available data for both deposition estimates and effects estimates. A "weight-of-evidence" approach could be used that would corroborate estimates using other approaches.
- A descriptive tool box is needed with multiple approaches, including:
  1) Screening level approaches for sensitive receptors
  2) Model descriptions for
     - Order of magnitude estimates
     - Static or Empirical Models
     - Dynamic Models
  3) Synthesis reports that summarize research on the effects of deposition on sensitive resources

- Total deposition (wet+ dry+cloud/fog) is the preferred measure for expressing CL. The components of total deposition include:
  - Wet- NADP estimates, modified for elevation and snowpack

  - Dry- measurement techniques should continue to be improved to reduce uncertainty
  - Lower bound of total deposition estimate = NADP wet + CASTNet dry
  - Upper bound of total deposition estimate = NADP wet + CASTNet dry + other methods, including cloud deposition estimates
  - Total deposition should also be estimated on the scale and at the location of the most sensitive receptor
- A combined approach of monitoring and modeling is recommended for estimating total deposition.
- There are multiple interactions among stressors, including ozone, mercury methylation, invasive species, climate change, and others in addition to sulfur and nitrogen that can affect sensitive species. These interactions should be considered in addition to N and S loading when looking at ecosystem changes.
- Currently, the most generally accepted sensitive receptor indicator for acidification is ANC for aquatic ecosystems. Base Saturation decline and a decrease in the Ca/Al ratio are generally accepted indicators for terrestrial ecosystems. These could be a focus for further development of more spatially extensive assessment of critical loads across the U.S.
- An ANC greater than or equal to 50 μeq/L has been used in some areas to protect the most sensitive aquatic species, but the values should be site-specific wherever possible.
- Ultimately, linkages directly from deposition to biological effects are desired. However, during the interim, as these relationships are established, a two step process might be used in establishing CL:
  1) Deposition => Indicator Chemical Response
  2) Chemical Threshold => Biological Effect
- There is no single approach for estimating CL that is preferred. Multiple models, tools, indicators, and techniques should be used, understanding the time and budget constraints of using multiple methods.
- Modeled deposition scenarios should mimic current, expected, and desired rates of deposition, rather than a model sensitivity approach of +/- 100% change in deposition.
- C:N ratios in soils are useful in estimating the effects of excess nitrogen addition to terrestrial ecosystems.

<u>Recommendations for Critical Loads Research and Synthesis Products</u>
Several research topics and synthesis products were identified that would help FLMs use CLs in policy and management contexts:

- Determine which sensitive receptors and indicators for terrestrial ecosystems are most sensitive to deposition, and identify CLs for these.
- Develop sensitive receptor indicators for excess nitrogen additions for both terrestrial and aquatic ecosystems.
- More research is needed regarding thresholds at which "change" occurs to sensitive receptor indicators.

- Develop a “synthesis article” on current literature related to nitrogen induced changes in aquatic species productivity and composition changes.
- The effects of acidification on both terrestrial and aquatic ecosystems are better understood than the effects of excess nitrogen addition. Better understanding is needed regarding N fertilization effects.
- Conduct a synthesis of literature related to any changes/effects linked to loss of ANC, at higher ANC levels (between 50-200ueq/l).
- Conduct additional fertilization experiments to determine specific ecosystem thresholds that could be used to develop critical loads.
- Explore "trophic state index" as a tool for FLMs to use in determining aquatic ecosystem thresholds.
- Determine whether DIN/DON ratios can be used to show N saturation stages.
- Determine potential for developing CL for S based on Me-Hg (how much S does it take to increase Me-Hg to some unacceptable level).
- Develop “total uncertainty estimates”, including input, parameter, model constructs, etc.
- Establish approaches for partitioning the interactions and synergy among stressors, such as climate change, invasive species, from those effects due to S and N deposition.

Next Steps

<u>Policy Considerations Summary</u>
Rich Fisher and Chris Shaver provided impromptu comments on the workshop recommendations, decision matrix table, and their observations throughout the workshop. There were similar themes running through both their comments. While the workshop was a major step forward in moving toward consensus among FLMs in the USDA and DOI, more discussions are needed to develop a set of common definitions, sensitive receptors, or sensitive receptor indicators among the FLMs. In addition, a common framework or process is needed in developing quantitative CL. This process needs to be science-based, use consistent methods, provide information of value to FLMs, and be properly communicated. Differences among agencies are acceptable as long as the process is similar. All assumptions included as part of the CL/TL development process need to be fully documented.

A CL framework or process needs to be developed quickly because it should be integrated into the FS Planning and the NPS Inventory and Monitoring Processes. This framework is needed now. The desired end result is to integrate CLs into the daily decision-making process. To help move the process toward the desired end, a navigation chart with a series of lighthouses is needed to guide the way. These lighthouses include a set of common definitions, synthesis documents that provide case studies, a tool box with multiple approaches from simple to dynamic modeling for estimating CL and TL, studies that document the cascading effects and linkages from deposition to ecological endpoints, and examples of how CL and TL have been incorporated into the planning, inventory and monitoring, and decision-making process. Stakeholders, from state regulators to permittees, need to be engaged and understand the CL/TL process.

Remaining questions that also need to be addressed include: If FLMs use CL, is anything left behind? What are the remaining concerns about CL? Is CL the natural follow-on for ecosystem management? FLAG was a major milestone. These workshop recommendations could be the next major milestone and lighthouse.

Action Items

Action Items identified at the workshop included:

Action	**Time**
Presentation on ftp site	16 April
Draft workshop report	7 May
Follow-up Conference Call	9 June
Shenandoah, Rocky Mountain NP Test Cases	within next 2 years

Attachment A
Workshop Agenda
FLM Critical Sulfur & Nitrogen Loading Workshop
Denver, CO
March 30, 31, April 1, 2004

FLM Critical Loads Workshop Goals:

1. Discuss approaches for using critical loads and target loads in regulatory and policy recommendations, and management decisions in order to make the critical loads concept something that can be used by FLMs to protect and restore ecosystems.
2. Develop common understanding of critical load terminology and definitions so that staff from all FLM agencies can communicate critical loads issues effectively.
3. Understand the history and science behind development of critical loads in Europe and the U.S. in order to give context and background for future us of critical loads model outputs and empirical data by FLMs.
4. Develop strategies for selecting site specific critical and target loads from empirical data and modeling results where a range of critical loads and target loads are possible, to strive for consistency between parks, forests, regions, agencies in the application of critical loads.
5. Determine where a consistent approach (between regions, parks, forests, agencies) is possible for selecting types of information needed to determine critical loads (which sensitive receptors, which deposition data, which modeling tools to use) in areas where these decision have not yet been made.
6. Communicate specific critical loads data needs to researchers involved in critical loads modeling, and ecosystem effect of deposition, so that research and modeling results are most likely to meet manager's needs.
7. Develop strategy (and subsequent report) for items 2-6 above, in order to document progress and agreement on critical loads issue by FLMs.

SESSION I
March 30, 2004

Time	Topic	Individual
0800-0825	Workshop Goals, Introductions, Review Agenda, Logistics:	T. Blett, NPS
0825-0830	Facilitator Overview	K. Thornton, FTN
0830- 0900	Critical Loads Approach • Concept of Critical, Target Loads • Selecting Sensitive Species/Processes • Estimating Total Deposition Loads	E. Porter, NPS

- Selecting Desired Sensitive Endpoints and Effects
- Time to Recovery, Restoration
- Selecting from Ranges of Critical Loads
- Science versus Policy

0900-0915	Current FS Policy & Management Decisions on Critical Loads • FS Research and FLM Roles • EPA Issues in Critical Loads • FS Regional Workshops – Sensitive Receptors and Thresholds of Concern • NEPA • Future FS Uses of Critical Loads (Land Management Planning and Decision Making)	R. Fisher, FS
0915-0930	Current NPS Policy & Management Decisions on Critical Loads • FLAG • PSD/DAT • GPRA/Future Desired Conditions • Future NPS Uses of Critical Loads	C. Shaver, NPS
0930-0945	Decision Matrix Table	C. Huber
0945-1000	Questions, Discussion	All
1000	**BREAK**	
1020-1050	Western U.S. Science Overview: Target Species/ Processes/Effects Thresholds • Target Ecosystems and Sensitive Species/ Processes • Low Deposition Areas and Critical Loads • CL Information Available from LT (Temporal) Research • Comparative (Spatial) Studies • Modeling • Manipulative Studies • Top Three Research Needs in the West	J. Baron, USGS
1050-1120	Eastern U.S. Science Overview: Target Species/ Processes/Effects Thresholds • Target Ecosystems and Sensitive Species/Processes • High Deposition Areas and Critical Loads • CL Information Available from LT (Temporal) Research • Comparative (Spatial) Studies • Modeling • Manipulative Studies • Top Three Research Needs in the East	H. Van Miegroet, Utah State
1120-1140	Questions/Discussion	
1140-1210	Estimating Deposition Loads • Overview methods: Air Atlas, CASTNET, Eric Miller Estimates • Geographic Region Estimates	K. Morris, NPS

- Scenarios and Atmospheric Species
- Deposition Modeling versus Monitoring
- Deposition Loading Estimation Procedures: Pros/Cons
- Recommendations for Interagency Consistency

1210-1230 Questions, Discussion

1230-1330 **LUNCH – Order Box Lunches to Eat In**

1330-1345 Morning Summary, Critical Captures — K. Thornton

1345-1430 ICP Deposition Critical Loads- European Approach — P.Padgett, FS

- Overview of European Approach, History, Structure
- Sensitive Receptors, Deposition Loads: Process for Selection
- Estimating Effects and Time Frames
- Selecting The Critical or Target Load from a Geographic Range
- Incorporating Critical Loads Into European Management/Policy
- Contrasting Terrestrial versus Aquatic Resources
- Lessons Learned – What Can be Incorporated by FLMs in U.S?

1430-1500 Estimating Deposition Effects on Soils and Forest Ecosystems — L. Pardo, FS

- Estimation Procedures: ICP Forest model and other options
- Time to Recovery, Restoration
- Trend Monitoring Indicators – Which Ones?
- Receptor Effects- Examples of Results for FLM lands
- Moving from Thresholds to Critical Loads
- Decisions Needed by FLMs to Make Use of Modeling Results

1500-1515 Questions, Discussion

1515-1530 **BREAK**

1530-1600 ICP Waters Critical Loads — K. Thornton

- Sensitive Receptors, Deposition Loads: Process for Selection
- Estimating Effects and Time Frames
- Selecting The Critical or Target Load from a Geographic Range
- Static versus Dynamic Critical Load Estimates
- Incorporating Critical Loads Into European Management/Policy
- Lessons Learned – What Can be Incorporated by FLMs in U.S?

1600-1630 Estimating Deposition Effects on Surface Waters — T. Sullivan, E&S

- Estimation Procedures: MAGIC and other modeling options
- Time to Recovery, Restoration
- Receptor Effects- Examples of Results for FLM lands
- Decisions Needed by FLMs to Select From Modeled Ranges

1630-1650 Questions, Discussion — K. Thornton

1650-1705 Remaining Holes and Uncertainties: Group Discussion — K. Thornton

- Critical Gaps in Critical Loads
- Moving From Modeling to Management
- Assessing Progress
- Other Uncertainties

1705-1715 Wrap up Session I, Adjourn — K. Thornton

(1715-1730)	Day II Breakout Group Facilitators meet briefly for instructions)	

SESSION II
March 31, 2004

0800-0815	Things That Went Bump In The Night Session II Introduction and Objectives	K. Thornton
0815-0830	Case studies exercise: what do we hope to learn and accomplish?	E. Porter
0830-0845	Introduction to Shenandoah NP Case Study	E. Porter

For this case study, focus on S deposition loads, aquatic ecosystem impacts, highly impacted systems, modeling output data.

0845-1015	Research Break-out group discussions (concurrent)	
0845-1015	Shenandoah Break-out group discussions (concurrent)	
1015-1030	BREAK	
1030-1100	Reporting out Questions Discussion	ALL
1100-1115	Introduction to Monongahela NF Case Study	C. Huber

For this case study, focus on S and N deposition loads, terrestrial ecosystem impacts, critical loads assessment tools.

1115-1245	Research Break-out group discussions (concurrent)	
1115-1245	Monongahela Break-out group discussions (concurrent)	
1245-1345	**LUNCH ON YOUR OWN**	
1345-1415	Reporting out Questions Discussions	ALL
1415-1430	Introduction to Rocky Mountain NP Case Study	T. Blett

For this case study, focus on N deposition loads, aquatic and terrestrial impacts, subtly impacted systems, use of empirical data

1430-1615	Research Break-out group discussions (concurrent)	
1430-1615	Rocky Mountain NP Break-out group discussions (concurrent)	
1530-1545	BREAK	
1615-1645	Reporting out Questions Discussions	ALL
1645-1710	Afternoon Summary, Critical Captures Tomorrow's Agenda	K. Thornton

1710	**ADJOURN**	
1730-1830	Poster Session	

SESSION III
1 APRIL 2004

0800	Things That Went Clunk In The Night	K. Thornton
0815-0845	Synthesis of Discussion From Days 1 and 2 • Consensus of Breakout Groups - Criteria for Selecting Sensitive Receptors - Criteria for Selecting Critical and Target Loads - Prioritization of Actions to Facilitate Use of Critical Loads for Sensitive Areas - Incorporating Critical Loads Into Management Process and Decision-making • Areas of General Agreement • Issues	K. Thornton
0845-0915	Policy Implications of Discussions • Policy Implications From Consensus Activities • Future Science/Policy Needs	R. Fisher, C. Shaver
0915-1000	Issues Remaining to Develop Guidance For Incorporating Critical Loads Into The Management Process • Criteria for Selecting Sensitive Receptors • Criteria for Selecting Critical and Target Loads ▪ Prioritization of Actions to Facilitate Use of Critical Loads for Sensitive Areas • Incorporating Critical Loads Into Management Process and Decision-making	Group Discussion
1000-1015	**BREAK**	
1015-1100	Prioritization of Remaining Issues for Guidance Development	Group Discussion
1100-1130	Next Steps • Action Items • Milestones • Timeline	K. Thornton
1130-1145	Workshop Summary, Critical Captures	K. Thornton
1145-1200	Parting Words	T. Blett, R. Fisher
1200	**ADJOURN**	

Attachment B
Workshop Participants List
Critical Loads Meeting Participants:

FLM CRITICAL LOADS WORKSHOP MARCH 30-APRIL 1, 2004

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Attachment C

Poster Session

A poster session was held on the evening of the second day of the workshop. The intent of the poster session was to provide participants with an opportunity to provide additional information about critical loads or ecosystem thresholds projects that they have been involved with. Workshop participants were asked to provide input about the information presented in the posters, by answering a questionnaire as they reviewed the posters.

Poster Session Questions

(1) How could this approach be used to develop critical loads in Class I or other sensitive areas that I manage?
(2) What level-of -effort would it take to apply this method to other parks/forests or areas of the country?
(3) What are the strengths/weaknesses of the FLMs using this approach on a large scale?
(4) Will this methodology help us explain to the public "what sensitive resources we are protecting" and "what thresholds apply"?

Participant Comments

Poster 1: Forest Sensitivity to Acid Deposition (Eric Miller, Paul Arp, Ian DeMerchant, Natasha Duarte, Rock Ouimet, Linda Pardo, Sandy Wilmot)

1. Use same models with local data; needs more management input; what if scenario; good that it identifies sensitive areas and possible improvement.
2. Other weathering rate models needed; not clear how much data needed; split response – high/low level of effort.
3. + good to broad scale, can be used for what if scenarios.
   - maybe not good for specific sites – could be data intensive (not sure).
4. Yes.

Poster 2: Tree Nutrient Chemistry Database for New England Species (Molly Robin-Abbott, Natasha Duarte, Linda Pardo, Eric Miller)

1. Not clear addresses most sensitive receptor; I want to know natural range variability. Level of effort highest 4 being consistent; across FLM areas, less 4 site-specific; need more information on natural range soil chemistry to use it; 1 person/year for 10 years.
2. + uniform approach; public can understand.
   - we need data for all tree species in all ecotones; don't know natural range; same CL one species at locations? Other factors could dominate (climate….)

3. Yes (2 replies) — *Split response*
   Not directly/maybe (1 each) — Yes/maybe

Poster 3: DIN/DON As an Indicator of Ecosystem Status (Mark Williams, University of Colorado Boulder)

1. Looks useful as early alert tool/for N saturation
2. More technical approach
3. Would be easy to apply to other areas
   a. Strength – easy, simple, maybe cheap? (a number of folks said this)
   b. But perceived to require extensive sampling.

Poster 4: Developing A Lichen-Based CL (Linda Geiser- USDA Forest Service)

1. Good approach, broadly applicable, public can understand (low cost)
2. Data available (?) – varies (less w/NPS vs FS)
3. Weakness – less effective where heavily polluted; may not protect most sensitive
4. High level of effort to develop CL where data not currently available; need trained survey of collection crews

Poster 5: DOI Development and Application of Deposition Analysis Thresholds (Ellen Porter and Tamara Blett, National Park Service)

1. Needs much discussion with FS to be understood and adopted.
2. "Natural background" provides minimum values for CL
3. Strengths
   a. If we could agree and use over US would provide consistency.
   b. Calculations simple
4. Weakness
   a. Assumptions simplistic and therefore vulnerable.
   b. Unachievable – progress milestones needed
5. Helps articulate concern of degrading from a "natural condition".

Attachment D

List of Web Sites and Documents Related to Critical Loads

WEB SITES AND DOCUMENTS RELATED TO CRITICAL LOADS:

1. United Nations Economic Commission for Europe: Working Group on Effects
http://www.unece.org/env/wge/welcome.html

2. The International Cooperative Programme on Assessment and Monitoring of Acidification of Rivers and Lakes (ICP Waters)
http://www.unece.org/env/wge/waters.htm

3. The International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)
http://www.icp-forests.org

4. The New England Governors' and Eastern Canadian Premiers' Pilot Phase Report and Executive Summary (2003)
http://www.ecosystems-research.com/fmi/index.htm

5. ICP Mapping and Modeling
http://www.oekodata.com/icpmapping/index.html

6. Empirical Critical Loads for N
http://www.oekodata.com/icpmapping/index.html
Click on Publications in the 'Contents' at the left-hand side of the page, there is a link for this document at the very bottom of this page under Related Documents.

7. Very Simple Dynamic (VSD) soil acidification model
http://arch.rivm.nl/cce
Click on Methods and Models at the left-hand side of the page. The information on the VSD model is at the bottom of the page.

8. **Federal Land Managers Air Quality Related Value Work Group**

http://www2.nature.nps.gov/air/Permits/flag/flagfreeindex.htm

9. Forest Service Critical Loads web site

http://www.sgcp.ncsu.edu/criticalloads/workinggroups.html