DRAFT

Protocol for calculating critical loads of Nitrogen and Sulfur deposition for forest ecosystems in Forest Service class I areas

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1 Purpose

The purpose of this document is to outline a procedure for calculating critical loads of nitrogen (N) and sulfur (S) for forest ecosystems in Forest Service class I areas. A main objective in developing a protocol is to insure that the same approach can be used across all of these sites. It is highly advantageous to use a defined and consistent approach both so that critical loads from different sites can be compared easily, and so that the process and assumptions used are easily documented and readily available. The protocol would also ensure that the critical loads calculated would represent the protection of the same receptors, resources, or ecosystem components.

Although sulfur emissions have decreased as a result of SO_2 abatement legislation, projected emissions of both sulfur and nitrogen compounds are expected to have continuing negative impacts on forests, and to present serious long-term threats to forest health and productivity in the US. Critical loads can be used to determine the level of deposition expected to cause harmful ecological effects. Rather than providing detailed explanations of critical load equations and calculations, this document refers to other protocols (for example the European International Coordination Programme Mapping and Modelling manual for calculating critical loads; http://www.oekodata.com/pub/mapping/manual/mapman_5.pdf). For additional background about the approaches for calculating critical loads and the assumptions inherent in them, please see Pardo (In prepation; attached).

This document has two audiences: (1) federal land managers (FLM) - to give them information about the process of calculating critical loads and for reference about how the calculations were made and (2) research scientists - to give them instructions for how to make the calculations and to provide a standard format for documenting their calculations. The document begins with a description of the process of using a standard protocol (Section 2), provides an overview of the different types of approaches that can be used to calculate critical loads (Section 3), explains how the calculations are made in each of these cases (Section 4), and [this section will be completed later] makes recommendations about which approach would be best for each of the Forest Service class I areas (Section 5). Several companion documents are attached: (1) a description of ecosystem type and physical characteristics for each FS class I area, Appendix A1 ; (2) a summary of data available for each FS class I area, Appendix A2; (3) Data Management Protocol—instructions for manipulating data and entering it into the database, Appendix C; and (4) description of database structure, Appendix D. Ultimately, an additional document will be included that details the recommendations for calculation approach at each site.

2 Background

2.1 General background

Using a standardized protocol has many advantages both in terms of generating repeatable and documented results and clarifying the multi-step process used to calculate critical loads. The standardized protocol:

(1) gives specific instructions for how to go about calculating the CL

(2) makes explicit any assumptions

(3) addresses the two main factors that drive the CL values:

   a. data availability and procedures for handling gaps in data

   b. defining the critical threshold, based on the receptor of concern

(4) ensures that the process for calculating CL was repeatable

(5) ensures that when CL calculations are made, the process would be documented and therefore traceable.

A standard method for the class I areas has to incorporate considerable flexibility, because the data availability varies tremendously from site to site. Thus, the protocol does not call for eliminating detailed data at one site, because they are not available at another site. Instead, the protocol gives the order of preference of approach based on data availability. For a site with very intensive data, simple mass balance equations can be used with measured site data (like the ICP approach or the NEG/ECP approach for northeastern North America). If only some data are available, the simple mass balance method can be used in conjunction with empirically determined values. For example, at some sites, good soils data may be available from (NRCS) surveys, but there may be no vegetation data associated directly with the site. In this case, the soils data would be used with estimated vegetation data. Finally, when there are very few or no data available at a site, an empirical approach can be used, which classifies the site into a one of several categories associated with a value or range of values for each parameter.

The process of determining the best approach to use for calculating critical loads involves assembling information about the physical characteristics of a site, identifying any particular sensitive receptors at the site, selecting the critical threshold, determining which data are available, and, finally, selecting the calculation method based on data availability. These steps are taken by the research scientist making the CL calculation in collaboration with the FLM or air quality specialist. The next steps involve assembling the data necessary and making the CL calculations. Typically, the research scientist would assemble the data with input from the FLM, and would make the calculations.

2.2 How a standardized protocol is used

This protocol is intended to be used as an instruction manual for calculating critical loads. Because of the high level of detail involved in calculating critical loads, we refer to several previously developed protocols and manuals and point out deviations from their approach, rather than including that additional text in this protocol. The main protocols that we refer to are: the European ICP Mapping Manual (http://www.oekodata.com/pub/mapping/manual/mapman_5.pdf); European Empirical Critical Loads for Nitrogen (http://www.oekodata.com/icpmapping/index.html); the New England Governors and Eastern Canadian (NEG/ECP) Premiers Forest Mapping Project Protocol (FMG, 2001); and the Data Management Protocol developed for this project (Appendix C). Data management for these calculations is not a trivial task and is generally done using a relational database such as Microsoft Access. It requires extensive QA/QC and rigorous documentation.

3 General Approach scheme

3.1 Overview of factors that influence method selection

Data availability determines which method is used to calculate critical loads, as described above. It is preferable to use reliable site data, or as much of the site data as possible, rather than modeled or empirically estimated values.

The other significant factor in critical loads equations is the ***critical threshold*** that is used. One of the challenges in estimating critical loads is trying to relate the ultimate biological or ecosystem effect to some measurable quantity—often a chemical characteristic. This chemical characteristic is referred to as a *critical threshold*. In general, the critical threshold that best addresses the receptor of concern is selected (for example, for some receptors, a change in pH would be the problem, for others, the Al concentration).

3.2 General description of approaches

There are three main types of approaches for calculating critical loads.

3.2.1 Empirical Approach

Empirical approaches are based on observations of response of ecosystem or ecosystem component (e.g. foliage, lichens, soil) to a given, observed deposition level. Empirical critical loads are then applied to similar sites where such data are not available.

3.2.2 Steady-State Mass Balance Approach

Simple mass balance approaches are based on estimating the net loss or accumulation of nutrients based on inputs and outputs of the nutrient of concern (e.g. base cation, nitrogen). Simple mass balance methods are *steady-state* models used to calculate the critical load of deposition to an ecosystem over the long term (i.e. one rotation in land managed for timber, 100+ years in wilderness). They are used at sites with moderate to intensive data available.

3.2.3 Dynamic modelling

Dynamic models use a mass balance approach expanded by incorporating internal feedbacks—such as accumulation of N in the system, or exchange of base cations between soil and soil solution from year to year. Dynamic models allow the prediction of time to damage and time to recovery. Dynamic models are generally used at sites where intensive data are available.

3.2.3.1 Very Simple Dynamic Model

The Very Simple Dynamic (VSD) model (Posch et al., 2003a) is currently used by the EU ECE ICP Mapping and Work Group. The VSD model is much simpler than most dynamic models and requires only slightly more data than the steady-state mass balance data. Therefore, it can be used at sites where these additional data are available (soil characteristics: cation exchange capacity, base saturation, and C:N ratio). This approach can provide valuable additional information without the major time investment of more complex models.

3.2.3.2 Complex Dynamic Modelling

Models that have been used in critical loads calculations include MAGIC (Cosby and Wright 1998), SAFE (Sverdrup et al. 1995), SMART (Posch et al. 2003b), PnET-BGC (Backx 2004) and DayCent-Chem. These models tend to have extensive data requirements and are typically used at sites with considerable data. However, it is possible to apply a thoroughly tested dynamic model using sparser data inputs—the quality and reliability of the results, as always, are related to the quality of the input data. Therefore, a regional application of a dynamic model using broad, small regional datasets will not provide the kind of results that a dynamic model can provide at a site with intensive data.

3.3 Order of preference

For FS class I areas, given the size and range of sites, often there are only limited data available. In this section we discuss which approach is preferred based on how much data is available.

3.3.1 Intensive data—calculations/modelling

If extensive data are available, the critical load can be calculated using the steady-state mass balance approach. If sufficient data are available for either VSD or more complex dynamic modelling, these models (see section 3.2.3) may be used to estimate time to damage or time for recovery.

3.3.2 Moderate data—calculations/empirical estimation

When moderate data are available or detailed data are available for some parameters (e.g. soil) but not others (e.g. deposition), a combination of the steady-state mass balance method using data and using empirically derived categories should be used. In this example, actual soil data would be used in the SSMB equations coupled with deposition data estimated using the categorical approach.

3.3.3 Empirical

Finally, if few data are available, the empirical approach would be used. The empirical approach can be enhanced by categorizing the site according to its characteristics and thereby limiting the range of the parameters used in estimating the critical load. This type of empirical approach is referred to as the categorical approach.

4 Specific Approach scheme

4.1 SSMB

Generally, the steady-state mass balance approach is described in the ICP Mapping Manual (http://www.oekodata.com/pub/mapping/manual/mapman_5.pdf). Because of the extensive description there, what we note below are deviations from the instructions given in the mapping manual Chapter 5. Specific data handling instructions are given in the data management protocol (Appendix C).

4.1.1 ICP Approach

The main equations used in the ICP approach are given in the following boxes. The equations are numbered as they are in the ICP Mapping Manual for ease of reference. The derivation of these equations is covered in detail in the Mapping Manual (http://www.oekodata.com/icpmapping/index.html).

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

(5.19) $CL(S)+CL(N) = BC_{dep} - Cl + BC_w - BC_u + N_a + N_u + N_{de} - ANC_{le,crit}$

Maximum critical load for sulfur $\boldsymbol{CL_{max}(S)}$***)***

The maximum critical load for sulfur is given by:

(5.22) $CL_{max}(S) = BC_{dep} - Cl + BC_w - BC_u - ANC_{le,crit}$

where:

Bc_{dep} - sum of Ca + Mg + Na+ K deposition rate (eq ha-1 yr-1)

BC_w - soil weathering rate of Ca + Mg + K + Na (eq ha-1 yr-1)

BC_u - net Ca + Mg + K uptake rate (eq ha-1 yr-1) ultimately removed by harvest or disturbance

$ANC_{le,crit}$ - sustainable acid neutralizing capacity (ANC) leaching rate (eq ha^{-1} yr^{-1}).

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Minimum critical load of N, $\boldsymbol{CL_{min}(N)}$***)***

As long as N deposition stays below *CLmin(N)*, all deposited N is consumed by N sinks within the ecosystem or lost via denitrification. In this case, *CLmax (S)* alone determines the maximum critical load for acidity.

(5.23) $N_{dep} \leq N_a + N_u + N_{de} = CL_{min}(N)$

where:

N_{dep} - nitrogen deposition

N_a - net N accumulation rate in the soil (eq ha-1 yr-1)

N_u - net N uptake rate (i.e., increment of nutrient in biomass; eq ha^{-1} yr^{-1})

N_{de} - soil denitrification rate (eq ha-1 yr-1)

Maximum critical load of N, $\boldsymbol{CL_{max}(N)}$***)***

(5.24) $CL_{max}(N) = CL_{max}(N) + CL_{max}(S)$

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Maintenance of the soil base saturation is closely linked with a base cation leaching rate, calculated as

$$(5.31)\quad ANC_{le,crit} = -1.5\frac{BC_{dep}+BC_w-BC_u}{(BC/Al)_{crit}} - Q^{2/3}\left(1.5\frac{BC_{dep}+BC_w-BC_u}{(BC/Al)_{crit}K_{gibb}}\right)^{1/3}$$

where:

$(BC/Al)_{crit}$	- ratio of base cations to Al (eq/eq) in the soil percolate that would be consistent with maintaining a particular base saturation level
Kgibb	- gibbsite dissolution constant that controls Al solubility (m6 eq-2) the multiplication factor 1.5 arises from the conversion from moles to equivalents
Q	- rate of soil percolation (combined lateral and downward), which can be assumed equal to stream water flux (m yr-1).

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Finally,

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Exceedance

The magnitude of the exceedance indicates the severity of nutrient depletion caused by sulfur and nitrogen deposition and is calculated as:

Exceedance = Sdep + max {Ndep –SDmin(N), 0} - SDmax(S)

where:

S_{dep}	- sulfur deposition
N_{dep}	- nitrogen deposition
$CL_{min}(N)$	- the minimum critical load of nitrogen
$CL_{max}(S)$	- the maximum critical load of sulfur

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4.1.2 Deviations from ICP Approach

The deviations for forest ecosystems in class I areas from the ICP protocol are noted below:

- BC_u is replaced by BC_{fire} - net Ca + Mg + K uptake rate (eq ha-1 yr-1) ultimately removed by fire. In class I areas, there would be no biomass removal by harvesting.

Similarly,

- N_u is replaced by N_{fire} - net N removed by fire (eq ha^{-1} yr^{-1}). In class I areas, there would be no biomass removal by harvesting.
- The $\boldsymbol{BC/Al_{crit}}$ value of 1 is replaced by 10, which is a more conservative value, more likely to result in no reduction in base saturation.
- The ICP protocol calls for the use of throughfall as total deposition. At most US sites, the total deposition is generally estimated based on wet+dry deposition and includes cloud/fog deposition when estimates are available.

4.2 Empirical critical loads for acidity

Empirical critical loads are used when site-specific data are not available or are not reliable. This section details categorical approaches for estimating mineral weathering, nutrient removal via fire biomass removal, and total deposition inputs. The categorical approach is a type of empirical approach, the accuracy of which can be enhanced when more precise information about site characteristics are available.

4.2.1 Mineral Weathering

The approach we propose for estimating mineral weathering is based directly on the approach described in the ICP Mapping Manual. The simplest approach involves classifying mineral type and estimating the critical load for acidity directly, by assuming that the mineral weathering rate is the most important factor driving the critical load calculations. If one has slightly more information about the relative proportions of different minerals at a site, it is possible to make a more refined estimate of the mineral weathering rate. Furthermore, one can adjust the estimates within the ranges given based on several factors. These include precipitation, conifers/hardwoods present, elevation, soil texture, soil drainage, and base cation deposition.

It is preferable, if one has some information about the relative percent of different minerals present, to use this slightly more nuanced approach.

Deviations from the ICP protocol include modifying Table 5.4 to include broader descriptive categories, and adding the minerals found in class I areas that were not already included in the classification of minerals to be used with Table 5.6.

The following text is excerpted from Section 5.2.2 Empirical Critical loads of acidity of the Mapping Manual

The numbering of tables follows that of the mapping manual.

Empirical approaches assign an acidity critical load to soils on the basis of soil mineralogy and/or chemistry. For example, at the Critical Loads Workshop at Skokloster (Nilsson and Grennfelt 1988) soil forming materials were divided into five classes on the basis of the dominant weatherable minerals. A critical load range, rather than a single value, was assigned to each of these classes according to the amount of acidity that could be neutralized by the base cations produced by mineral weathering (Table 5.4). Other methods of estimating base cation weathering are discussed in Chapter 5.3.2.

Modified version of Table 5.4: Mineralogical classification of soil materials and soil critical loads.

Mineral Class	**Examples of minerals controlling weathering**	**Critical load range (eq/ha/yr)**
Inert or very slow weathering minerals	Quartz, K-feldspar	<200
Slow and intermediate weathering minerals (<5%)	Muscovite, Plagioclase, Biotite	200-500
Intermediate weathering minerals (<5%)	Biotite, Amphibole	500-1000
Fast and intermediate weathering minerals (<5%)	Pyrozene, Epidote, Olivine	1000-2000
Very fast weathering minerals	Carbonates	>2000

In addition, a number of modifying factors were identified that would enable the critical load value to be adjusted within the ranges (Table 5.5, after Nilsson and Grennfelt 1988). For example, some factors could make the soil more sensitive to acidification, requiring the critical load to be set at the lower end of the range; while other factors could make the soil less sensitive, setting the critical load at the upper end of the range.

Table 5.5: Modifying factors causing an increase or decrease in critical loads.

Modifying factor	**Effect on critical load:**	
	Decrease	**Increase**
Precipitation	High	Low
Vegetation	Coniferous forest	Deciduous forest
Elevation, slope	High	Low
Soil texture	Coarse-sandy	Fine
Soil drainage	Free	Impeded
Soil sulphate adsorption capacity	Low	High
Base cation deposition	Low	High

The classification of soil materials developed at Skokloster (Table 5.4) used a relatively small range of primary silicate minerals and carbonates. A larger range of minerals has been classified by Sverdrup and Warfvinge (1988) and Sverdrup et al. (1990). The following mineral classes have been identified. *The text below has been expanded to include the minerals found in class I areas. These additions are shown in italics*:

Very fast weathering minerals (carbonates) include minerals that have the potential to dissolve very rapidly, in a geological perspective. The group includes *aragonite*, brucite, calcite, dolomite, and magnesite.

Fast weathering minerals include the silicate minerals with the fastest weathering rate. The group comprises minerals such as anhydrite, anorthite, diopside, *forsterite*, garnet, *gypsum*, *halite*, jadeite, *leucite*, nepheline, olivine, *spodimene*, *sylvite*, and *wollastonite*. A soil with a major content of these minerals would be resistant to soil acidification.

Intermediate weathering minerals include *actinolite, andesine, antophyllite***,** augite, biotite, chlorite, *chrysotile***,** enstatite, epidote, *fluorite***,** glaucophane, hornblende, *hedenbergite*, hypersthene, *lizardite, riebeckite, serpentine, talc***,** tremolite, and zoisite.

Slow weathering minerals include albite, *andalusite***,** illite, *kyanite***,** labradorite, oligoclase, and *sillimanite*. Soils with a majority of such minerals will be sensitive to soil acidification.

Very slow weathering minerals include *antigorite, barite*, K-feldspar, mica, montmorillonite, muscovite, *sanidine*, and vermiculite. Soils with a majority of these minerals will be sensitive to soil acidification.

Inert minerals are those that dissolve so slowly or provide so little neutralizing substance that they may be considered as inert for soil acidification purposes. This includes minerals such as anatase, *apatite, goethite*, gibbsite, *hematite*, kaolinite, *lazurite, magnetite*, quartz, rutile, *staurolite, tourmaline*, zeolite, and *zircon*.

For each of the above mineral classes, weathering rates for soils with different mineral contents have been proposed (Table 5.6, Sverdrup et al. 1990).

Table 5.6: Weathering rates (in *eq/(ha · M)/yr*) for four selected mineral classes of soil material based on a soil depth of one meter – to convert to critical load values multiply by soil thickness in meters.

Mineral class	***Average soil mineral class content***			
	100%	30%	3%	0.3%
Very fast weathering	25000	15000	10000	3000
Fast weathering	15000	10000	3000	300
Intermediate weathering	10000	3000	300	30
Slow weathering	600	200	20	-
Very slow weathering	300	100	10	-
Inert	100	100	-	-

The information provided in Tables 5.4 to 5.6 above provide the basis on which empirical acidity critical loads can be assigned to soils. If mineralogical data are available for the units of a soil map, critical loads can be assigned to each unit and a critical loads map produced.

An example of the development of a critical load map at the national scale using empirical approaches is given by Hornung et al. (1995). In the UK this approach has been used to define acidity critical loads for non-forest ecosystems, by setting a critical load that will protect the soil upon which the habitat depends (Hatt et al. 1998, 2003). The critical load is effectively the base cation weathering rate, with the leaching of acid neutralizing capacity (ANC) set to zero (see section 5.3.2), and can be used in the calculations of the maximum critical loads of sulphur and nitrogen (see section 5.3.3).

A State Soil Geographic (STATSGO) data base exists for entire U.S.; the approximate minimum area delineated is 625 ha, mapped at a 1:250,000 scale. While soil is highly variable spatially, in the absence of any other data, attributes from the STATSGO database can be used to modify the categorical approach. Among the many attributes included in the STATSGO database, those that affect the critical load include soil taxonomic class, general mineralogy, soil depth to limiting layer, soil depth to bedrock, soil texture, soil drainage, soil pH, bulk density, presence of carbonates, and ranges of cation exchange capacity. Typically, associations or complexes of two to four soil types are identified in each STATSGO map unit ID. The categorical critical loads can be modified for each soil type to assign a potential minimum and maximum critical load for the map unit area, or an average can be assigned.

4.2.2 Vegetation

For class I areas, harvesting is not allowed, so the vegetation removal by harvesting component is, by definition, zero. Note that disturbance such as blow-down is not considered the same as harvesting, because the biomass is not **removed** from the site. Fire, on the other hand, does include removal, so in that case it is necessary to include information about the severity and frequency of fire, in order to determine the biomass that would be removed over the period of concern (100+ years).

In order to develop an empirical approach for estimating nutrient removal via fire at those sites for which fire is significant, information about ecosystem biomass, nutrient content and fire patterns would be used to classify each site. For sites where the frequency or intensity of fire is low, nutrient removal by fire would be zero.

In certain areas, for example, in the northeastern US, it is possible to make estimates of nutrient removal via biomass removal based on a compilation of tree chemistry data for the region (Pardo et al., 2005). This Tree Chemistry Database was designed to be a comprehensive and searchable relational database of C, N, P, K, Ca, Mg, Mn, and Al concentrations in aboveground tree biomass compartments (i.e. bole bark, bole wood, branches, foliage) for tree species found in the northeastern United States. When species composition and diameter at breast height (DBH) are known, allometric equations can be used to calculate total above-ground biomass and biomass by tree compartment (bole wood, bark, branch, and foliage). The mass of the tree compartments harvested multiplied by species-specific nutrient content from the Tree Chemistry Database gives the estimates of nutrient removal.

It would be possible to develop a similar database for tree chemistry across the U.S. Then, it would be necessary to develop estimates of biomass removed by fire based on estimates for fire frequency and intensity over a one hundred year period.

If biomass removal is not included in critical loads estimates, this would result in over-estimating the CL for acidity (because the loss of base cations in biomass was ignored), and would result in under-estimating the CL for N and Nutrient N (because the loss of N in biomass was ignored). Based on past work in the Northeast, the effect of biomass removal could range from 125 eq/ha/yr to 863 eq/ha/yr for base cations, and from 8 eq/ha/yr to 389 eq/ha/yr for N.

4.2.3 Atmospheric deposition

In order to determine the exceedance or excess deposition, it is necessary to estimate the actual deposition at each site (Exceedance=actual deposition – critical load). On the national scale, maps of total deposition are not available. National Atmospheric Deposition Program (NADP) maps include wet deposition only. It has been suggested that a single factor between 1.4 and 2 (total:wet deposition) be applied across the country to estimate total deposition. However, there is considerable variability across sites and between S and N. At some sites, inputs from dry deposition and cloud and fog account for more than wet deposition. For example, based on and NADP data for the mean of ratios from 1989-2003, the total to wet deposition ratio ranged from 1.1 to 2.7 for S and 1.1 to 4.8 for N (Table 1). When the individual years were evaluated, there was considerably more variability.

Table 1. Total:wet deposition ratios based on and NADP data from 1989-2003

	S total:wet deposition	**N total:wet deposition**
Minimum for 1994-2003 ratios mean	1.1	1.1
Maximum for 1994-2003 ratios mean	2.7	4.8
Minimum for 1994-2003 ratios (individual years)	1.03	1.05
[1]Penultimate value for 1994-2003 ratios (individual years)	6.2	10
Maximum for 1994-2003 ratios (individual years)	9	21

[1]This value is included in case the highest value was an outlier—the second highest value.

Because of the scarcity of, variability in quality of, and complexity in modelling dry deposition data, it has also been proposed that only NADP wet deposition data values be used, because they are broadly available. Using a known underestimate, however, is not an acceptable solution. In that case, the actual exceedance of critical loads would systematically be higher than reported, potentially resulting in detrimental ecological effects at some sites.

Any total to wet deposition factor that is used will include some inaccuracy. For the purpose of these calculations, we propose modifying the deposition ratio based on several factors: precipitation volume, elevation, climate (seasonality), and tree species (hardwood or conifer). Table 2 shows how these factors tend to affect the total:wet deposition ratio. One of our main goals is to try to ensure that we capture the extremes of high deposition, especially N deposition at dry sites or high elevation sites with significant cloud cover and/or fog events.

Table 2. Trends in total:wet deposition ratio with Precipitation, elevation, climate, and species

Total: Wet Deposition Ratio	**Precipitation volume**	**Elevation**	**Climate**	**Species**
Low ↓ **High**	↑	↓	Year-round precipitation ↓ Seasonally dry	Hardwood ↓ Conifer

The information in Tables 1 and 2 will be used to determine deposition factors for each of the class I areas based on the deposition factor at nearby /NADP sites (in the absence of site data).

That deposition factor will be adjusted according to the factors in Table 2. One very significant factor in determining the total:wet deposition ratio is whether there is a long dry period. Sites with a significant dry period may receive the vast majority of deposition inputs as dry deposition and fog, and may have a total:wet deposition ratio as high as 10. Since seasonal dryness is such an important issue, information such as that in Table 3 could be used to adjust the total to wet deposition ratio. The result of this process will be a table like Table 4.

Table 3 Effect of seasonal dry periods on total:wet deposition ratio

	Annual precipitation volume (cm)			# months< (mean ann. ppt vol/24)			# months< (mean ann. ppt vol/48)			Affect on deposition ratio
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	
DRY DOMAIN										
Temperate Desert Division	27	36	56	0	2.00	3	0	0.00	0	High
Temperate Steppe Regime Mountains Division	41	79	155	0	0.49	3	0	0.00	0	Low
Tropical/Subtropical Desert Division	10	31	53	3	3.13	4	0	1.38	2	High
Tropical/Subtropical Regime Mountains Division	38	50	63	1	2.43	3	0	0.14	1	Moderately high
Tropical/Subtropical Steppe Division	45	49	52	1	2.18	3	0	0.91	1	Moderately high
HUMID TEMPERATE DOMAIN										
Hot Continental Division	102	133	152	0	0.00	0	0	0.00	0	Low
Marine Regime Mountains Division	55	165	233	1	3.64	5	0	1.12	2	High
Mediterranean Regime Mountains Division	26	91	270	0	4.69	6	0	2.46	5	Very high
Subtropical Division	126	140	147	0	0.00	0	0	0.00	0	Low
Warm Continental Division	72	79	141	0	2.47	3	0	0.00	0	Low

Table 4. Total:wet deposition ratio based on NADP deposition ratios, precipitation, climate, and species composition

Class I area	NADP Total:Wet Deposition Ratio	Precpitation volume	Climate	Species (conifer, hardwood)	Estimated Total:Wet Deposition Ratio
1					
2					
3					
4					
5					

4.2.4 Mixed

At some sites, for certain parameters, sufficient data will be available that one of the necessary parameters may be calculated, but there are not sufficient data to calculate the others. In that case, the best approach is to use the measured site data for the parameter for which it is available, and use the categorical approach for the other parameters. [give specific scenarios here]

5 Site recommendations

This section consists of a table listing the class I areas and summarizing the recommended method for calculating critical loads for each site. Appendix B gives more specific information about data sources, data availability and reasoning. The highest quality level for data is 1, the lowest if 5. The categories of data quality are also described in Appendix B.

	Class 1 Area	State	Model Type	Quality of data available for model		
				Deposition	Vegetation	Soil
REGION 1						
1	**Anaconda Pintler Wilderness**	MT	**Categorical**	**3**	**3**	**5**
2	**Bob Marshall Wilderness**	MT	**Categorical**	**4**	**3**	**5**
3	**Cabinet Mountains Wilderness**	MT	**Categorical**	**4**	**4**	**5**
4	**Gates of the Mountains Wilderness**	MT	**Categorical**	**3**	**4**	**5**
5	**Mission Mountains Wilderness**	MT	**Categorical**	**4**	**4**	**5**
6	**Scapegoat Wilderness**	MT	**Categorical**	**4**	**3**	**5**
7	**Selway-Bitterroot Wilderness**	ID/MT	**Categorical**	**3**	**3**	**5**
REGION 2						
1	**Eagles Nest Wilderness**	CO	**Categorical**	**4**	**5**	**5**
2	**Fitzpatrick Wilderness**	WY	**Categorical**	**3**	**4**	**5**
3	**Flat Tops Wilderness**	CO	**Categorical**	**4**	**5**	**5**
4	**La Garita Wilderness**	CO	**Categorical**	**4**	**4**	**5**
5	**Maroon Bells-Snowmass Wilderness**	CO	**Categorical**	**3**	**4**	**5**
6	**Mount Zirkel Wilderness**	CO	**Categorical**	**4**	**5**	**5**
7	**North Absaroka Wilderness**	WY	**Categorical**	**4**	**4**	**5**
8	**Rawah Wilderness**	CO	**Categorical**	**4**	**5**	**5**
9	**Washakie Wilderness**	WY	**Categorical**	**4**	**4**	**5**
10	**Weminuche Wilderness**	CO	**Categorical**	**3**	**5**	**5**
11	**West Elk Wilderness**	CO	**Categorical**	**4**	**3**	**5**
REGION 3						
1	**Chiricahua Wilderness**	AZ	**Categorical**	**1(dated); 4**	**4**	**5**

	Class 1 Area	State	Model Type	Quality of data available for model		
				Deposition	**Vegetation**	**Soil**
2	**Galiuro Wilderness**	AZ	**Categorical**	**4**	**4**	**5**
3	**Gila Wilderness**	NM	**Categorical**	**3p**	**2**	**3**
4	**Mazatzal Wilderness**	AZ	**Categorical**	**4**	**4**	**5**
5	**Mount Baldy Wilderness**	AZ	**Categorical**	**4p**	**2**	**3**
6	**Pecos Wilderness**	NM	**Categorical**	**4p**	**2**	**3**
7	**Pine Mountain Wilderness**	AZ	**Categorical**	**4p**	**2**	**3**
8	**San Pedro Parks Wilderness**	NM	**Categorical**	**3p**	**2**	**3**
9	**Sierra Ancha Wilderness**	AZ	**Categorical**	**4p**	**4**	**5**
10	**Superstition Wilderness**	AZ	**Categorical**	**4p**	**4**	**5**
11	**Sycamore Canyon Wilderness**	AZ	**Categorical**	**4p**	**2**	**3**
12	**Wheeler Peak Wilderness**	NM	**Categorical**	**4p**	**2**	**3**
13	**White Mountain Wilderness**	NM	**Categorical**	**4**	**3**	**5**
REGION 4						
1	**Bridger Wilderness**	WY	**Categorical**	**3**	**4**	**5**
2	**Hells Canyon Wilderness**	ID/OR	**Categorical**	**4**	**4**	**5**
3	**Hoover Wilderness**	CA	**Categorical**	**4**	**4**	**5**
4	**Jarbidge Wilderness**	NV	**Categorical**	**4**	**4**	**5**
5	**Sawtooth Wilderness**	ID/OR	**Categorical**	**4**	**4**	**5**
6	**Teton Wilderness**	WY	**Categorical**	**1**	**3**	**5**
REGION 5						
1	**Agua Tibia Wilderness**	CA	**Categorical**	**2**	**4**	**4**
2	**Ansel Adams Wilderness**	CA	**SMB, D (ICP Demo Plot)**	**2**	**5**	**5**

	Class 1 Area	State	Model Type	Quality of data available for model		
				Deposition	**Vegetation**	**Soil**
3	**Caribou Wilderness**	CA	**Categorical**	**2**	**5**	**5**
4	**Cucamonga Wilderness**	CA	**Categorical**	**2**	**5**	**4**
5	**Desolation Wilderness**	CA	**Categorical**	**2**	**5**	**4 (partial)**
6	**Domeland Wilderness**	CA	**Categorical**	**2**	**4**	**5**
7	**Emigrant Wilderness**	CA	**Categorical**	**2**	**5**	**5**
8	**John Muir Wilderness**	CA	**SMB, D (ICP Demo Plot)**	**2**	**5**	**5**
9	**Kaiser Wilderness**	CA	**SMB, D (ICP Demo Plot)**	**2**	**5**	**5**
10	**Marble Mountain Wilderness**	CA	**Categorical**	**2**	**5**	**5**
11	**Mokelumne Wilderness**	CA	**Categorical**	**2**	**4**	**5**
12	**San Gabriel Wilderness**	CA	**Categorical**	**2**	**5**	**4**
13	**San Gorgonio Wilderness**	CA	**Categorical**	**2**	**4**	**4 (partial)**
14	**San Jacinto Wilderness**	CA	**Categorical**	**2**	**4**	**4 (partial)**
15	**San Rafael Wilderness**	CA	**Categorical**	**2**	**4**	**4**
16	**South Warner Wilderness**	CA	**Categorical**	**2**	**5**	**5**
17	**Thousand Lakes Wilderness**	CA	**Categorical**	**2**	**5**	**5**
18	**Ventana Wilderness**	CA	**Categorical**	**2**	**4**	**4**
19	**Yolla Bolly-Middle Eel Wilderness**	CA	**Categorical**	**2**	**4**	**4 (partial)**
REGION 6						
1	**Alpine Lakes Wilderness**	WA	**Categorical**	**4p**	**5**	**4 (partial)**
2	**Diamond Peak Wilderness**	OR	**Categorical**	**4p**	**5**	**5**
3	**Eagle Cap Wilderness**	OR	**Categorical**	**3p**	**4**	**5**

	Class 1 Area	State	Model Type	Quality of data available for model		
				Deposition	Vegetation	Soil
4	**Gearhart Mountain Wilderness**	OR	**Categorical**	**4p**	**5**	**5**
5	**Glacier Peak Wilderness**	WA	**Categorical**	**4p**	**5**	**4 (partial)**
6	**Goat Rocks Wilderness**	WA	**Categorical**	**3p**	**5**	**5**
7	**Kalmiopsis Wilderness**	OR	**Categorical**	**4p**	**5**	**4**
8	**Mount Adams Wilderness**	WA	**Categorical**	**3p**	**5**	**5**
9	**Mount Hood Wilderness**	OR	**Categorical**	**3p**	**5**	**5**
10	**Mount Jefferson Wilderness**	OR	**Categorical**	**4p**	**5**	**5**
11	**Mount Washington Wilderness**	OR	**Categorical**	**4p**	**5**	**5**
12	**Mountain Lakes Wilderness**	OR	**Categorical**	**4p**	**5**	**5**
13	**Pasayten Wilderness**	WA	**Categorical**	**4p**	**5**	**5**
14	**Strawberry Mountain Wilderness**	OR	**Categorical**	**4p**	**5**	**5**
15	**Three Sisters Wilderness**	OR	**Categorical**	**4p**	**5**	**5**
REGION 8						
1	**Bradwell Bay Wilderness**	FL	**Categorical**	**2**	**4**	**4**
2	**Caney Creek Wilderness**	AR	**Categorical**	**2**	**4**	**4**
3	**Cohutta Wilderness**	GA/ TN	**SSMB, Dynamic**	**2**	**2**	**1**
4	**James River Face Wilderness**	VA	**SSMB, Dynamic**	**1**	**2**	**1**
5	**Joyce Kilmer-Slickrock Wilderness**	NC/TN	**SSMB, Dynamic**	**2**	**1**	**1**
6	**Linville Gorge Wilderness**	NC	**SSMB, Dynamic**	**1**	**1**	**1**
7	**Shining Rock Wilderness**	NCl	**SSMB, Dynamic**	**1**	**2**	**1**

	Class 1 Area	State	Model Type	Quality of data available for model		
				Deposition	Vegetation	Soil
8	**Sipsey Wilderness**	AL	**SSMB, Dynamic**	**2**	**2**	**1**
9	**Upper Buffalo Wilderness**	AR	**Categorical**	**2**	**4**	**4**
REGION 9						
1	**Boundary Waters Categoricalanoe Area Wilderness**	MN	**Categorical**	**4**	**4**	**5**
2	**Dolly Sods Wilderness**	WV	**SMB, D (ICP Demo Plot)**	**1**	**4**	**5**
3	**Great Gulf Wilderness**	NH	**Categorical**	**2**	**2**	**4**
4	**Hercules-Glades Wilderness**	MO	**Categorical**	**3**	**4**	**4**
5	**Lye Brook Wilderness**	VT	**SSMB, Dynamic**	**2**	**2**	**2**
6	**Otter Creek Wilderness**	WV	**SSMB, Dynamic**	**1**	**1**	**1**
7	**Presidential Range-Dry River Wilderness**	NH	**Categorical**	**2**	**2**	**4**
8	**Rainbow Lake Wilderness**	WI	**Categorical**	**4**	**4**	**4**

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Sverdrup, H., M. Alveteg, S., Langan, and T. Paces. 1995. Biogeochemical Modelling of Small Catchments using PROFILE and SAFE, in Solute Modelling in Catchment Systems, S.T. Trudgill, Editor., John Wiley & sons: Chichester. p. 75-99.

6.1 Web sites

European Empirical Critical Loads for N: http://www.oekodata.com/icpmapping/index.html
ICP Mapping Manual: http://www.oekodata.com/pub/mapping/manual/mapman_5.pdf

7 Companion documents

Appendix A List of Forest Service class I areas

A.1 Ecosystem Types

A.2 Data availability

Appendix B Detailed recommendations for each site

B.1 Specific criteria, categories and data sources

B.2 Explanation of reasons for selecting approach

B.3 Expected changes in data availability and consequences

Appendix C Data Management Protocol

Appendix D Description of Database Structure