Pacific Northwest Nitrogen and Sulfur Deposition Critical Loads Workshop

Co-Sponsored by:
Northwest Clean Air Agency
National Park Service
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Workshop Summary Report
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Executive Summary

Background

The Northwest Nitrogen and Sulfur Critical Loads Workshop was co-sponsored by the Northwest Clean Air Agency, National Park Service (NPS), U. S. Department of Agriculture, Forest Service (USFS), and U. S. Geological Survey (USGS). Day 1 focused on presentations relating to management efforts and research related to nitrogen and sulfur critical loads. Day 2 (half day) focused on exploring research gaps and developing an agenda for future research activity to support setting nitrogen critical loads for northwest Class I areas, with a focus on Northwestern Washington. The Workshop was held at the North Cascades Environmental Learning Center September 6 – 7, 2006.

Critical Load Concept

A critical load is “the quantitative estimate of an exposure of one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge.” The European Union and Canada have successfully used critical loads to manage air quality. Environment Canada is currently working on developing critical loads for sulfur and nitrogen for the Georgia Basin. There is growing interest in the U. S., especially from the Environmental Protection Agency (EPA) and the Federal Land Managers (FLMs) to establish and use critical loads. A critical load for eutrophication of high elevation aquatic ecosystems has been established for Rocky Mountain National Park (RMNP) at 1.5 kg N/ha/yr wet deposition.

Current Northwest Knowledge of Sulfur and Nitrogen Deposition Effects

NADP data indicate that sulfur deposition is declining while there has been no significant change in nitrogen deposition which is among the lowest in the country ranging between just under 1 kg N/ha/yr to just over 2 kg N/ha/yr. However, the three northwest NADP monitors are all at low elevation and are not representative of deposition rates at the most sensitive higher elevation ecosystems. Further, cloud deposition is thought to be a significant source of nitrogen inputs in the northwest and is not measured. Recent work with resin collectors, which have been used with success elsewhere in the country to better estimate total deposition, resulted in much lower than expected values for “throughfall” and higher than expected values in bulk deposition buckets. It may be that lichens are absorbing nitrogen before it can reach the resin collectors.

Lichens are sensitive to nitrogen and sulfur and are more vulnerable than vascular plants. In addition, the northwest is unique in the diversity and biomass of its lichens which play many important roles in northwest ecosystems. Long term lichen monitoring by the USFS has resulted in a large database on lichen species distributions in the northwest. Analysis in the Columbia Gorge produced a tentative critical load for lichens of 2.4 kg N/ha/yr. This value is based on 2 kg N/ha/yr dry deposition and 0.4 kg N/ha/yr wet deposition.

It is generally thought that nutrient effects of nitrogen will occur at deposition levels lower than acidification effects of the combined deposition of sulfur and nitrogen. The MAGIC model for examining acidification effects in catchments has been used to estimate the deposition rate at which acidification would occur at Lake Eunice in Mount Rainier National Park. The model identified a 10 kg/ha/yr critical load for acidification effects.

Northwest Critical Load Research Priorities

The following research priorities were identified:

<u>Nutrient Effects on Aquatic Ecosystems</u>:

1. Mine existing northwest water quality data: Considerable data has been collected on water quality in the northwest including limnological data for mountain lakes currently being compiled by Gary Larson; USFS data on lake water chemistry and algae; USFS and USGS NAWQA program data on streamflow and chemistry; and NPS North Coast and Cascades Network water quality data for lakes and streams. This large body of knowledge should be reviewed for algal indicator species, chemical factors like nitrate, sulfate, alkalinity, N:P ratios, and dissolved inorganic nitrogen to identify areas which may already be affected by nitrogen or sulfur deposition and which areas would be sensitive to addition nitrogen inputs.

2. Establish a northwest critical load for eutrophication of high elevation aquatic ecosystems using the work at RMNP focusing on shifts in diatom communities and hindcasting as a model.

<u>Nutrient Effects on Terrestrial Ecosystems</u>:

1. Establish a northwest critical load for terrestrial effects using lichen community changes. Additional research needed: collect lichens from NADP and "throughfall" sites; refine deposition modeling and/or conduct additional monitoring to better establish a deposition gradient to compare to lichen distribution data.

2. Conduct fertilization effects research on alpine meadows using Bowman's work at Niwot Ridge (Colorado) and RMNP as a model.

3. Leverage an emergent Natural Resources Conservation Service (NRCS) soils mapping effort for nitrogen and aluminum to identify sensitive areas.

4. Consider conducting research into the possibility of using mycorrhizal diversity as an index for nitrogen deposition. Mycorrhizae are similar to lichens in terms of northwest ecological importance and diversity.

Additional Issues

Participants identified several additional issues which must be kept in mind as we research nitrogen and sulfur effects:

1. climate matters;
2. nitrogen accumulates;
3. an annualized critical load value may be insufficient (e.g., species/ecosystems may be more sensitive to inputs during specific periods)

Workshop Summary Day 1
September 6, 2006, 8:00 am – 5:00 pm

Elizabeth Waddell and Janice Peterson welcomed participants and provided a brief overview of the purpose and desired outcomes for the workshop. They indicated an interest in developing a cross-discipline research plan for Class I areas in the northwest, with an emphasis on Northwest Washington State. They indicated such a plan would help to direct future research efforts and assist with the allocation of research funds as they become available. Elizabeth and Janice also thanked the Northwest Clean Air Agency for its sponsorship of the workshop.

In keeping with the overall purpose of the workshop, the stated objectives for the effort were the following.

- Communicate the scientific basis for, policy approaches to, and uses of critical loads.
- Discuss ecological effects of nitrogen and sulfur deposition and how these relate to establishing critical loads.
- Review current and identify future research needed to establish critical loads for nitrogen and sulfur in the Pacific Northwest, with an emphasis on Northwest Washington State.
- Outline an agenda for future research to support further progress on establishing nitrogen and sulfur critical loads.
- Enhance coordination among scientists and resource managers who are working to set nitrogen and sulfur critical loads in the Pacific Northwest.

Day 1 of the workshop was focused on presentations relating to current research and resource management efforts linking to critical loads. Participants moved through four presentation and discussions sessions: Critical Loads Concepts;

Critical Loads Case Studies; Deposition Research; and Ecological Effects Research. Highlights from these sessions are provided below.

Session 1: Critical Loads Concepts

Ellen Porter from the National Park Service began Day 1 with a background presentation on critical loads. The presentation addressed the following questions:

- What is a critical load;
- How is science used to establish them;
- How are significant ecological end points determined/identified;
- What are the mechanisms Federal Land Managers (FLMs) use to establish them; and
- Once established, how can they be used in policy and management?

Highlights from Ms. Porter's presentation include the following.

- The definition of "critical load" adopted by Europeans, Environment Canada, U.S. FLMs, and U.S. EPA is "the quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge." (Nilsson and Grennfelt 1988)
- Critical loads can be developed for any pollutants, but the FLMs are currently focused on nitrogen (N) and sulfur (S), and they are generally expressed as a loading rate (e.g., kilograms per hectare per year (kg/ha/yr).
- In 2000, FLMs declared the intent to develop critical loads for resource assessment and management, and in 2004, the National Academy of Science recommended EPA consider using critical loads for ecosystem protection. In 2005, EPA allowed that States can use critical loads in lieu of increment, and a Rocky Mountain National Park initiative to develop a critical load got underway.
- N andsulfurdeposition are both associated with acidification effects in aquatic and terrestrial environments, and nitrogen deposition is associated with excess nutrient effects in both environments, while the critical load will depend on the nature of the endpoint selected (more or less sensitive to deposition effects) and the resource management goal desired (and associated tolerance for ecosystem effects). Class I areas are subject to a strict resource management goal associated with the requirement to project the resources "unimpaired" for future generations.
- There are two basic approaches (often used in tandem) used to set critical loads: empirical (compare resource response across a gradient of pollution and/or manipulate conditions by adding acid or nitrogen to the ecosystem and observe response; and modeling (steady-state, input minus output models and/or dynamic models that include a time element).
- For critical loads to be useful to FLMs, researchers should:
    - Consult with land mangers on resources of concern and thresholds for effects;

- Prefer critical loads be expressed in kg/ha/yr for a specific pollutant;
- Specify what the critical load is for (e.g., “soil chemistry for healthy forests” or “acidification of terrestrial ecosystems”);
- State what threshold the critical load represents in terms of ecosystem effects (e.g., protect lake ANC of 50 ueq/L to maintain healthy biota); and
- If a range of critical loads is presented, state what the range represents (e.g., spatial variability, range of sensitivity, range of effects endpoints, modeling uncertainty, etc.).

Session 2: Critical Loads Case Studies

Session 2 focused on two presentations of efforts to establish critical loads: the Georgia Basin in Canada (presentation by Patrick Shaw from Environment Canada); and Rocky Mountain National Park (presentation by Ellen Porter from the National Park Service). These presentations focused on the history of the critical loads efforts and current and anticipated activities for these efforts.

Highlights from the Georgia Basin effort include the following.

- Environment Canada’s efforts began in the 1980’s with a focus on acid rain that lead to a nation-wide acid rain strategy and a critical load for wet sulfate of 20 kg/ha/yr that was used to drive emissions reductions. Acid rain, however, was not considered an issue for the Western Provinces.
- From 1999 to 2003 the Georgia Basin Ecosystem Initiative took a closure look at nitrogen and sulfur deposition effects in the Basin and found significant deposition of nitrogen and sulfur. The initiative included a biomonitoring program for three lichen species and one moss species across 50 sites.
- Environment Canada has now established the Georgia Basin Action Plan to set acidification-based critical loads focused on forest health endpoints. A Critical Loads Work Team has been established to assemble data, develop critical loads (region-wide initially, then more detailed), and verify the critical loads. The effort will go until 2008.
- Current research indicates an anticipated critical load for SO4 deposition of between 0 and 20 kg/ha/yr, with most of the Basin currently exceeding the 20 kg/ha/yr level. High alpine areas are deemed most at risk due to their limited buffering capacity.
- In response to questions, Dr. Shaw indicated that the primary source of pollution is nitrogen from cars, poultry, and livestock withsulfuremissions not being that large. The Action Plan is focused on acidification effects linked to forest growth.

Highlights from the Rocky Mountain National Park (ROMO) presentation include the following.

- The catalyst for developing the critical load for ROMO was a September 2004 petition from Environmental Defense and Colorado Trout Unlimited to the Department of Interior (DOI). DOI was asked to immediately declare adverse impacts on air quality related values and establish a critical load for nitrogen deposition in the Park. EPA and the State of Colorado were asked to fulfill their legal responsibilities to lower NOx and NH3 to protect human health, ecosystems, and visibility.

- The management threshold for ROMO derives from several acts of Congress including the National Park Organic Act and the Wilderness Act of 1964, both of which use the term "unimpaired" for future use/generations. This establishes a stringent protective requirement.
- Developing the critical load was supported by 20+ years of research including 80+ studies on nitrogen deposition and impacts at the Park.
- Key sources of nitrogen emissions affecting the Park include: vehicles; industry; energy development/production; wildland fires; livestock production; and crop production.
- A "weight of evidence" approach was used to determine the critical load. The evidence indicated nitrogen deposition is currently significantly elevated over natural background, and nitrogen deposition is significantly higher on the east side of the Park. Evidence included nitrate concentrations in lakes; nitrogen saturation in soils; elevated soil microbial activity; elevated nitrogen levels in spruce tree needles, alpine community composition shifts, and abundance and species shifts in diatoms.
- The critical load set for eutrophication of high elevation aquatic ecosystems was based on "hindcasted" deposition corresponding to a species composition shift in 1950. The critical load was set at 1.5 kg wet N/ha/yr. Current nitrogen wet deposition is estimated between 3 and 4 kg wet N/ha/year. ROMO strategy is to create a "glidepath" with interim target loads focusing on reducing deposition over time to, or below, the critical load.
- Next steps for the ROMO effort include: developing emissions inventories; identifying source attribution; modeling; developing an emissions reduction plan; and conducting periodic assessments of progress.
- In response to questions, Ms. Porter indicated that the petition was a critical catalyst to agency action, that all parties have worked effectively and cooperatively together, and that the 2000 FLAG Guidance announced the FLMs intention to begin using critical loads to protect Air Quality Related Values.

Session 3: Deposition Research

Session 3 focused on four presentations relating to deposition research.

- Don Campbell (USGS Research Hydrologist) – Research Overview, NADP/CASTNet, and Snow. Presentation highlights include the following.
    - NADP data indicatesulfurdeposition has been declining (as much as 40 percent), while there has been no significant change in nitrogen deposition where it remains among the lowest in the country.
    - Most NADP sites (which are located at lower elevations), however, are not representative of deposition rates at the most sensitive ecosystems at higher elevations.

    - To round out NADP data, additional deposition sampling work is being undertaken. This includes the use of bulk collectors and ion-exchange resin collectors in the summer and snow pack samples in the winter. It was noted that the northwest experiences a "challenging" winter precipitation regime from a sampling standpoint.
    - 25 years of nitrogen deposition data for Olympic Park indicate average deposition of 1.0 kg/ha/yr.
    - An important and poorly understood factor in northwest deposition is cloud water chemistry.
    - In response to questions, Mr. Campbell indicated that NADP shortcomings require the data be used with caution, while at the same time, NADP deposition methods are well established providing for data consistency. Mr. Campbell further indicated the importance of atmospheric stratification with surface conditions varying from those above the surface.
- Mark Fenn (USDA Forest Service Research Plant Pathologist) – Monitoring N/S with Ion-Exchange Resin Collectors. Presentation highlights include the following.
    - Currently working with second generation devices – experience to date has been very positive. Collectors require infrequent changes, lowering costs and allowing for more sample sites.
    - Sample results indicate potentially much higher nitrogen deposition rates (25 kg/ha/yr inn the Columbia Gorge) than indicated by NADP. However, in the NW, he has found through-fall to be very low, while bulk deposition is high. Ammonia has been difficult to sample. Dr. Fenn speculates that the canopy – especially the heavy lichen growth - is taking up much of the N
- Matt Porter/Joe Vaughan (WSU Laboratory for Atmospheric Research) – Modeling Deposition Using CMAQ. Presentation highlights follow below.
    - Mr. Porter provided an overview of the logic model for CMAQ indicating the model inputs for producing dry and wet deposition estimates. In looking at the North Cascades using a 36 kilometer grid and a 1,000 meter cut off, CMAQ estimates total nitrogen dry deposition of 1 kg/ha/yr and total nitrogen Wet deposition of 1.4 kg/ha/yr.
    - Current analysis indicates CMAQ over predicts nitrogen dry deposition and underpredicts nitrogen wet deposition. CMAQ does not include cloud deposition.
    - In response to questions, Mr. Porter indicated that a resolution finer than 36 kilometer grid is desirable, although finer resolution presents capacity challenges for the model. However, the model is currently being run daily at 12 km and annual deposition rates will be available from these runs.
    - Mr. Porter also indicated that limited or no sensitivity analysis had been conducted to date to better understand current model deficiencies related to emission data inputs and underlying model assumptions.

- Don Campbell – Hindcasting Nitrogen and Sulfur Deposition. Dr. Campbell presented on the hindcasting methods used to establish critical loads for diatoms in ROMO. Highlights include the following.
    - Fundamental premise behind hindcasting is that deposition should mimic emissions, while Paleolithic evidence is key to answering the question regarding when deposition-related effects occurred. Hindcasting uses these two data areas to produce estimates of deposition at the time of an ecological effects change.
    - For ROMO, trend data were available for population and NOx emissions and there was a strong data set from 1984 to 2006 for wet deposition. These data sets were combined with a pre-industrial deposition "anchor" (1900 - .5 kg/ha/yr) to create a deposition regression line back to 1900, assuming a constant rate of change..
    - Based on a 1950 – 1960 diatom species composition change found in lake core samples, the hindcasting effort estimated a critical load of 1.5 kg/ha/yr for diatoms.
    - In response to questions, Dr. Campbell indicated it likely would not be appropriate to use the same ROMO regression curves for the northwest. He indicated differences in soil, plant, and climate all factor into the likely need to calculate new critical loads for the northwest.

Session 4: Ecological Effects Research

Session 4 focused on research presentations related to nitrogen and sulfur ecological effects research. The session had seven presentations.

- Linda Geiser (USDA Forest Service Ecologist) – Monitoring Air Pollution Using Lichens. Dr. Geiser presented research related to lichen response to nitrogen andsulfurdeposition. Presentation highlights follow below.
    - Lichens are sensitive to nitrogen and sulfur, and are more vulnerable than plants making them a potentially effective "sensitive species" for critical loads purposes.
    - Research has examined lichen community composition as well as lichen chemistry parameters. Initial estimate of potential nitrogen critical load for lichens is approximately 2.4 kg/ha/yr.
    - Opportunities for additional research include: examining and further mapping nitrogen concentrations in lichens as a percent of a "clean site" threshold; relating lichen data to NADP data (including lichen research conducted near monitors) to create a community-based air score; and making connections to CMAQ modeling efforts.
    - In response to questions, Dr. Geiser indicated that there are very strong gradients that will require modeling efforts to have grid sizes with fine resolution, and that lichens have been shown to be a very sensitive species and, therefore, a good candidate for northwest critical loads.

- David Clow (USGS Research Hydrologist) – Water Chemistry and Soils. Dr. Clow reviewed research related to nitrogen and sulfur deposition effects on soil and water chemistry. Highlights include the following.
  - S deposition is associated with acidification in soils, leading to soil cation depletion and leaching of aluminum into water. Nitrogen deposition is associated with both soil/water acidification and eutrophication.
  - Soil parameters that can be measured include: cation exchange capacity; percent base saturation; pH; C:N ratio; and soil volume.
  - For water chemistry, Dr. Clow identified two types of sampling regimes: synoptic sampling (snap shot across lakes); and intensive sampling of a few sites. He identified several lake chemistry sampling efforts including the 1983 Western Lakes Survey, and intensive efforts at Lake Louise, Lake Eunice, Thornton Creek, and Newhalem Creek.
  - Dr. Clow also discussed efforts to link seasonal patterns in NO3 to nitrogen saturation providing a graph showing 3 stages of water body nitrate concentrations relative to precipitation concentration levels.
  - In response to questions, Dr. Clow indicated that the presence of Alders can be a confounding factor for deposition sampling, while this will be less important at high evaluation areas (which lack Alder growth). He also indicated it would not be easy to establish a deposition flux value.
- Steve Perakis (USGS Research Ecologist) – Effects of Nitrogen Deposition on Soil Nitrogen Cycling. Dr. Perakis presented on research conducted looking at nitrogen deposition and soil nitrogen cycling. Highlights follow below.
  - Dr. Perakis identified research linking nitrogen cycling to soil acidification and species composition shifts and discussed a conceptual model examining vegetative succession from spruce and fir trees to birch and maple in relation to nitrogen cycling. He also indicated that loss of mycorrhizal diversity could be a possible index for nitrogen deposition effects.
  - A variety of "major issues" were identified for examining nitrogen deposition effects on soils in the northwest including: canopy nitrogen fixation; Alders (given their large nitrogen fixing capacity); land use (silvacultural activities); soil bases (with .4 percent soil nitrogen as a key threshold); fire, and climate.
- Koren Nydick (Director of Research & Education, Mountain Studies Institute) - Relationship Between Nitrogen Deposition and Eutrophication in Lakes. Dr. Nydick discussed research conducted on nitrogen eutrophication effects in lakes. Highlights follow.
  - Earlier research view was that eutrophication was associated with phosphorus, but more current research has indicated alpine lakes can be different and be nitrogen limited. Research has indicated that there is a substantial amount of nitrogen limitation in lakes, including the northwest.

    - A variety of potential nitrogen deposition effects indicators are possible including: DIN:TP; and lake DIN compared to Chlor A/TP. Using these parameters as indicators, potential speculation that 2.6 kg/ha/yr could be an nitrogen deposition critical load for lake eutrophication.
- Brenda Moraska Lafrancois (National Park Service Aquatic Ecologist) – Nitrogen Deposition Effects on Phytoplankton and Zooplankton. Dr. Lafrancois presented on research relating to species impacts in Rocky Mountain lakes. Highlights include the following.
    - Research focused on responses to nitrogen exposure in aquatic communities along the Front Range of the Colorado Rocky Mountains and in the Wyoming Snowy Range. Research showed phytoplankton to be sensitive indicators, with substantial species composition shifts in response to both nitrogen enrichment and acidification. Interactive nutrient and acidification effects were stronger than effects of nitrogen enrichment alone, with large differences observed in phytoplankton and zooplankton composition and biomass.
    - With respect to diatoms, their silica cell walls make them well suited for historical (paleolimnological) analysis, allowing for historical inferences regarding water chemistry. Some diatom species may be particularly good indicators of nitrogen enrichment.
    - A combined weight-of-evidence approach (including lake surveys, experiments, and paleolimnological work) was useful in determining species responses to nitrogen deposition.
    - In response to questions, Dr. Lafrancois indicated the relationship between nitrogen enrichment and potential fish impacts remained unclear, but that one set of experiments suggested N-induced changes in algal composition may have affected zooplankton species composition and biomass in ways that could negatively affect fish.
- Stuart Weiss (Creekside Center for Earth Observations) – Nitrogen Deposition Threats to Biodiversity. Dr. Weiss presented on research conducted in the South San Francisco Bay Area on nitrogen deposition effects on grasslands. Highlights follow below.
    - Research included dry nitrogen deposition from smog on serpentine forms. The research identified a strong local nitrogen deposition gradient with significant South Bay impacts of grass invasions (species composition shifts). These composition shifts created a change in habitat affecting other species. Research indicated a 4 – 5 kg/ha/yr critical load for serpentine grasses.
    - Research results have been used to establish mitigation requirements for new or increased nitrogen emission activities. Research is also supporting the creation of a Santa Clara County HCP/NCPP.
    - A critical consideration for future research efforts is the tendency of systems to accumulate nitrogen load over time. Cumulative effects (in the nature of hundreds of kilos over years) are important in terms of supporting invasive species. In this context, a critical load may postpone, but not eliminate a future threshold effect.

- David Clow – Modeling Ecosystem Responses to Nitrogen and Sulfur Depostion. Dr. Clow addressed the current and prospective use of models to estimate ecosystem responses to nitrogen and sulfur deposition. Highlights follow below.
    - Dr. Clow provided general background on the concept of empirical modeling to identify sensitive resources using "index" periods. He provided an example using Yosemite National Park where regression analysis was used to relate water chemistry data to basin characteristics, enabling researchers to isolate sensitive areas.
    - Dr. Clow also discussed the use of the MAGIC model for examining acidification effects in catchments. The MAGIC model has been used to estimate the deposition rate at which acidification will occur at Lake Eunice, Mount Rainier NP. The model identified a 10 kg/ha/yr critical load for acidification effects. Although well above current NADP measured deposition rates, this is a relatively low input for acidification effects indicating the sensitivity of many NW lakes to acidification.
    - Dr. Clow further discussed the use of the DayCent model used to predict eutrophication from nitrogen deposition. In this context, he discussed a Mt. Ranier example looking at climate effects. Modeling efforts incorporated air temperature increases which did not affect total precipitation, but did affect the ratio of snow to rain. Predicted effects included little change in Net Primary Productivity, but a shift of the NPP peak to earlier in the year. There was also an indication that sulfate and nitrate stream concentrations would go down in part as a result of earlier snowmelt runoff.

Workshop Summary Day 2
September 7, 2006, 8:00 am – 1:30 pm

Day 2 of the northwest Class I Areas Critical Loads Workshop focused on producing an outline of a research agenda to support further progress on establishing critical loads in the northwest, with a focus on Northwest Washington State. Day 2 drew and built upon the research presentations delivered during Day 1 and was approached as a building process moving through a series of six agenda items: Overview - What Is Needed to Establish A Critical Load; Review and Identify Additions to Day 1 Research Compilation; Identify Indicator Endpoints with the Most Promise for Establishing Critical Loads; Identify Deposition Research Gaps/Needs for the Selected Indicator Endpoints; Identify Ecological Effects Research Gaps/Needs for the Selected Indicator Endpoints; and Outline a Preliminary Critical Loads Research Agenda.

The deliberations from these agenda items are summarized below in seven discussion areas: Needs for Establishing Critical Loads; Key Considerations; Additions to Day 1 Research Compilation; Most Promising Ecological Endpoints and Research Directions; Deposition Research Gaps and Needs; Ecological

Effects Research Gaps and Needs; and Critical Path Research Agenda. Summaries for these areas are provided below. Attachment A contains the verbatim “hexagon notes” for each of these areas.

Discussion Area 1: Needs for Establishing Critical Loads

Tamara Blett opened Day 2 with a presentation identifying the key building blocks for establishing critical loads. This presentation was designed to help participants focus their critical loads research agenda discussions. Tamara identified three categories of work for critical loads development:

- Ecosystems Effects Research – understanding “is there a problem?”
- Threshold/Significance of Effect – understanding “what is the threshold/concentration causing the effect” and “what is the significance related to resource management goals?”
- Deposition Loading (Past, Present, and Future) – loading at which “significant” effect “harms” part of the ecosystem = critical load.

A key point made to participants was the science/policy interface leading to setting a critical load. Scientific research establishes the relationship between nitrogen and S exposure and a continuum of ecological effects, while management policy (through, for example, enabling legislation) indicates the point on the ecological effects continuum that is deemed a “significant harmful effect.” In the case of Class I areas, which are guided by a charge to preserve resources “unimpaired” for the future, critical loads are targeted for sensitive indicator endpoints in sensitive environments.

Tamara also drew a distinction between setting critical loads and acting on them. She identified four aspects of critical loads use:

- Emissions source attribution;
- Emissions reduction options development;
- Co-operative efforts; and
- Public sentiment and political will.

Discussion Area 2: Key Considerations

Throughout the discussion during Day 2, participants were asked to identify, as needed, what they viewed as “key considerations” for moving research forward on critical loads for the northwest, with an emphasis on Northwest Washington State. In total, participants identified 13 key considerations summarized below as five bullet points.

- Research should proceed forward on two fronts and in two sequential steps: initial “data mining” making use of potentially relevant research already available on the northwest (e.g., lake chemistry data collected by the Park Service through, for example, the Vital Signs Monitoring Program); and focused new research guided by what initial data mining efforts indicate is needed. For deposition research, there was a sense that the “two fronts” included, 1) utilizing existing deposition data (e.g., NADP data) and establishing "linkages" (correlations) to existing ecological effects data, and 2) conducting new, focused deposition research to better establish actual and more spatially specific deposition rates.

- Participants believed the initial focus of additional research should be on nitrogen enrichment in Western Washington, as nitrogen enrichment was seen as the primary and most immediate problem, with Western Washington likely the most impacted area. At the same time, participants indicated that, although S emissions have been on the decline, they could reverse in the future, including the potential for long-range transport of emissions from Asia. In the context of the potential for emissions shifts and/or other exogenous factors that may affect deposition, ecological effects, and/or appropriate critical load levels, participants further included climate change, ozone, and fire-related considerations.
- Several participants noted the significant effects of nitrogen fixing capacity of Alders. This was seen as both potentially confounding nitrogen deposition effects research and an opportunity to establish nitrogen enrichment gradients. One result of these observations was the suggestion that some research must "get above the Alders."
- One participant observed the challenge that may exist if a clear "threshold effect" does not exist for a selected sensitive endpoint. It was suggested that such conditions could be addressed using work done by the National Academy of Sciences (NAS) in 1995/96 and/or establishing "reference conditions."
- Additional considerations included discussion of the unique nature of alpine environments and the extent in the northwest they are likely to be the most sensitive areas but may not be where highest deposition is occurring, the anticipated need to use a "weight of evidence" approach to setting critical loads as was done at Rocky Mountain NP – long term records of water chemistry will be important in achieving this, the anticipation that new field research on diatoms in lake water will be challenging from a resources standpoint, and the importance of not getting "paralyzed" by uncertainty.

Discussion Area 3: Additions to Day 1 Research Compilation

At the outset of Day 2, participants were asked to reflect on the research presentations from Day 1 and to identify additional research that might be pertinent to setting critical loads in the northwest. This discussion topic was "seeded" with the presentation of a matrix that provided a general summary of Day 1 research presentations.

By design, this discussion area was limited to initial ideas, with more specific and structured discussion regarding additional research needs reserved for later sessions. Participant observations focused on potential additional ecological indicators that might be suited as "sensitive" for purposes of setting critical loads. The participants identified the following endpoints: plant growth (including foliage ratios); invertebrates; grasslands impacts (with a note that such areas do include threatened and endangered species); biochemical (such as foliar nutrient ratios); fish and amphibians (with the note that they may not be sufficiently sensitive to detect early effects); relative nitrification; soil biology; and mycchorhizae.

Discussion Area 4: Most Promising Ecological Endpoints and Research Directions

In this discussion area, participants were asked to consider the Day 1 research presentations, as well as any additional knowledge they had regarding pertinent research, and identify the indicator endpoints with the "most promise" for establishing critical loads in the near term. Participants were asked to use the following four criteria for identifying these endpoints:

- Research completed to date provides (or nearly provides) the ability to set a critical load;
- The critical load will provide effective protections for park and forest resources;
- It is scientifically defensible; and
- The critical load will be practical from a policy standpoint.

In response, participants conducted a fairly wide ranging discussion while identifying ten initial areas for consideration. At the outset of this discussion it was indicated that participants should focus their thinking in terms of effects in northwest Class I areas, with a focus on Northwest Washington. These ten were grouped into three categories: Terrestrial (West Side of Cascade Mountains); Terrestrial (East Side of Cascade Mountains); and Aquatic.

- Terrestrial (West Side of Cascade Mountains) – This category included ideas focused on both forest and alpine environments with the following ecological endpoints identified as candidates: lichens; mycorrhizae; nitrification; alpine plant community composition; and northern extent of southern plant species. When asked to identify the most promising of these, participants identified, in particular, lichens and nitrification, with additional interest in (or a sense that further exploration would be justified for) mycorrhizae and alpine plant community composition.
- Terrestrial (East Side of Cascade Mountains) – Participants discussed the fact that northwest Class I areas include shrub steppe ecological systems primarily located on the east side of the Cascade Mountains. In these areas, vegetative structure was identified as a potentially promising ecological indicator. At the same time, participants discussed the likelihood that these systems, due to wind flow patterns and their location relative to industrial and urban nitrogen sources, may receive less nitrogen deposition than west side environments. However, this assumption needs to be tested in light of the intensive agriculture in eastern Washington.
- Aquatic – in aquatic environments, participants indicated an interest in lakes and streams and identified a variety of potential ecological effects indicators. These included: DIN/TP ratio; Chlor A/TP ratio, nutrient ratio in

phytoplankton; diatom, phytoplankton, and zooplankton composition; dissolved oxygen; percent nitrate of total nitrogen; and pH. When asked to indicate the most promising from a critical loads perspective, participants identified: diatom, phytoplankton, and zooplankton composition; and the "chemistry indicators" of percent nitrate of total nitrogen and pH. Discussion also indicated that there is a 20-year research site in Olympic National Park (located above Alder growth) that can provide potentially useful data.

Overall, participants emerged from this discussion of "most promising" ecological endpoints with a focus on nitrogen enrichment related to lichens and soil nitrification for the terrestrial environment and diatoms, phytoplankton, and nitrification for the aquatic environment. Subsequent critical load research opportunities and gaps discussions primarily, although not solely, focused on these endpoints.

Discussion Area 5: Deposition Research Gaps and Needs

At the outset of this discussion, participants were asked to explore what more we need to know about current/historical deposition rates and what is the best way to obtain this information? In addition, participants were asked to consider the role deposition modeling could play and to explore the pros/cons of these methods. On this basis, participants identified a wide variety of deposition research potential gaps, needs, and opportunities.

A key theme that ran through these discussions was a prevailing sense that current northwest deposition estimates were subject to a variety of limitations and constraints and held the potential to underestimate actual deposition rates. This concern emerged from Day 1 deposition research presentations that indicated differences (some substantial) in nitrogen deposition rates emerging from different estimation methods. Participants also believed this research indicated a prevailing weakness in nitrogen deposition rate coverage and understanding for Class I areas in the northwest. As a result, a strong interest emerged in research focused on improving deposition estimating techniques, including both modeling and field sampling. A group exercise to organize these ideas resulted in three major idea categories: Deposition Models; Opportunities for Existing Deposition Data; and Deposition Monitoring Research.

- Deposition Models – research ideas reflected in this category focused on improving CMAQ modeling to estimate the spatial distribution of nitrogen deposition. CMAQ research ideas included: CMAQ resolution improvement (12 km or 4 km grid); efforts to validate CMAQ modeling estimates through passive gaseous sampling; coordinating and correlating CMAQ outputs with lichen effects data (preferably at finer resolution). Sensitivity mapping for nitrogen and S could be done using a combination of GIS coverages and the PRISM/MM5 model. Research areas identified as "critical path" were: CMAQ resolution improvement; coordination/correlation with Lichen effects data; passive sensor use; and sensitivity mapping.

- Opportunities for Existing Deposition Data – participant ideas in this category reflected a recognition that it is not necessary to completely characterize actual total deposition because it is likely to be proportional to existing deposition data (i.e., NADP). Therefore, it should be possible to create linkages with known effects data and draw "indexed" inferences about potential critical loads for selected ecological endpoints. This category was of interest based on a belief that research in this area could provide the most expedient path to establishing, at least, initial critical loads, while research focused on improving deposition estimation methods takes place. Ideas in this category included the following: improving NADP spatial coverage by using NADP derived concentrations and precipitation estimates derived from PRISM or MM5 and ground truthing this approach with snow pack data linked to PRISM.
- Deposition Monitoring Research – this category was reflective of the strong sense of need to improve field techniques for determining deposition rates in the northwest while simultaneously expanding the coverage and granularity of empirical deposition rate estimates. In terms of "critical path" research, participants identified the immediate need to conduct a "deposition data comparison" between NADP data and recent field research data to better understand deposition data deficiencies and chart a more refined and structured research path. .

Discussion Area 6: Ecological Effects Research Gaps and Needs

For this discussion, participants were asked to consider what the key ecological effects research gaps and needs are and what will be the best way to obtain this information? Participants were also asked to examine opportunities related to chemical indicators from soils, water, and/or plants and to consider ecological effects and/or chemical indicator modeling. In this context, participants identified two categories: Acidification effects and Nitrogen fertilization effects. MAGIC Model; Lichens; Aquatic (diatoms, phytoplankton, and water chemistry); Soils and Plants; and Screen for Risk Areas.

Acidification effects - this category received limited attention due to the focus on nitrogen enrichment. Participants indicated, however, that the results of the MAGIC model could be used to produce an "upper bound" acidification estimate of 10 kg/ha/yr

Nitrogen fertilization effects

Lichens – lichens received considerable attention as a result of substantial work conducted to date on lichen response to nitrogen enrichment in the northwest. At the same time, this research has focused on USFS lands and has included limited research within northwest National Parks. Of particular concern was that no lichens have been collected from areas near the three NADP monitors. However, research done in the Columbia Gorge produced a tentative critical load of 2.4 kg N/ha/yr of which 2 kg/ha/yr was from dry deposition and 0.4 kg/ha/yr was from the wet deposition component. Research ideas identified by participants included: controlled field experiments on lichen nitrogen response; leveraging data that well characterize alpine lichens in other parts of the country to better understand northwest alpine lichen conditions; combined field studies with bulk deposition collectors and lichen nitrogen response (with the hope of better characterizing an nitrogen gradient for lichens); more work to refine CMAQ and compare to lichen response; and lichen sampling in the Parks and/or an FHM data look. Specifically, a network could be established of "resin bulk collectors" (or whatever method was determined to be most effective for monitoring deposition) and passive air monitors to verify the CMAQ model – some co-located with NADP sites – to provide a method to compare and contrast different modeling and monitoring methods with the established NADP method. Data from this network would help to characterize the spatial distribution of nitrogen deposition through both modeling and monitoring and correlate that with lichen effects. Snow data could also be incorporated. In terms of "critical path" research, participants identified the importance of "side-by-side" measurements of nitrogen deposition and lichen ecological effects.

Aquatic (diatoms, phytoplankton, and water chemistry) – participant discussions indicated a strong interest in further pursuing the "Rocky Mountain model for diatoms" as well as examining a number of water chemistry parameters for both lakes and streams to establish a weight of evidence. Participants identified many opportunities for leveraging existing research data as a starting point for identifying possible aquatic effects of concern. These opportunities included the following: 1980's Alpine Lakes Wilderness Area lake studies; data from the Northwest Aquatic Monitoring Program; archived lake sediment core samples for a variety of Parks; detailed, long-term data for Summit Lake; as well as a variety of other existing lake data from both the Forest Service and the Park Service. These data could be "mined" for biological data (algal indicator species, relationships between algal species) and key water chemistry parameters (e.g., nitrate, alkalinity, DIN in lakes, nitrate leaching in streams) and ratios (N:total P). This database could provide important historical data and help to determine trends across years. It could also help to identify sensitive lakes for further research. Archived sediment cores could be analyzed for diatom composition shifts. In addition to these existing data mining opportunities, participants identified a number of additional research gaps/needs including: taking new lake core samples (for diatom composition purposes); and in-lake field experiments like were done in the Rockies to assess effects of nitrogen and P inputs on diatoms/phytoplankton. When asked to identify the “critical path” research items for this category, participants focused on mining existing lake core samples, lake and stream data for water chemistry parameters, and taking new lake core samples.

Soils and Plants – participant research ideas in this category were predominated by a recognition that little research had been done in this area. Mycorrhizae were identified as a potentially key focus in the NW. Mycorrhizae are similar to lichens in terms of ecological importance and diversity. There was also interest in following Bowman’s work to develop critical load for alpine plant communities in Rocky Mountain NP. Ideas included: an nitrogen response study in northwest alpine systems; leveraging an emergent NRCS (Natural Resources Conservation Service) soils mapping effort (for nitrogen and aluminum); and using Alder stands to better investigate nitrogen gradients. In terms of “critical path” research, participants identified an nitrogen response study in northwest alpine systems and leveraging the NRCS soils mapping effort.

Screen for Risks – participants believed that further efforts to identify potentially sensitive northwest areas, as well as those that could be considered risk areas (sensitive areas with higher anticipated nitrogen deposition levels) are important for targeting further intensive research. Ideas in this area included the use of “back trajectory” model efforts (done for WACAP); CMAQ modeling, mining existing lakes data (see “aquatic” bullet point above); and soils mapping (see “soils and plants” bullet point above).

Discussion Area 7: Critical Path Research Agenda

The last major Day 2 discussion area focused on examining the full range of deposition and ecological effects research ideas and identifying a “critical path” research agenda. Participants were asked to identify those ideas that could help establish critical loads the soonest and that represented an effective use of research resources. On this basis, participants “cherry picked” through the ideas and highlighted a variety of areas. These areas have already been identified in the previous discussion area summaries, but are brought together below to provide a focused sense of an overall future critical path research agenda.

As indicated in Day 2 Discussion Area 4, participants believed the “most promising” ecological endpoints (with a focus on nitrogen enrichment) related to lichens and soil nitrification for the terrestrial environment and diatoms, phytoplankton, and nitrification for the aquatic environment. Subsequent research opportunities and gaps discussions, and in particular the critical path discussions, focused on these endpoints.

The nitrogen deposition research critical path contained the following ideas:

- Undertaking CMAQ resolution improvement;
- Increasing coordination/correlation with lichen effects data;
- Using passive sensors to collect atmospheric concentrations to better understand and validate deposition modeling;
- Undertaking sensitivity mapping;
- Conducting a deposition data comparison between NADP data and recent field research data; and
- Establishing a network of resin bulk collectors to refine deposition estimation techniques, help validate deposition models, correlate deposition with ecological effects (in particular lichen effects), and increase the coverage of deposition data.

With respect to the ecological effects critical path research items, participants identified the following:

- mining existing lake core samples, lake and stream data for water chemistry parameters, and taking new lake core samples;
- conducting a nitrogen response study in northwest alpine vegetation systems; and
- working with the emergent NRCS soil mapping effort to include nitrogen and aluminum as map parameters.

Meeting Wrap and Future Directions

At the close of Day 2, Janice Peterson, Elizabeth Waddell, and Tamara Blett thanked participants for their efforts and indicated next steps. They indicated the workshop sponsors plan to produce a proceedings report from the workshop that will be available for review by the participants. They further indicated that, as research money for critical loads becomes available, the research ideas identified during the workshop will receive special consideration for funding. Participants were encouraged to begin thinking about how to translate the research ideas into research proposals.

Attachment A
Verbatim Hexagon Notes from Day 2
(Note: critical path items highlighted in red)

Initial Research Gaps Discussion

Hexagon 9: Plant Growth Indicator
Hexagon 8: Invertebrates as Indicator
Hexagon 7: Grasslands Impacts (include threatened and endangered species)
Hexagon 6: Biochemical Indicators (e.g., foliar nutrient ratios)
Hexagon 5: Ratios of Foliage (weight of evidence)
Hexagon 4: Fish and Amphibians (salamanders) Indicator (not obvious, has limitations)
Hexagon 3: Relative Nitrification Indicator
Hexagon 2: Soil Biology Indicators
Hexagon 1: Fungi as Indicator

Key Considerations Discussion (drawn from discussion throughout Day 2)

Hexagon (Pink) 13: 1. Data Mining; 2. Focused Research
Hexagon (Pink) 12: Don't Get Paralyzed by Uncertainty
Hexagon (Pink) 11: Diatoms in Lake Water Challenging ($ and FTE)
Hexagon (Pink) 10: Deposition – Two Fronts, linkage and basic research
Hexagon (Pink) 9: Vital Signs Monitoring Program Role? (General Potential)
Hexagon (Pink) 8: Climate Change/Ozone/Fire/Asia – Emissions Projections
Hexagon (Pink) 7: Must Get Above the Alders, Can Be Good Proxy for N-Gradient
Hexagon (Pink) 6: S May Reverse, Can You Affect Decisions?
Hexagon (Pink) 5: N Is the Lakes Problem
Hexagon (Pink) 4: Alpine Environments Unique
Hexagon (Pink) 3: West Side Most Impacted
Hexagon (Pink) 2: Weight of Evidence
Hexagon (Pink) 1: What To Do If No Threshold? NAS 95/96; Reference Conditions

Most Promising Areas Discussion

Category: Terrestrial - West
Hexagon 11: Forests and Alpine
- Lichens
- Mycorrhizae
- Nitrification
Hexagon 14: Alpine Plant Communities
- strong research
Hexagon 18: Northern Extent of Southern Species
Hexagon 10: Lichens

- Terrestrial
- Forest
- Alpine (possible)
- N enrichment
- SO2

Category: Terrestrial – East
Hexagon 16: Shrub Steppe System ?
- Eastside of Washington State
- Vegetation Structure
- Fire

Category: Aquatic
Hexagon 13: Olympic 20-Year Research Site Above Alders (stream)
Hexagon 19: Lakes
- DIN/TP
- Chlor A/TP
- Nutrient Ratio in Phytoplankton

Hexagon 15: Sensitive Lakes
- Diatoms
- Phytoplankton
- Zooplankton
- Dissolved Oxygen

Hexagon 12: Stream Chemistry Indicators
- Nitrate
- Percent Nitrate of Total Nitrogen
- pH

Hexagon 20: Inflows to Lakes

Deposition Research Gaps and Needs Discussion

Category: Deposition – Deposition Models
Hexagon 35: CMAQ Resolution Improvement
- Nested Domain
- 4 Kilometer Grid
- Coordinate with Lichens

Hexagon 25: CMAQ Estimate Foliar Throughfall
Hexagon 28: Total Deposition
- Dry: modeling and validation

Hexagon 23: Passive Sensors to Validate
Hexagon 36: Campaign Reflecting Current CMAQ Uncertainties (e.g., Alpine Areas)
Hexagon 59: Sensitivity Mapping – N/S; GIS/PRISM

Category: Deposition – Opportunities for Existing Data
Hexagon 27: Indexing to NADP Data

Hexagon 32: NADP Spatial Gap – Like Methods in Non-Covered Areas
Hexagon 31: NADP Correlation to Ecological Conditions (spatial coverage)
Hexagon 54: Historical Trends in Deposition Data
- Emissions Accounting
- Concentrations
Hexagon 33: NADP – Snowpack Data w/PRISM to Address Spatial Limitations

<u>Category: Deposition – Deposition Monitoring Research</u>
Hexagon 23: Passive Sensors for Gases Concentration
- Ground Truth CMAQ Dry
- Pilot Data
- Lichens Correlation
Hexagon 22: Cloud Water and Through Fall
Hexagon 26: Data on Chemistry of Cloud Water
Hexagon 24: Bulk Deposition
Hexagon 29: Can't Model Cloud Water Deposition
Hexagon 30: Intensive
- Range of Gases
- Cloud Chemistry and Volume
- Wet Fall
- Methods (not widely accepted) and Deposition Research
- Correlate to Lichens
Hexagon 37: Resin Bulk Collectors for Relative Deposition (Network)
Hexagon 38: Side-By-Side Measurement
- bulk, wet, resin, etc.
- total N
- co-locate at future NADP
Hexagon X (added at end of day): Deposition Data Comparison

<u>Category: Deposition – Technology</u>
Hexagon 21: Technologies
- Old Measurements Indexed with New Technologies

Ecological Effects Research Gaps and Needs Discussion

<u>Category: Ecological Effects – MAGIC Model</u>
Hexagon 57: MAGIC Model Leverage
- Upper Bound Acidification

<u>Category: Ecological Effects – Lichens</u>
Hexagon 52: Controlled Experiments on Lichen N Response
Hexagon 51: Sub Alpine Protocol Can Leverage
- Could Collect "Known" Lichens
Hexagon 54: Lichen/Bulk (etc.) Deposition and Survey Lichens (need gradient)
Hexagon 53: Lichen Sampling in Parks or FHM Data Look

Hexagon 58: Side-by-Side Measurements

Category: Ecological Effects – Aquatic – Diatoms, Phytoplankton, Chemistry
Hexagon 39: Rocky Mountain Model for Diatoms
Hexagon 40: Effects
- Take Cores in Lakes
- Water Chemistry Ratios from Existing Data

Hexagon 44: Stream Chemistry Responses
Hexagon 34: 1980's Alpine Lakes Work
Hexagon 42: Examine Existing Lake Data from Forest Service/NPS
Hexagon 41: NW Aquatic Monitoring Plan
- Diatoms for Streams
- Confounded?

Hexagon 43: Archived Lake Core Analysis for All Parks
Hexagon 58: Summit Lake
Hexagon 56: Field Experiments for Forest/Aquatic N Response

Category: Ecological Effects – Soils/Plants
Hexagon 45: Nitrogen Response Study in Alpine Systems in NW
Hexagon 46: NRCS Soil Mapping Effort Leverage
- N
- Al

Hexagon 48: Examine Where You Actually Begin to Nitrify = Threshold
- Mature Systems

Hexagon 47: Alder Stands for N Gradient
Hexagon 50: Critical Cumulative Load Threshold
- Alpine Plants
- Sage Steppe
- Total N

Hexagon 49: Mycorrhizae? Need More Information

Category: Ecological Effects – Screen for Risk Areas
Hexagon 57: Screen for Risk Areas
Hexagon 55: Back Trajectory Model Efforts?
Hexagon 56: WACAP Lakes Potential (sensitivity?)

Attachment B
Meeting Agenda

Pacific Northwest Nitrogen and Sulfur
Critical Loads Workshop
September 6 – 7, 2006
North Cascades National Park Learning Center

Final Agenda

Co-Sponsors: Northwest Clean Air Agency, National Park Service, USDA Forest Service, and US Geological Survey

Workshop Objectives

1. Communicate scientific basis for, policy approaches to, and uses of critical loads.
2. Discuss ecological effects of nitrogen and sulfur deposition and how these relate to establishing critical loads.
3. Review current and identify future research needed to establish critical loads for nitrogen and sulfur in Pacific Northwest, with an emphasis on Northwest Washington State.
4. Outline an agenda for future research to support further progress on establishing nitrogen and sulfur critical loads.
5. Enhance coordination among scientists and resource managers who are working to set nitrogen and sulfur critical loads in the Pacific Northwest.

DAY ONE – September 6
8:00 am – 5:00 pm

8:00 Introductions and Agenda Review — Rob Greenwood

8:15 Workshop Background and Purpose — Elizabeth Waddell, Janice Peterson

- Acknowledgements
- Anticipated use of workshop products
- Geographic context for discussion
- Class I areas of interest

8:30 Critical Load Concepts: Presentation and Discussion — Ellen Porter

Overview: What is a critical load, how is science used to establish them, how are significant ecological end points determined/identified, what are the mechanisms for Federal Land Managers to establish them, and, once established, how can they be used in policy and management?

9:00 Critical Load Case Studies: Presentations and Discussion

- Georgia Basin — Patrick Shaw
- Rocky Mountain National Park — Ellen Porter

Discussion items: ecological endpoints considered, basis for determining "significant ecological response," anticipated/actual administrative mechanism for establishing the critical load(s), and anticipated/actual use.

10:15 Break

10:30 Deposition Research: Presentation and Discussion

- Research Overview, NADP/CASTNe, and Snow — Don Campbell
- Monitoring N/S with ion-exchange resin collectors — Mark Fenn
- Modeling deposition using CMAQ — Matt Porter, Joe Vaughan
- Hindcasting N and S deposition — Don Campbell

12:00 LUNCH

1:00 Discussion: How does the research relate to setting critical loads in the PNW?

1:30 Ecological Effects Research: Presentation and Discussion

- Monitoring air pollution using lichens — Linda Geiser
- Water chemistry and soils — David Clow
- Effects of N deposition on soil N cycling — Steve Perakis

2:30 Break

2:45 Ecological Effects Research: Presentation and Discussion (Continued)

- Relations between N deposition and eutrophication in lakes — Koren Nydick
- N/S deposition effects on algal species/diatoms/zooplankton — Brenda LaFrancois
- Nitrogen deposition threats to biodiversity — Stu Weiss
- Modeling ecosystem responses to N and S deposition — David Clow

4:05 Discussion: How does the research relate to setting critical loads in the PNW?

4:30 Preview Day Two Agenda — Rob Greenwood

- Discussion Topics
- Questions to Consider
- Anticipated Products

4:50 Wrap Up — Janice Peterson, Elizabeth Waddell

5:00 ADJOURN

DAY TWO – September 7
8:00 am – 1:30 pm

8:00 Introductions and Agenda Review — Rob Greenwood

8:10 Overview: What Is Needed to Establish a Critical Load? — Tamara Blett

8:30 Review and Identify Additions to Day One Research Compilation
- Review Day One synthesis
- Identify relevant additions

8:50 Identify Ecological Endpoints with Most Promise for Establishing Critical Loads
- Research completed to date provides (or nearly provides) the ability to set a critical load.
- The critical load will provide effective protections for park and forest resources.
- It is scientifically defensible.
- The critical load will be practical from a policy standpoint.

9:30 Identify Deposition Research Gaps/Needs for the Selected Endpoints
- What more do we need to know about current/historical deposition rates and what is the best way to obtain this information?
- What role can deposition modeling play in developing the critical loads, and what are the pros/cons of the different types of deposition modeling efforts?

10:30 Break

10:40 Identify Ecological Effects Research Gaps/Needs for the Selected Endpoints
- What are the key ecological effects research gaps, and what is the best way to get this information?
- What chemical indicators from soils, water, or plants could/should be used as a surrogate or threshold for ecological effects at a given critical load?
- What role can ecological and/or chemical indicators modeling play to establish critical loads, and what are the pros/cons of the modeling efforts?

12:00 Working Lunch: Outline a (Preliminary) Critical Loads Research Agenda

- What are the “critical path” deposition and ecological effects research tasks?
- What approach would support setting critical loads the soonest?
- How much time and resources will be needed to conduct this research?

1:15 Future Directions — Janice Peterson and Elizabeth Waddell

- Workshop findings to guide future research proposals
- As resources become available, leverage findings

1:30 ADJOURN

Attachment C
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