**Published Sources of Critical Loads**

## National scale information

*CLs of Acidity for Surface Waters:*

Lynch, J., L.H. Pardo, and C. Huber. 2012. Detailed documentation of the CLAD US critical loads of sulfur and nitrogen Access database, version 15.03.11. Created for the Critical Loads of Atmospheric Deposition (CLAD) Science Subcommittee of the National Atmospheric Deposition Program (NADP). http://nadp.sws.uiuc.edu/committees/clad/CLAD_Database_v15_03_11_Doc_FINAL.pdf

- Steady state CLs calculated using surface water and deposition chemistry, and a threshold for acid neutralizing capacity (ANC=50) in a simple mass balance equation.
- Available only for sites with surface water chemistry data (point data), with the exception of the Southern Appalachians.
- For the Southern Appalachians, CLs have been extrapolated across the landscape so that estimates are available for all surface waters (EMDS project).

*CLs of Acidity for Forested Ecosystems (terrestrial soils):*

McNulty, S.G., E.C. Cohen, J.A. Moore Myers, T.J. Sullivan, and H. Li. 2007. Estimates of critical acid loads and exceedances for forest soils across the conterminous United States. Environmental Pollution 149: 281-292. www.treesearch.fs.fed.us/pubs/28964

- Steady state CLs calculated using information available in geospatial format: soils data from STATSGO, wet deposition data from NADP and Grimm & Lynch, dry and cloud deposition estimates from CASTNet, and forested land type coverage from RSAC, using a simple mass balance equation.
- Large scale mapping of CLs (at 1 km resolution) for the lower 48 states.
- Designed for terrestrial systems (the critical threshold in the SMB equation is based on vegetation effects) but can have broader implications for aquatic systems in the watershed due to the interaction between soils and surface water.
- A discussion of uncertainty surrounding simple mass balance models is available.

*Empirical CLs for Nutrient Nitrogen:*

Pardo, L.H., M.J. Robin-Abbott, and C.T. Driscoll. 2011a. Assessment of nitrogen deposition effect and empirical critical loads of nitrogen for ecoregions of the Untied States. Gen. Tech. Rep. NRS-80. U.S. Department of Agriculture, Forest Service Northern Research Station. 291 pp. http://treesearch.fs.fed.us/pubs/38109

- Based on observations of detrimental ecological effects at specific nitrogen deposition levels. Lowest deposition associated with the effect is considered the critical load.
- Simple and easy to use, applicable over a broad set of conditions.
- Based on measurable ecosystem responses to N inputs, however the CL will be overestimated (set it too high) if the system has not reached steady state (if a similar response would occur at a lower deposition level over a longer period of time).
- CLs have been reported for diatoms, lichens, bryophytes, mycorrhizal fungi, herbaceous plants and shrubs, and forests for 15 ecoregions.

- In many ecoregions, lichens and diatoms will have the lowest CLs.
- Some Regions have calculated empirical N CLs using more site-specific environmental data.

Pardo, L.H., M. Fenn, C.L Goodale, L.H. Geiser, C.T. Driscoll, E. Allen, J. Baron, R. Bobbink, W.D. Bowman, C. Clark, B. Emmett, F.S. Gilliam, T. Greaver, S.J. Hall, E.A. Lilleskov, L. Liu, J. Lynch, K. Nadelhoffer, S. Perakis, M.J. Robin-Abbott, J. Stoddard, L. Weathers, and R.L. Dennis. 2011b. Effects of nitrogen deposition and empirical critical loads for nitrogen for ecoregions of the United States. Ecological Applications 21(8): 3049-3082. http://nrs.fs.fed.us/pubs/41197

Fenn, M.E., K.F. Lambert, T.F. Blett, D.A. Burns, J.H. Pardo, G.M. Lovett, R.A. Haeuber, D.C. Evers, C.T. Driscoll, and D.S. Jefferies. 2011. Setting limits: Using air pollution thresholds to protect and restore of U.S. Ecosystems. Issues in Ecology. Report No. 14. 21 pages. http://esa.org/science_resources/issues/FileEnglish/issuesinecology14.pdf

## Regional Information

*Northern US (Region 1)*

*Determine whether CLs have been calculated and used for your Forest's Class I areas by contacting your Regional Air Specialists and consulting the FS Air Program Class I Areas web site.*

Baron, J.S. 2006. Hindcasting nitrogen deposition to determine an ecological critical load. Ecological Applications, 16(2): 433–439. http://www.fort.usgs.gov/Products/Publications/21484/21484.pdf

- The author used hindcasting to estimate mean wet N-deposition values for the period 1950–1964 equal to 1.5 kg N/ha/yr. This value corresponded to the reported time of alteration of diatom assemblages attributed to N deposition in alpine lakes in Rocky Mountain National Park (USA), suggesting that the CL that defines a threshold for ecological change from eutrophication in this area is 1.5 kg N/ha/yr.

Nanus, L, D.W. Clow, J.E. Saros, V.C. Stephens, and D.H. Campbell. 2012. Mapping critical loads of nitrogen deposition for aquatic ecosystems in the Rocky Mountains, USA. Environmental Pollution 166: 125-135.
http://www.sciencedirect.com/science/article/pii/S0269749112001315#
http://co.water.usgs.gov/publications/non-usgs/Nanus_2012.pdf

- Critical loads of nitrogen deposition for nutrient enrichment in aquatic ecosystems were estimated and mapped in aquatic ecosystems of the Rocky Mountains using a geostatistical approach.
- Regression equations were developed for basins where surface water nitrate has been measured using basin characteristics and nitrogen deposition estimates as explanatory variables.
- The regression equations were applied to unsampled basins to identify threshold values of nitrate concentrations at which ecological effects were likely to occur in surface waters.
- Came up with a CL for N dep of $<1.5 \pm 1$ kg N $ha^{-1}$ $yr^{-1}$.
- Found N deposition exceeded CL in 21 (± 8) % of the study area (>3.0 kg N $ha^{-1}$ $yr^{-1}$).

- The study was challenged by lack of regionally consistent high-resolution landcover, geology, and other input data layers.
- Inorganic N was not included.
- The N deposition estimates were also calculated using PRISM data.

Saros, J.E., D.W. Clow, T. Blett, and A.P. Wolfe. 2011. Critical Nitrogen Deposition Loads in High-elevation Lakes of the Western US Inferred from Paleolimnological Records. Water Air Soil Pollution 216: 193–202. http://faculty.eas.ualberta.ca/wolfe/eprints/Saros_et_al_WASP_2010.pdf

- Changes in diatom species over the last century indicate nitrogen enrichment in two areas, the eastern Sierra Nevada and the Greater Yellowstone Ecosystem; no changes in diatom community structure were apparent in lakes of Glacier National Park.
- Critical loads of nitrogen (N) from atmospheric deposition were determined for alpine lake ecosystems in the western US using fossil diatom assemblages in lake sediment cores. CL is the point at which shifts in diatom community composition occurs.
- A critical load of 1.4 kg N/ha/yr was determined by modeling wet deposition rates for the period in which diatom changes first occurred in each area.
- Sedimentary diatom profiles were taken from two lakes in each area to determine and compare CLs (these CLs were also compared with Baron 2006—1.5 kg N $ha^{-1}$ $year^{-1}$).
- Diatom communities in the last century are largely unchanged –probably because of P limitations.

*Rocky Mountains (Region 2)*

*Determine whether CLs have been calculated and used for your Forest's Class I areas by contacting your Regional Air Specialists and consulting the FS Air Program Class I Areas web site.*

Baron, J.S. 2006. Hindcasting nitrogen deposition to determine an ecological critical load. Ecological Applications, 16(2): 433–439. http://www.fort.usgs.gov/Products/Publications/21484/21484.pdf

- The author used hindcasting to estimate mean wet N-deposition values for the period 1950–1964 equal to 1.5 kg N/ha/yr. This value corresponded to the reported time of alteration of diatom assemblages attributed to N deposition in alpine lakes in Rocky Mountain National Park (USA), suggesting that the CL that defines a threshold for ecological change from eutrophication in this area is 1.5 kg N/ha/yr.

Baron, J.S., C.T. Driscoll, J.L. Stoddard, and E.E. Richer. 2011. Empirical critical loads of atmospheric nitrogen deposition for nutrient enrichment and acidification of sensitive U.S. Lakes. BioScience 61(8): 602-613.
http://www.jstor.org/stable/10.1525/bio.2011.61.8.6
http://www.fort.usgs.gov/Products/ProdPointer.asp?AltID=1846

- Summarizes knowledge of N deposition effects on freshwater lake ecosystems and proposes critical loads.
- Empirically derives N critical loads from measured chemical and biological changes in N deposition using published literature and data sets.
- Discusses nitrogen deposition impacts on aquatic biota and surface water acidification .
- Presents N deposition estimates across lower 48 with high degree of spatial resolution using modeled precipitation data to account for orographic effects and dry deposition data.

- Estimates critical load ranges for the Rocky Mountains, Sierra Nevada, and Northeast.
- Discusses the potential for water body recovery from nitrogen induced nutrient enrichment and acidification.

Bowman, W.D., J. Murgel, T. Blett, E. Porter. 2012. Nitrogen critical loads for alpine vegetation and soils in Rocky Mountain National Park. Journal of Environmental Management 103: 165-171. http://www.sciencedirect.com/science/article/pii/S030147971200120X#

- Presents results of an experimental application of ammonium nitrate to a high-elevation alpine meadow in Rocky Mountain National Park.
- Study purpose was to develop nitrogen deposition critical loads for vegetation and soils in the park.
- Various attributes including species composition and plant biomass were measured to determine the level of added nitrogen that would result in ecosystem responses.
- Authors recommend critical loads of 3 kg N/ha/yr to protect vegetation and less than 10 kg N/ha/yr to protect surface waters and soils from acidification.

Nanus, L, D.W. Clow, J.E. Saros, V.C. Stephens, and D.H. Campbell. 2012. Mapping critical loads of nitrogen deposition for aquatic ecosystems in the Rocky Mountains, USA. Environmental Pollution 166: 125-135.
http://www.sciencedirect.com/science/article/pii/S0269749112001315#
http://co.water.usgs.gov/publications/non-usgs/Nanus_2012.pdf

- Critical loads of nitrogen deposition for nutrient enrichment in aquatic ecosystems were estimated and mapped in aquatic ecosystems of the Rocky Mountains using a geostatistical approach.
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- The regression equations were applied to unsampled basins to identify threshold values of nitrate concentrations at which ecological effects were likely to occur in surface waters.
- Came up with a CL for N dep of $<1.5 \pm 1$ kg N $ha^{-1}$ $yr^{-1}$.
- Found N deposition exceeded CL in 21 (± 8) % of the study area (>3.0 kg N $ha^{-1}$ $yr^{-1}$).
- The study was challenged by lack of regionally consistent high-resolution landcover, geology, and other input data layers.
- Inorganic N was not included.
- The N deposition estimates were also calculated using PRISM data.

Porter, E. and S. Johnson. 2007. Translating science into policy: Using ecosystem thresholds to protect resources in Rocky Mountain Nation Park. Environmental Pollution 149: 268-280. http://www.sciencedirect.com/science/article/pii/S0269749107003296
www.nature.nps.gov/air/pubs/pdf/Porter_Johnson_EP_2007.pdf

- Provides an overview of research on nitrogen deposition in the park and management efforts underway to address concerns about this deposition
- Concern over impacts to Rocky Mountain National Park has resulted in a multi-agency initiative to reduce nitrogen deposition
- Observed increasing trends in nitrate concentrations in wet deposition on the east side of the park are not consistent with decreasing trends in emissions

- A nitrogen critical load that was developed based upon aquatic resources is providing the basis for a deposition goal to provide resource protection
- Strategies are being developed to determine the types and locations of emissions to be reduced, the timeline for emission reductions, and the impact of emission reductions from programs already in place

Saros, J.E., D.W. Clow, T. Blett, and A.P. Wolfe. 2011. Critical Nitrogen Deposition Loads in High-elevation Lakes of the Western US Inferred from Paleolimnological Records. Water Air Soil Pollution 216: 193–202. http://faculty.eas.ualberta.ca/wolfe/eprints/Saros_et_al_WASP_2010.pdf

- Changes in diatom species over the last century indicate nitrogen enrichment in two areas, the eastern Sierra Nevada and the Greater Yellowstone Ecosystem; no changes in diatom community structure were apparent in lakes of Glacier National Park.
- Critical loads of nitrogen (N) from atmospheric deposition were determined for alpine lake ecosystems in the western US using fossil diatom assemblages in lake sediment cores. CL is the point at which shifts in diatom community composition occurs.
- A critical load of 1.4 kg N/ha/yr was determined by modeling wet deposition rates for the period in which diatom changes first occurred in each area.
- Sedimentary diatom profiles were taken from two lakes in each area to determine and compare CLs (these CLs were also compared with Baron 2006—1.5 kg N $ha^{-1}$ $year^{-1}$).
- Diatom communities in the last century are largely unchanged –probably because of P limitations.

Sverdrup, H., T.C. McDonnell, T.J. Sullivan, B. Nihlgard, S. Belyazid, B. Rihm, E. Porter, W.D. Bowman, L. Geiser. 2012. Testing the feasibility of using the ForSAFE-VEG model to map the critical load of nitrogen to protect plant biodiversity in the Rocky Mountains Region, U.S.A. Water Air Soil Pollution 223: 371-387. http://www.springerlink.com/content/0836g41q2t550h47/

- The ForSAFE-VEG model was used to simulate effects of nitrogen deposition on alpine and subalpine soil chemistry and vegetation in the northern and central Rocky Mountains over a 750-year period.
- The simulation was used to estimate critical loads of nitrogen deposition to protect plant diversity.
- The study estimated critical loads of 1-2 kg N/ha/yr, with decreasing plant biodiversity occurring at deposition loads over 3 kgN/ha/yr.
- Simulated deposition under assumptions of emissions controls similar to current conditions resulted in pronounced plant species changes.
- Model results suggest that response times are long (~ 100 years).

*Southwest (Region 3)*

*Determine whether CLs have been calculated and used for your Forest's Class I areas by contacting your Regional Air Specialists and consulting the FS Air Program Class I Areas web site.*

Nanus, L, D.W. Clow, J.E. Saros, V.C. Stephens, and D.H. Campbell. 2012. Mapping critical loads of nitrogen deposition for aquatic ecosystems in the Rocky Mountains, USA. Environmental Pollution 166: 125-135. http://www.sciencedirect.com/science/article/pii/S0269749112001315# http://co.water.usgs.gov/publications/non-usgs/Nanus_2012.pdf

- Critical loads of nitrogen deposition for nutrient enrichment in aquatic ecosystems were estimated and mapped in aquatic ecosystems of the Rocky Mountains using a geostatistical approach.
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- The regression equations were applied to unsampled basins to identify threshold values of nitrate concentrations at which ecological effects were likely to occur in surface waters.
- Came up with a CL for N dep of $<1.5 \pm 1$ kg N ha$^{-1}$ yr$^{-1}$.
- Found N deposition exceeded CL in 21 ($\pm$ 8) % of the study area ($>3.0$ kg N ha$^{-1}$ yr$^{-1}$).
- The study was challenged by lack of regionally consistent high-resolution landcover, geology, and other input data layers.
- Inorganic N was not included.
- The N deposition estimates were also calculated using PRISM data.

*Intermountain (Region 4)*

*Determine whether CLs have been calculated and used for your Forest's Class I areas by contacting your Regional Air Specialists and consulting the FS Air Program Class I Areas web site.*

Baron, J.S. 2006. Hindcasting nitrogen deposition to determine an ecological critical load. Ecological Applications, 16(2): 433–439. http://www.fort.usgs.gov/Products/Publications/21484/21484.pdf

- The author used hindcasting to estimate mean wet N-deposition values for the period 1950–1964 equal to 1.5 kg N/ha/yr. This value corresponded to the reported time of alteration of diatom assemblages attributed to N deposition in alpine lakes in Rocky Mountain National Park (USA), suggesting that the CL that defines a threshold for ecological change from eutrophication in this area is 1.5 kg N/ha/yr.

Nanus, L, D.W. Clow, J.E. Saros, V.C. Stephens, and D.H. Campbell. 2012. Mapping critical loads of nitrogen deposition for aquatic ecosystems in the Rocky Mountains, USA. Environmental Pollution 166: 125-135.
http://www.sciencedirect.com/science/article/pii/S0269749112001315#
http://co.water.usgs.gov/publications/non-usgs/Nanus_2012.pdf

- Critical loads of nitrogen deposition for nutrient enrichment in aquatic ecosystems were estimated and mapped in aquatic ecosystems of the Rocky Mountains using a geostatistical approach.
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- Came up with a CL for N dep of $<1.5 \pm 1$ kg N ha$^{-1}$ yr$^{-1}$.
- Found N deposition exceeded CL in 21 ($\pm$ 8) % of the study area ($>3.0$ kg N ha$^{-1}$ yr$^{-1}$).

- The study was challenged by lack of regionally consistent high-resolution landcover, geology, and other input data layers.
- Inorganic N was not included.
- The N deposition estimates were also calculated using PRISM data.

Saros, J.E., D.W. Clow, T. Blett, and A.P. Wolfe. 2011. Critical Nitrogen Deposition Loads in High-elevation Lakes of the Western US Inferred from Paleolimnological Records. Water Air Soil Pollution 216: 193–202. http://faculty.eas.ualberta.ca/wolfe/eprints/Saros_et_al_WASP_2010.pdf

- Changes in diatom species over the last century indicate nitrogen enrichment in two areas, the eastern Sierra Nevada and the Greater Yellowstone Ecosystem; no changes in diatom community structure were apparent in lakes of Glacier National Park.
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- Sedimentary diatom profiles were taken from two lakes in each area to determine and compare CLs (these CLs were also compared with Baron 2006—1.5 kg N ha$^{-1}$ year$^{-1}$).
- Diatom communities in the last century are largely unchanged –probably because of P limitations.

*California (Region 5)*

*Determine whether CLs have been calculated and used for your Forest's Class I areas by contacting your Regional Air Specialists and consulting the FS Air Program Class I Areas web site.*

Baron, J.S., C.T. Driscoll, J.L. Stoddard, and E.E. Richer. 2011. Empirical critical loads of atmospheric nitrogen deposition for nutrient enrichment and acidification of sensitive U.S. Lakes. BioScience 61(8): 602-613. http://www.jstor.org/stable/10.1525/bio.2011.61.8.6 http://www.fort.usgs.gov/Products/Publications/22649/22649.pdf

Fenn, M.E., E.B. Allen, S.B. Weiss, S. Jovan, L.H. Geiser, G.S. Tonnesen, R.F. Johnson, L.E. Rao, B.S. Gimeno, F. Yuan, T. Meixner, and A. Bytnerowicz. 2010. Nitrogen critical loads and management alternative for N-impacted ecosystems in California. Journal of Environmental Management 91: 2404- 2423. http://www.sciencedirect.com/science/article/pii/S0301479710002306

Fenn, M.E., S. Jovan, F. Yuan, L. Geiser, T. Meixner, and B.S. Gimeno. 2008. Empirical and simulated critical loads for nitrogen deposition in California mixed conifer forests. Environmental Pollution 155: 492-511. http://www.sciencedirect.com/science/article/pii/S0269749108001528

Saros, J.E., D.W. Clow, T. Blett, and A.P. Wolfe. 2011. Critical Nitrogen Deposition Loads in High-elevation Lakes of the Western US Inferred from Paleolimnological Records. Water Air Soil Pollution 216: 193–202. http://faculty.eas.ualberta.ca/wolfe/eprints/Saros_et_al_WASP_2010.pdf

- Changes in diatom species over the last century indicate nitrogen enrichment in two areas, the eastern Sierra Nevada and the Greater Yellowstone Ecosystem; no changes in diatom community structure were apparent in lakes of Glacier National Park.
- Critical loads of nitrogen (N) from atmospheric deposition were determined for alpine lake ecosystems in the western US using fossil diatom assemblages in lake sediment cores.  CL is the point at which shifts in diatom community composition occurs.
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- Sedimentary diatom profiles were taken from two lakes in each area to determine and compare CLs (these CLs were also compared with Baron 2006—1.5 kg N $ha^{-1}$ $year^{-1}$).
- Diatom communities in the last century are largely unchanged –probably because of P limitations.

Weiss, S. B. 2006. Impacts of Nitrogen Deposition on California Ecosystems and Biodiversity. California Energy Commission, PIER Energy-Related Environmental Research.  CEC-500-2005-165.

*Pacific Northwest (Region 6)*

*Determine whether CLs have been calculated and used for your Forest's Class I areas by contacting your Regional Air Specialists and consulting the FS Air Program Class I Areas web site.*

*Lichen-based CLs for N:*

Geiser, L.H., S.E. Jovan, D.A. Glavich, and M. Porter. 2010. Lichen-based critical loads for atmospheric nitrogen deposition in Western Oregon and Washington Forests, USA. Environmental Pollution 158: 2412-2421. http://nadp.sws.uiuc.edu/committees/clad/2010PNW_N_CLs.pdf

*Episodic Acidification of Surface Waters:*

Clow, D.W., Campbell, D.H., 2008. Atmospheric Deposition and Surface Water Chemistry in Mount Rainier and North Cascades National Parks, USA. Denver, Colorado, U.S. Geological Survey Scientific Investigations Report 2008-5152, 37 p. http://pubs.usgs.gov/sir/2008/5152/pdf/SIR08-5152_508.pdf

- Identifies that streamwater chemistry data sampled in 2006 from Mt. Rainier National Park provides evidence of episodic acidification (p. 54).

*Chronic Acidification of Surface Waters:*

Eilers, J.M., K. Vache, B. Eilers, and R. Sweets. 2009. Water Quality & Biological Response to Current and Simulated Increases in Atmospheric Deposition of Sulfur and Nitrogen to Four Lakes in the Oregon and Washington Cascade Range. MaxDepth Aquatics, Inc. Bend, OR. 88 p. http://www.fs.fed.us/air/documents/Wilderness%20Lakes%20Final%20Report.pdf

- Examines sediment cores and water chemistry from four lakes in a north-south transect across the Cascades Mountains.
- Estimates N and S total deposition from CMAQ modeling.
- Uses the CE-QUAL-W2 model to estimate the additional amount of N and S deposition before chronic acidification would be realized.

*Nutrient Enrichment of Alpine Lakes:*

Saros, J. 2009. Determining critical N loads to subalpine lakes in the Pacific Northwest. Climate Change Institute, University of Maine. Final Report: 1-11. http://www.fs.fed.us/air/documents/PNWCL-FinalReport.pdf

- Author performed N-enrichment studies on two subalpine lakes in the Cascade Mountains of Washington.
- Found that the lakes were P-limited or N and P co-limited.

Sheibley, R.W., J.R. Foreman, P.W. Moran, and P.W. Swarzenski. 2012. Atmospheric deposition, water-quality, and sediment data for selected lakes in Mount Rainier, North Cascades, and Olympic National Parks, Washington, 2008–10: U.S. Geological Survey Data Series 721, 34 p. http://pubs.usgs.gov/ds/721/pdf/ds721.pdf

*Southeastern US, including the Mid-Atlantic (Region 8)*

*Determine whether CLs have been calculated and used for your Forest's Class I areas by contacting your Regional Air Specialists and consulting the FS Air Program Class I Areas web site.*

Sullivan, T.J. and B.J. Cosby. 2004. Aquatic critical load development for the Monongahela National Forest. Report prepared for the US Forest Service, December 2004. 84 pp. http://www.fs.fed.us/air/documents/Developing%20Aquatic%20CL%20Monongahela%20NF.pdf

Sullivan, T.J. and B.J. Cosby. 2002. Critical loads of sulfur deposition to protect streams within Joyce Kilmer and Shining Rock wilderness areas from future acidification. Report to USDA Forest Service, National Forests in North Carolina, 160 Zillicoa St, Suite A, Asheville, NC 28801. April 2002.

Sullivan, T.J., B.J. Cosby, and W.A. Jackson. 2011. Target loads of atmospheric deposition for the protection and recovery of acid-sensitive streams in the Southern Blue Ridge Province. Journal of Environmental Management 30: 1-8. http://www.treesearch.fs.fed.us/pubs/38762

Sullivan, T.J., B.J. Cosby, and T.C. McDonnell. 2010. Aquatic critical loads and exceedances in acid-sensitive portions of Virginia and West Virginia. E&S Environmental Chemistry, Inc. Final Report: 1-91. www.esenvironmental.com/PDF/multiagency_report.pdf

Sullivan, T.J., B.J. Cosby, T.C. McDonnell, E.M. Porter, T. Blett, R. Haeuber, C.M. Huber, and J. Lynch. 2012. Critical loads of acidity to protect and restore acid-sensitive streams in Virginia and West Virginia. Water, Air, and Soil Pollution 223(9): 5759-5771. http://www.springerlink.com/content/j2573461r4181533/

*Lake States (Region 9)*

*Determine whether CLs have been calculated and used for your Forest's Class I areas by contacting your Regional Air Specialists and consulting the FS Air Program Class I Areas web site.*

*Northeastern US (Region 9)*

*Determine whether CLs have been calculated and used for your Forest's Class I areas by contacting your Regional Air Specialists and consulting the FS Air Program Class I Areas web site.*

Baron, J.S., C.T. Driscoll, J.L. Stoddard, and E.E. Richer. 2011. Empirical critical loads of atmospheric nitrogen deposition for nutrient enrichment and acidification of sensitive U.S. Lakes. BioScience 61(8): 602-613. http://www.jstor.org/stable/10.1525/bio.2011.61.8.6 http://www.fort.usgs.gov/Products/Publications/22649/22649.pdf

- Empirically derived Nitrogen Critical Loads from measured chemical and biological changes in N deposition using published literature and data sets of sensitive lakes of western and northeastern US.
- Surveys are decades old, but remain the most extensive and uniformly collected lake data available for a national assessment.
- Inflection point where $NO_3^-$ concentrations increase in response to increasing N deposition defines the empirical CL.
- Used three methods for determining lake CL: a) NADP wet, b) PRISM and NADP wet, c) PRISM and NADP wet and CMAQ dry.

- Developed CL by relating deposition to lake chemistry: a) for western mountains nutrient enrichment CL of 1.0 – 3.0 kg N/ha/yr, b) for lakes in forested catchments in northeast nutrient enrichment CL of 3.5 – 6.0 kg N/ha/yr, c) for western mountains acidic episodes CL of 4.0 kg N/ha/yr, and d) for lakes in forested catchments in northeast acidic episodes CL of 8.0 kg N/ha/yr.
- Suggest blending empirically derived CL with steady-state and dynamic models.

Duarte, N., L.H. Pardo, M.J. Robin-Abbott. 2013. Susceptibility of Forests in the Northeastern USA to Nitrogen and Sulfur Deposition: Critical Load Exceedance and Forest Health. Water, Air, & Soil Pollution 224: 1355 – 1376. http://link.springer.com/article/10.1007%2Fs11270-012-1355-6

- Calculated the critical loads of nutrient N and of acidity (S + N) using the steady-state mass balance method at >4,000 regional and national vegetation and soil monitoring network plots in the northeastern USA.
- The critical load, and therefore the exceedance, varied depending on the weathering rate scenario used, resulting in worst case (using minimum weathering rates), mid, best case (using maximum weathering rates), and NSSC mean scenarios for each site.
- For the scenario most representative of regional conditions, over 80 % of the critical loads of S + N fell into the range of 850–2050 eq/ha/yr. Deposition exceeded critical loads for acidity at 45 % of the plots across the region.
- The critical load for nutrient N for this same scenario was 200–300 eq/ha/yr. Deposition exceeded critical loads for nutrient N at 98.5 % of the plots across the region.
- Significant negative correlations were observed between CL exceedance and growth (17 species) and crown density (4 species). Significant positive correlations were observed between CL exceedance and declining vigor (four species), crown dieback (six species), and crown transparency (seven species).
- Among the species which demonstrate the most significant detrimental responses to atmospheric deposition are balsam fir, red spruce, quaking aspen, and paper birch.

Dupont, J., T.A. Clair, C. Gagnon, D.S. Jeffries, J.S. Kahl, S.J. Nelson, and J.M. Peckenham. 2005. Estimation of critical loads of acidity for lakes in northeastern United States and Canada. Environmental Monitoring and Assessment 109:275-291. http://www.springerlink.com/content/b168611822nl5r87/

- Selected Henriksen's Steady-State Water Chemistry Model to develop "CL of acidity (S+N) and the relative sensitivity of surface waters to acidification" map of northeastern North America based on water chemistry from 2053 lakes.
- Produced "sensitivity of bedrock to acid deposition" map.
- Does not focus on specific lake CL, but rather defined five CL classes of S + N in deposition.
- 12.9% of lakes in this review receive deposition in exceedance of lake CL, while another 8.6% are near the exceedance threshold, most of which should benefit from additional $SO_2$ emission reductions and eventually recover from acidification.

Miller, E. 2012. Steady-State Critical Loads and Exceedance for Terrestrial and Aquatic Ecosystems in the Northeastern United States. Technical Report to the Mulit-Agency Critical Loads Project of CLAD, NADP. http://www.nescaum.org/documents/steady-state-critical-loads-and-exceedance-for-terrestrial-and-aquatic-ecosystems-in-the-

northeastern-united-states/steady-state-critical-loads-and-exceedance-for-terrestrial-and-aquatic-ecosystems-in-the-northeastern-united-states/

- Based on extensive evidence of excessive nutrient cation depletion in New York state and the New England states, Miller et. al. has carried out a series of S and N steady-state (i.e. atmospheric deposition and plant growth rates are unchanging and in-balance such that system state properties, such as soil base saturation and surface water pH, are not changing) critical loads estimations and estimates of their exceedance, utilizing aquatic and terrestrial factors, and comparing modeled S and N deposition rates for the base year of 2002 and the projected year 2018, to identify, among other things, those areas most likely to be at continued risk from S and N deposition, even after expected emission reductions.
- Recognizing the limitations of national and regional CMAQ deposition model runs even with their numerous corrections by EPA and others relative to those spatial scales, for the much smaller area of NY and NE a High Resolution Deposition Model (HRDM), previously developed by the principal author to calculate mercury deposition, was used to calculate S and N deposition rates for the targeted years. This model corrects, somewhat, for deposition differences brought about by differences in elevation, particularly for dry deposition and cloud water. The HRDM utilizes a smaller grid (1 $km^2$) than previous CMAQ model runs, recognizing that coarser grids in regions of complex geology and mountains as exist in NY and NE can lead to erroneous results. HRDM utilizes landscape properties (elevation, slope, forest species, etc), landscape position (elevation, differences in solar radiation, etc), climatology, meteorology, atmospheric chemistry, and available NADP, CASTNET, and cooperative observer network precipitation stations. Modeled deposition of Ca, Mg, K, Na, and Cl were assumed to be the same for the 2002 and 2018 model runs.
- Calculated terrestrial and aquatic critical loads were integrated, with the assumption of an average 36% reduction in S and 24% reduction in N across NY and NE between 2002 and 2018. Various maps and GIS databases were generated, illustrating that with expected emissions reductions, some areas in NY and NE experiencing critical load exceedances in 2002 will not experience those exceedances in 2018. However, the vast majority of those sites will continue to be in exceedance.
- Two target pH and ANC combinations were considered (6.6 & 50 µeq/L and 7.15 & 100 µeq/L), and both resulted in net improvements in the number of surface waters in exceedance. However, the number unable to meet attainment was found unchanged for both combinations and target years (16% and 40% for 50 and 100 µeq/L respectively). It appeared that some areas in both the WMNF and the GMNF were among these. While no areas in the Adirondacks were among these (curious to this reviewer), and a large area of the Catskills were.

Sullivan, T.J., B.J. Cosby, C.T. Driscoll, T.C. McDonnell, A.T. Herlihy, and D.A. Burns. 2012. Target loads of atmospheric sulfur and nitrogen deposition for protection of acid sensitive aquatic resources in the Adirondack Mountains, New York. Water Resource Research. 48 (W01547): 1-16. http://www.springerlink.com/content/05840545m5354163/

- “The Model of Acidification of Groundwater in Catchments (MAGIC) was used to simulate a matrix of Target Load values for use in protection and restoration of forest resources in the Adirondack Mountains of New York against soil acidification against acidic deposition.”

- 44 statistically selected modeled watersheds were extrapolated to represent the 1320 watersheds in the Adirondack Ecoregion.
- The matrix of Target Load estimates was developed based on differing sensitive resources and associated indicators, critical thresholds, and evaluation year
- Some critical threshold criteria were simulated to be unobtainable for given watersheds, even if acidic deposition was held to zero until the endpoint year, due either to pre-industrial acidic conditions or due to base cation depletion.

**Critical Levels (Ozone and Mercury)**

Lefohn, A.S., and R.C. Musselman. 2012. Development of Ozone Thresholds for Vegetation Air Quality Related Value (AQRV). Forest County Potawatomi Community Forest County Potawatomi Community Natural Resources Department. Crandon, WI.

**Atmospheric Deposition**

Ollinger, S.V., J.D. Aber, G.M. Lovett, S.E. Milham, and R.G. Lathrop. 1993. A spatial model of atmospheric deposition for the northeastern US. Ecological Applications 3: 459-472. http://harvardforest.fas.harvard.edu/sites/harvardforest.fas.harvard.edu/files/publications/pdfs/Ollinger_EcoApps_1993.pdf

Grimm, J. W. and J. A. Lynch. 2004. Enhanced wet deposition estimates using modeled precipitation inputs. Environmental Monitoring and Assessment 90: 243-268. http://link.springer.com/article/10.1023%2FB%3AEMAS.0000003592.56006.a0?LI=true

Nanus, L., D.H. Campbell, G.P. Ingersoll, D.W. Clow, and A.M. Mast. 2003. Atmospheric deposition maps for the Rocky Mountains. Atmospheric Environment 37: 4881-4892. http://co.water.usgs.gov/lochvale/pdfs/Nanus_2003.pdf

Community Multiscale Air Quality Modeling System. Retrieved November 18, 2012, from http://www.airqualitymodeling.org/cmaqwiki/index.php?title=CMAQ_version_5.0.1_%28July_2012_release%29_Technical_Documentation