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**A National Picture of Acid Deposition Critical Loads
for Forest Soils in Canada**

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A National Picture of Acid Deposition Critical Loads for Forest Soils in Canada

A report prepared for the CCME Acid Rain Task Group.

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Introduction

The primary long-term goal of *The Canada-Wide Acid Rain Strategy for Post-2000 (The Strategy)* is “to meet the environmental threshold of critical loads for acid deposition across Canada”. A critical load is an effects-based measurement defined as “a 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”. *The Strategy* calls for a number of steps toward the achievement of this goal, including pursuing further acidifying emission reductions in Canada and the U.S., preventing pollution and keeping “clean” areas clean (i.e. protect ecosystems not yet impacted by acidifying emissions).

Since the signing of *The Strategy*, the science of critical loads in Canada and the measurements that support them have evolved significantly. Scientists are now able to estimate and map total (wet and dry) acid deposition (sulphur and nitrogen), critical loads and exceedances for both terrestrial (upland forest soils) and aquatic ecosystems. Since sulphur and nitrogen have different atomic weights, total acid deposition critical loads are expressed as a charge equivalent (eq/ha/yr) instead of as a mass (kg/ha/yr) as carried out in the past.

Until recently efforts in Canada were focused on developing critical loads and exceedances for forest soils and lakes in eastern Canada (Jeffries and Ouimet, 2005) due to widely observed acid deposition impacts, but concern over rising emissions of acidifying pollution and the objective to keep clean areas clean has encouraged a broadening in focus to include western Canada. Limited information in the west resulted in the Acid Rain Task Group funding a number of projects to develop critical loads for upland forest soils in Manitoba, Saskatchewan and Alberta. For consistency, the methodology followed the same protocol and guidelines applied in eastern Canada and northeastern U.S. (NEG-ECP, 2001).

The objective of this report is to present a national picture of critical loads and exceedances for forest soils across Canada (with the exception of the Territories) based on the most up-to-date estimates available. National maps of the sensitivity of ecosystems serve as a useful means to illustrate where and by how much forest ecosystems are at risk of sulphur and nitrogen deposition damage. This information is useful to determine where and by how much emission controls will be needed in order to protect sensitive ecosystems from potential or further damage.

Methodology

Critical loads

Critical loads have been previously determined and mapped for upland forest soils in eastern Canada south of 49°N latitude (New Brunswick, Nova Scotia, Prince Edward Island, Newfoundland, Quebec and Ontario) by Ouimet et al. (2006), and in western Canada (Manitoba, Saskatchewan and Alberta) by Aherne and Watmough (2006) and Aherne (2008a, 2008b) using the Steady-State Mass Balance (SSMB) model. The methodology used in all cases was consistent with the protocol established by the New England Governors and Eastern Canadian Premiers (NEG-ECP) Environmental Task Group on Forest Mapping (NEG-ECP, 2001). Detailed information on the approach used to calculate critical loads can be obtained from any of the above reports. In addition, preliminary estimates are available for British Columbia and northern Ontario (Aherne, 2007; J. Aherne, personal communication) where unlike the

other provinces, critical loads were based solely on base cation weathering rates (rather than a mass balance approach as estimates of base cation deposition are unavailable for these regions).

For the purposes of this report, all of the above information was compiled and 'knitted together' into a unified GIS data layer to create a map showing critical loads for upland forest soils in Canada. Unlike some of the above mentioned critical load assessments, the new map only includes forest upland soil critical loads (excludes non-forested and forested wetland areas). This methodology is deemed more appropriate given that the NEG-ECP protocol was developed for determining sulphur and nitrogen critical loads of forested upland soils only. Forested areas were defined using the Simple Biosphere model of the North American Land Cover Characteristics Data Base, <http://edcsns17.cr.usgs.gov/glcc/>). The wetland-upland delineation was based on the national digital elevation model of Canada (NRCAN, 2007), and by determining all topographically definable water bodies (Murphy et al., 2007) to identify all those areas with soils that are or would remain wet (e.g., imperfectly to poorly drained) in reference rising and falling water tables. Wetland areas also represent organic soils; thus, the national maps presented here exclude organic forest soils.

Exceedances

Critical load exceedance was produced for upland forest soils across Canada by mapping the difference between the total acid deposition value for a given spatial unit or map grid (35 km x 35 km resolution) and the critical load value. Average total (wet + dry) sulphur (SO_2 and SO_4^{2-}) and nitrogen (NO_3^- , HNO_3 and NH_4^+) deposition over forested areas only for the period 1994-1998 was used (M. Shaw, NATChem, personal communication). Wet deposition was estimated from interpolated observations and dry deposition was estimated inferentially (using a combined measurement/modeling technique). See Vet et al. (2005) for a more detailed explanation of deposition estimation methods. Given the absence of deposition information in northern Ontario and British Columbia, it was not possible to determine exceedance estimates based on measurement data at this time.

For comparative purposes as well as to be able to assess what may be happening in areas where deposition is not currently being monitored (e.g. British Columbia), a second critical load exceedance map was produced based on a one-year simulation of current (2002) deposition performed with Environment Canada's AURAMS model (A Unified Regional Air quality Modelling System). Hourly gridded anthropogenic emissions files used for the simulation were prepared from the 2002 Canadian, 2002 U.S., and 1999 Mexican national CAC emissions inventories; and hourly biogenic emissions were predicted using AURAM's chemical transport model. AURAMS hourly wet and dry deposition output fields for a number of sulphur (SO_2 , p- SO_4 and H_2SO_4) and nitrogen (NO_2 , HNO_3 , p- NO_3 , RNO_3 , PAN, NH_3 , p- NH_4) species were then processed for the entire annual period to obtain annual sulphur (S) total deposition and nitrogen (N) total deposition fields. AURAMS predicts dry deposition of sulphur and nitrogen species using predicted surface concentration fields and dry deposition velocities based on a resistance parameterization that includes dependence on land cover characteristics, soil wetness, and surface meteorology as predicted by GEM (a prognostic meteorological model). The above information on AURAMS and the 2002 run is described in more detail in Moran et al. (2008). Results of the 2002 deposition scenario are preliminary and revisions are in progress.

The Maps

Mapping results show that critical loads below 400 eq/ha/yr (Figure 1: red to yellow) occur along high elevation areas and the coast in BC, in large areas in northern AB, SK, MB and ON, in south-central QC, and in south-eastern NS and Nfld. These areas are mostly characterized by non-carbonate bedrock and shallow, coarse-textured, upland soils that have a low buffering capacity. The 400 eq/ha/yr value is mentioned here as a point of reference given that it is approximately equivalent to the 20 kg/ha/yr target load for sulphate deposition established in 1983 to protect sensitive lakes in eastern Canada; however, as can be seen here, new science shows the critical load for sulphur and nitrogen is significantly lower than the 1983 target load.

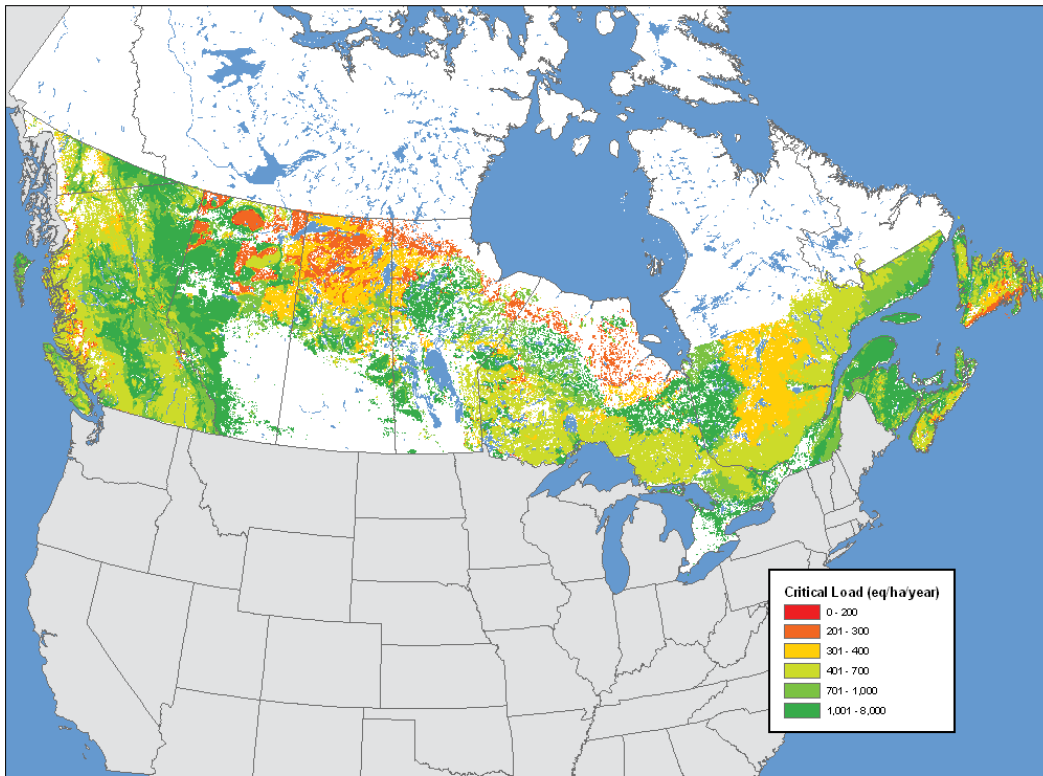


Figure 1. Sulphur plus nitrogen critical loads for upland forest soils across Canada.

The mapped critical load values were determined based on the NEG-ECP protocol. The approach excludes the effects of forest harvesting and fire, assumes all nitrogen removal processes from the soil are negligible, and uses a critical chemical limit based on a base cation to aluminum ratio of 10 ($BC:Al = 10$). More details can be obtained from reports cited under the Methodology section. Ultimately the approach should be revised to appropriately assess the chemical criterion, nitrogen parametrization, and the influence of forest harvesting and fire for all of Canada. Nonetheless, critical loads shown below present a consistent broad scale indication of the acid sensitivity of forest soils.

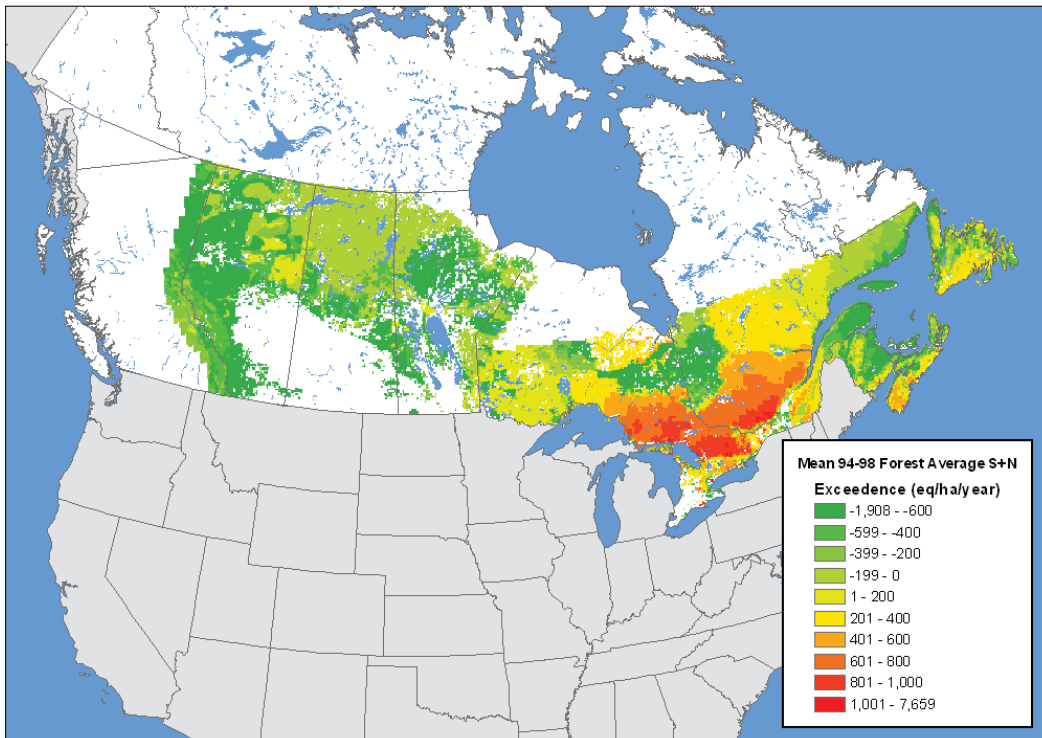


Figure 2. Exceedances of sulphur plus nitrogen critical loads for upland forest soils across Canada based on average (1994-1998) measured deposition. No deposition estimates were available for BC and northern ON.

Based on average total sulphur and nitrogen deposition maps for the period 1994-1998, approximately 38 % of the mapped upland forest area in Canada receives acid deposition in exceedance of the critical load (Figure 2). In some cases exceedances occur in areas where the critical load is low and the acid loadings are high (e.g. large portions of eastern Canada). In other cases, although the critical loads are comparatively high, high levels of acid deposition exceed the natural buffering capacity of the soils (e.g. southern ON and southern QC). When shown on the same map, exceedances in western Canada are relatively low compared to eastern Canada. It is important to note three critical points about the uncertainty of the exceedance estimates: (1) the exceedance values in western Canada are much more uncertain than those in eastern Canada due to the paucity of deposition data in western Canada; (2) no deposition data were available in the vicinity of the major emission sources so uncertainties are exceptionally high in those areas; and (3) exceedance values across the country are additionally uncertain due to the lack of measurement data for certain base cation size particles and for several nitrogen compounds (e.g., organonitrates, NO_2 and NH_3). Nevertheless, an area where the critical load is exceeded (yellowy green to red) presents a potential risk for new or ongoing damage.

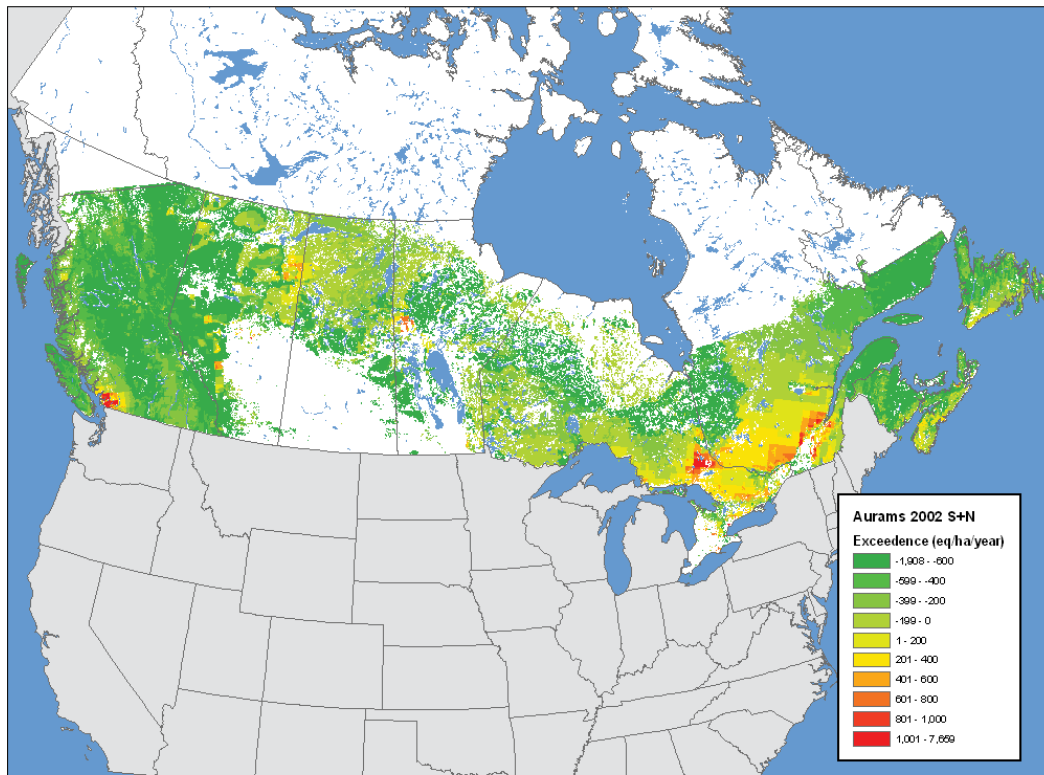


Figure 3. Exceedances of sulphur and nitrogen critical loads for upland forest soils across Canada based on preliminary estimates of current deposition (2002) from the AURAMS model.

Overall, upland forest soil areas across the country with the highest critical load exceedances based on modelled-deposition estimates (Figure 3) are consistent with those shown on Figure 2 although the magnitude of the exceedances differs in some cases. For instance, the degree of exceedance over southcentral ON and southwestern QC shown on Figure 2 is higher than that shown for the same area on Figure 3. Also, when taking a look across the map, highest exceedances (orange and red) are shown near large emission sources (e.g. the Lower Fraser Valley, Athabasca Oil Sands, MB smelters, Sudbury, Windsor-QC corridor). Differences between the two exceedance maps may be attributed to: (1) declines in sulphur and nitrogen deposition that have occurred in eastern Canada since the 1994-1998 measurement period and not captured in Figure 2; (2) deposition monitoring stations are located in regions remote from large emission sources and model deposition estimates are based on emission directly from sources; (3) total deposition estimates used in Figure 2 are to forest areas only, whereas total deposition used in Figure 3 are to all land cover types within each AURAMS grid (as such AURAMS modelled grids with a mix of forest and other land covers will have a lower deposition rate); and (4) uncertainties associated with deposition measurements (explained above) as well as uncertainties in emissions information.

Although the intent of this exercise is to show a national picture of acid deposition sensitivity, comparisons between provinces should be made with caution since they were mapped at different scales and there are differences in the underlying data used to calculate critical loads. Also, the above maps should be considered a first step in the process to be refined and updated as improved methods and new data become available.

Conclusion

Recent acid deposition sensitivity assessments completed for Alberta eastward show that in every province there are upland forest soils that currently receive acid deposition levels greater than their long-term critical load. Southeastern Canada in particular continues to be at risk of continued ecosystem damage despite past reductions in acidifying emissions.

References

- Aherne, J., Watmough, S. (2006) Calculating Critical Loads of Acid Deposition for Forest Soils in Manitoba and Saskatchewan: Data Sources, Critical Load, Exceedance and Limitations. Final Report prepared for CCME. Environmental and Resource Studies, Trent University, Peterborough, ON.
- Aherne, J. (2007). Assessment of the Impact on Canadian Coastal Ecosystems from Marine Vessel SO_x Emissions: Exceedance of Critical Loads of Acidic Deposition in British Columbia and Ontario. Interim Report, Environmental and Resource Studies, Trent University, Peterborough, Ontario.
- Aherne, J. (2008a). Calculating Critical Loads of Acid Deposition for Forest Soils in Alberta: Critical load, exceedance and limitations. Final Report, Environmental and Resource Studies, Trent University, Peterborough, Ontario.
- Aherne, J. (2008b). Critical Load and Exceedance Estimates for Upland forest Soils in Manitoba and Saskatchewan: Comparing Exceedance Outputs of Different Models. Final Report, Environmental and Resource Studies, Trent University, Peterborough, Ontario.
- Jeffries, D., Ouimet, R. (2005) Chapter 8: Critical loads: Are they being exceeded? In: 2004 Canadian Acid Deposition Science Assessment. Environment Canada, Ottawa.
- Ouimet, R., P.A. Arp, S.A. Watmough, J. Aherne, I. Demerchant (2006). Determination and mapping critical loads of acidity and exceedances for upland forest soils in eastern Canada. *Water, Air, and Soil Pollution* 172: 57-66.
- Moran, M.D., Q. Zheng, R. Pavlovic, S. Cousineau, V.S. Bouchet, M. Sassi, P.A. Makar, W. Gong, and C. Stroud (2008). Predicted acid deposition critical-load exceedances across Canada from a one-year simulation with a regional particulate-matter model. *Proc. 15th Joint AMS/A&WMA Conference on Applications of Air Pollution Meteorology*, Jan. 21-24, New Orleans, 20 pp. [Available from weblink <http://ams.confex.com/ams/pdfpapers/132916.pdf>]
- Murphy, P.N.C., J. Ogilvie, F.-R. Meng and P.A. Arp. (2007). Stream network modelling using LiDAR and photogrammetric DEMs: a comparison and field verification. *Hydrological Processes*.
- NEG-ECP (2001). Critical load of sulphur and nitrogen assessment and mapping protocol for upland forests. New England Governors and eastern Canadian Premiers Environment Task Group, Acid Rain Action Plan, Halifax, Canada.
- NRCAN (2007). Canada3D - Digital Elevation Model of the Canadian Landmass. <http://www.geogratis.ca/geogratis/en/collection/detail.doid=8880>.
- Vet, R., J. Brook, C. Ro, M. Shaw, J. Narayan, L. Zhang, M. Moran, M. Lusi (2005). Chapter 3: Atmospheric response to past emission control programs. In: The 2004 Canadian Acid Deposition Science Assessment. Environment Canada, Ottawa.