Critical loads of atmospheric nitrogen deposition for sensitive high-elevation ecosystems in the western United States

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High-elevation ecosystems in the western United States (US) are impacted by current and historic atmospheric nitrogen (N) deposition associated with local and regional air pollution. Documented effects include elevated surface water nitrate concentrations, increased algal productivity, and changes in diatom species assemblages. A predictive framework was developed for sensitive high-elevation basins in the Rocky Mountains and Sierra Nevada at multiple spatial scales. Critical loads of N deposition for nutrient enrichment of aquatic ecosystems were quantified and mapped using a geostatistical approach, with modeled N deposition, topography, vegetation, geology, and climate as potential explanatory variables. Rather than relying on a single predictive model, multiple predictive models were developed using various combinations of explanatory variables; this approach allowed for better quantification of uncertainty and more accurate identification of the aquatic ecosystems most sensitive to high atmospheric N deposition (> 3 kg N ha^{-1} yr^{-1}). The lowest critical loads estimates (<1.0 + 1 kg N ha^{-1} yr^{-1}) occurred in high-elevation basins with steep slopes, sparse vegetation, and exposed bedrock and talus. Estimated critical load exceedances correspond with areas of high N deposition and vary spatially. Broad areas of the Rocky Mountains and Sierra Nevada may be impacted by excess N deposition, with greatest impact at high elevations. The approach presented here may be transferable to other remote and protected high-elevation ecosystems that are sensitive to adverse effects of pollutant loading in the US and around the world.