Evaluation of the Sensitivity of Inventory and Monitoring National Parks to Acidification Effects from Atmospheric Sulfur and Nitrogen Deposition

Great Lakes Network (GLKN)

Natural Resource Report NPS/NRPC/ARD/NRR—2011/356
ON THE COVER

Some ecosystems and vegetation types, such as remote high-elevation lakes, sugar maple trees, headwater streams, and red spruce trees, are sensitive to the effects of acidification from atmospheric nitrogen and sulfur deposition.
Photograph by: National Park Service
Evaluation of the Sensitivity of Inventory and Monitoring National Parks to Acidification Effects from Atmospheric Sulfur and Nitrogen Deposition

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This report received peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data. Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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National maps of atmospheric S and N emissions and deposition are provided in Maps A through D as context for subsequent network data presentations. Maps A and B show county level emissions of total S and total N for the year 2002. Maps C and D show total S and total N deposition, again for the year 2002.

The Great Lakes Network contains six parks larger than 100 square miles: Apostle Islands (APIS), Isle Royale (ISRO), Pictured Rocks (PIRO), Saint Croix (SACN), Sleeping Bear Dunes (SLBE), and Voyageurs (VOYA). There are also three smaller parks in this network Grand Portage (GRPO), Indiana Dunes (INDU), and Mississippi (MISS).

Total annual S and N emissions, by county, are shown in Maps E and F for lands in and surrounding the Great Lakes Network. County-level S emissions within the network generally ranged from less than 1 ton per square mile to more than 50 tons per square mile per year. One county exceeded this amount, emitting more than 100 tons of S per square mile per year (Map E). Most of the counties in the network emitted less than 1 ton of S per square mile per year. County-level N emissions within the network ranged from less than 1 ton per square mile to more than 50 tons per square mile per year (Map F). In general, annual county N emissions were between 1 and 20 tons per square mile, although there were isolated counties that exhibited N emissions in the range of 20 to 100 tons per square mile per year. Individual SO$_2$ point sources are shown in Map G. There were only three SO$_2$ point sources within the network with emissions larger than 20,000 tons of S per year; one of these emitted more than 40,000 tons of S per year. SO$_2$ point source emissions values were generally in the range of less than 1 ton of S per year to 5,000 tons of S per year. SO$_2$ point sources of greater magnitude were found to the southeast, outside of the network boundary. Point source emissions of oxidized (nitrogen oxides, NO$_x$) and reduced (ammonia, NH$_3$) N are shown in Map H. Relatively large N point sources (greater than 2,500 tons per year) were consistently sources of oxidized, rather than reduced, N. Nevertheless, there were many smaller sources of reduced N within and near the network, mainly in the southern half of Minnesota. Many of the larger N point sources within the network were located along the perimeter of the southern section of Lake Michigan.

Urban centers within the network and within a 300-mile buffer around the network are shown on Map I. The largest urban centers are Chicago, Detroit, and Milwaukee. Columbus and Indianapolis also have large populations, and lie within the 300-mile buffer around the network (Map I).

Total S and N deposition in and around the network are shown in Maps J and K, respectively. Included in this analysis are both wet and dry forms of deposition and both the oxidized and reduced N species. Total S deposition within the network ranged from less than 2 kg S/ha/yr in the northwestern portion of the network, near the U.S.–Canadian border, to greater than 30 kg S/ha/yr in the south-southeast portion, near Chicago and Lake Michigan (Map J). In general, the estimated S deposition within the network ranged from 2 to 15 kg S/ha/yr; higher S deposition values occurred to the south and lower S deposition values to the north. Total N deposition throughout most of the network ranged from 5 to 10 kg N/ha/yr in the north to 10 to 15 kg N/ha/yr in the south. There were areas around the more heavily urbanized areas with higher...
deposition, between 15 and 20 kg N/ha/yr. There were also two small areas with N deposition in the range of 20 to 30 kg/ha/yr (Map K).

The largest I&M parks in this network, ISRO and VOYA, are located in the northernmost portion of the network, where emissions and deposition of S and N are generally lowest. Two smaller parks, INDU and MISS, are located in the more heavily populated and industrialized portion of the network to the south.

Land cover in and around the network is shown in Map L. The predominant cover types within this network are generally forest and wetlands in the north and a mix of row crops, urban development, and pasture/hay lands in the south and in northwestern Minnesota.

Park lands in the Great Lakes Network have very low relief (Map M). Average slope in all parks is less than 10º.

Park lands requiring special protection against potential adverse impacts associated with acidification from atmospheric S and N deposition are shown on Map N. Also shown on Map N are all federal lands designated as wilderness, both lands managed by NPS and lands managed by other federal agencies. The land designations used to identify this heightened protection included Class I designation under the Clean Air Act Amendments and wilderness designation. There are some wilderness and Class I areas in the northern portion of this network. VOYA and ISRO are both Class I.

Network rankings are given in Figures A through C as the average ranking of the Pollutant Exposure, Ecosystem Sensitivity, and Park Protection metrics, respectively. Figure D shows the overall network Summary Risk ranking. In each figure, the rank for this particular network is highlighted to show its relative position compared with the ranks of the other 31 networks.

The Great Lakes Network ranked at the bottom of the second highest quintile, a Moderate to High ranking among networks, in acid Pollutant Exposure (Figure A). Sulfur and N emissions and deposition within the network were both relatively high. The network Ecosystem Sensitivity ranking was also relatively high, in the middle of the second highest quintile among networks (Figure B). This is mainly because this network contains some vegetation types that are expected to be especially sensitive to acidification effects from S and N deposition and the park lands within this network occupy areas that are known to be sensitive to acidification. This network ranked in the middle quintile in Park Protection, having moderate amounts of protected lands (Figure C).

In combination, the network rankings for Pollutant Exposure, Ecosystem Sensitivity, and Park Protection yielded an overall network Summary Risk ranking that was in the second highest quintile among networks (Figure D). The overall level of concern for acidification effects on I&M parks within this network is considered High.

Similarly, park rankings are given in Figures E through H for the same metrics. In the case of the park rankings, we only show in the figures the parks that are larger than 100 square miles. Relative ranks for all parks, including the smaller parks, are given in Table A and Appendix A. As for the network ranking figures, the park ranking figures highlight those parks that occur in this network to show their relative position compared with parks in the other 31 networks. Note
that the rankings shown in Figures E through H reflect the rank of a given park compared with all other parks, irrespective of size.

Pollutant Exposure in five of the six larger parks was ranked Moderate; the sixth large park (ISRO) was ranked Low. Pollutant Exposure rankings were higher in the smaller parks that are located in the more populated and industrialized portions of the network: INDU was ranked Very High and MISS was ranked High (Table A). The third smaller park (GRPO) was ranked Low for Pollutant Exposure. The larger parks varied only slightly in rankings for Ecosystem Sensitivity (Figure F). ISRO and SLBE were ranked High while APIS, PIRO, SACN, and VOYA were all ranked in the highest quintile (Very High) for Ecosystem Sensitivity. The smaller parks were ranked Moderate or High for Ecosystem Sensitivity. Both VOYA and ISRO contain appreciable amounts of protected land and were ranked Very High in Park Protection (Figure G); the other parks in this network were all ranked Moderate for this theme. The park Summary Risk was Very High for VOYA and High for five other parks in this network, including four of the large parks. The remaining parks, including SLBE, were ranked Moderate for Summary Risk (Figure H, Table A).

<table>
<thead>
<tr>
<th>I&amp;M Parks² in Network</th>
<th>Relative Ranking of Individual Parks¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pollutant Exposure</td>
</tr>
<tr>
<td>Apostle Islands</td>
<td>Moderate</td>
</tr>
<tr>
<td>Grand Portage</td>
<td>Low</td>
</tr>
<tr>
<td>Indiana Dunes</td>
<td>Very High</td>
</tr>
<tr>
<td>Isle Royale</td>
<td>Low</td>
</tr>
<tr>
<td>Mississippi</td>
<td>High</td>
</tr>
<tr>
<td>Pictured Rocks</td>
<td>Moderate</td>
</tr>
<tr>
<td>Saint Croix</td>
<td>Moderate</td>
</tr>
<tr>
<td>Sleeping Bear Dunes</td>
<td>Moderate</td>
</tr>
<tr>
<td>Voyageurs</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

¹ Relative park rankings are designated according to quintile ranking, among all I&M Parks, from the lowest quintile (very low risk) to the highest quintile (very high risk).

² Park name is printed in bold italic for parks larger than 100 square miles.
Map A. National map of total $S$ emissions by county for the year 2002, in units of tons of $S$ per square mile per year. (Source of data: EPA National Emissions Inventory, [http://www.epa.gov/ttn/chief/net/2002inventory.html](http://www.epa.gov/ttn/chief/net/2002inventory.html))

Map B. National map of total $N$ emissions by county for the year 2002. Both oxidized (nitrogen oxides, $NO_x$) and reduced (ammonia, $NH_3$) forms of $N$ are included. The total is expressed in tons per square mile per year. (Source of data: EPA National Emissions Inventory, [http://www.epa.gov/ttn/chief/net/2002inventory.html](http://www.epa.gov/ttn/chief/net/2002inventory.html))

Map C. Total $S$ deposition for the conterminous United States for the year 2002, expressed in units of kilograms of $S$ deposited from the atmosphere to the Earth surface per hectare per year. For the eastern half of the country, wet deposition values were derived from interpolated measured values from NADP (three-year average centered on 2002) and dry deposition values were derived from 12-km CMAQ model projections for 2002. For the western half of the country, both wet and dry deposition values were derived from 36-km CMAQ model projections for 2002. NADP interpolations were performed using the approach of Grimm and Lynch (1997). CMAQ model projections were provided by Robin Dennis, U.S. EPA.

Map D. Total $N$ deposition for the conterminous United States for the year 2002, expressed in units of kilograms of $N$ deposited from the atmosphere to the Earth surface per hectare per year. Wet and dry forms of both oxidized (nitrogen oxides, $NO_x$) and reduced (ammonia, $NH_3$) $N$ are included. For the eastern half of the country, wet deposition values were derived from interpolated measured values from NADP (three-year average centered on 2002) and dry deposition values were derived from 12-km CMAQ model projections for 2002. For the western half of the country, both wet and dry deposition values were derived from 36-km CMAQ model projections for 2002. NADP interpolations were performed using the approach of Grimm and Lynch (1997). CMAQ model projections were provided by Robin Dennis, U.S. EPA.

Map E. Total $S$ emissions by county for lands surrounding the network, expressed as tons of $S$ emitted into the atmosphere per square mile per year. (Source of data: EPA National Emissions Inventory, [http://www.epa.gov/ttn/chief/net/2002inventory.html](http://www.epa.gov/ttn/chief/net/2002inventory.html))

Map F. Total $N$ emissions by county for lands surrounding the network, expressed as tons of $N$ emitted into the atmosphere per square mile per year. The total includes both oxidized (nitrogen oxides, $NO_x$) and reduced (ammonia, $NH_3$) $N$. (Source of data: EPA National Emissions Inventory, [http://www.epa.gov/ttn/chief/net/2002inventory.html](http://www.epa.gov/ttn/chief/net/2002inventory.html))


Map H. Major point source emissions of oxidized (nitrogen oxides, $NO_x$) and reduced (ammonia, $NH_3$) $N$ in and around the network. The base of each vertical bar is
positioned in the map at the approximate location of the source. The height of the bar is proportional to the magnitude of the source. (Source of data: EPA National Emissions Inventory, http://www.epa.gov/tnn/chieff/net/2002inventory.html)

Map I. Urban centers having more than 10,000 people within the network and within a 300-mile buffer around the perimeter of the network. (Source of data: U.S. Census 2000)

Map J. Total S deposition in and around the network. Values are expressed as kilograms of S deposited per hectare per year. (Source of data: Interpolated NADP wet and CMAQ Model dry deposition data for 2002; see information for Map C above for details)

Map K. Total N deposition in and around the network. Included in the total are wet plus dry forms of both oxidized (nitrogen oxides, NOx) and reduced (ammonia, NH3) N. Values are expressed as kilograms of N deposited per hectare per year. (Source of data: Interpolated NADP wet and CMAQ Model dry deposition data for 2002; see information for Map D above for details)

Map L. Land cover types in and around the network, based on the National Land Cover dataset. (Source of data: National Land Cover Dataset, http://www.mrlc.gov/nlcd_multizone_map.php)

Map M. Average land slope within park units that occur within the network, by 10-digit HUC. Some parks in this network are slightly larger than 100 mi², but yet too small to readily see the color within the park outline. These parks are represented on the map with a colored circle and a line from the circle indicating the park location. (Source of data: U.S. EPA National Elevation Dataset [http://ned.usgs.gov/])

Map N. Lands within the network that are classified as Class I or wilderness area. (Source of data: USGS 2005 [National Atlas; http://nationalatlas.gov] and NPS)

Figure A. Network rankings for Pollutant Exposure, calculated as the average of scores for all Pollutant Exposure variables.

Figure B. Network rankings for Ecosystem Sensitivity, calculated as the average of scores for all Ecosystem Sensitivity variables.

Figure C. Network rankings for Park Protection, calculated as the average of scores for all Park Protection variables.

Figure D. Network Summary Risk rankings, calculated as the average of the quintile ranks for the Pollutant Exposure, Ecosystem Sensitivity, and Park Protection themes.

Figure E. Park rankings for Pollutant Exposure for all parks larger than 100 square miles. Ranks for each park were calculated relative to all parks, regardless of size, as the average of scores for all Pollutant Exposure variables.
Figure F. Park rankings for Ecosystem Sensitivity for all parks larger than 100 square miles. Ranks for each park were calculated relative to all parks, regardless of size, as the average of scores for all Ecosystem Sensitivity variables.

Figure G. Park rankings for Park Protection for all parks larger than 100 square miles. Ranks for each park were calculated relative to all parks, regardless of size, as the average of scores for all Park Protection variables.

Figure H. Park rankings for Summary Risk for all parks larger than 100 square miles. Ranks for each park were calculated relative to all parks, regardless of size, as the average of the quintile ranks for the Pollutant Exposure, Ecosystem Sensitivity, and Park Protection themes.
Total Sulfur Emissions by County
Conterminous U.S.
(tons per square mile per year)

Map A
Figure E

Map G

SO₂ (Sulfur Dioxide) Point Sources
Great Lakes Network
(tons S per year)

SO₂ Point Sources (tons S per year)
- Less than 1
- 1 - 5,000
- 5,000 - 20,000
- 20,000 - 40,000
- 40,000 - 80,337

U.S. States
Great Lakes Network
Network Parks (larger than 100 sq. mi)
Network Parks (smaller than 100 sq. mi)

Data Source: National Emissions Inventory (EPA, 2002)
Projection: Lambert Conformal Conic, NAD 1983
Produced for: National Park Service, Air Resources Division, 2010
Prepared by: E&S Environmental Chemistry
Total Sulfur Deposition
Great Lakes Network
(kg/ha/yr)

Data Source: Interpolated NADP Wet and CMAQ Model Dry Deposition for 2002
Projection: Lambert Conformal Conic, NAD 1983
Produced for: National Park Service, Air Resources Division, 2010
Prepared by: E&S Environmental Chemistry

Map J
Figure A: Acidification Risk Assessment
Pollutant Exposure Ranking

Networks and Regions:
- Northeast Coastal and Barrier
- National Capital Region
- Mid Atlantic
- Eastern Rivers and Mountains
- South Florida / Caribbean
- Heartland
- Southeast Coast
- Mediterranean Coast
- Appalachian Highlands
- San Francisco Bay Area
- Northeast Temperate
- Great Lakes
- Pacific Island
- Gulf Coast
- Southern Plains
- Northern Great Plains
- North Coast and Cascades
- Sierra Nevada
- Klamath
- Rocky Mountain
- Mojave Desert
- Sonoran Desert
- Chihuahuan Desert
- Northern Colorado Plateau
- Upper Columbia Basin
- Greater Yellowstone
- Southern Colorado Plateau
- Central Alaska
- Southwest Alaska
- Southeast Alaska
- Arctic

Average of Network Ranking

Figure A
Acidification Risk Assessment

Ecosystem Sensitivity Ranking

Network

Average of Network Ranking

Appalachian Highlands
Sierra Nevada
Rocky Mountain
North Coast and Cascades
Greater Yellowstone
Mid Atlantic
Cumberland Piedmont
Klamath
Southern Colorado Plateau
Great Lakes
Heartland
Northern Colorado Plateau
Mojave Desert
Central Alaska
Northern Great Plains
Southwest Alaska
Northeast Temperate
Arctic
Sonoran Desert
Chihuahuan Desert
San Francisco Bay Area
Mediterranean Coast
Gulf Coast
Northeast Coastal and Barrier
Southeast Alaska
Pacific Island
Southeast Coast
Southern Plains
South Florida / Caribbean
Upper Columbia Basin

Figure B
Figure C
Acidification Risk Assessment
Summary Risk Ranking

Figure D
Figure E
Acidification Risk Assessment
Great Lakes Network - Ecosystem Sensitivity Ranking

Figure F
Figure H
The Department of the Interior protects and manages the nation’s natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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