



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

## *Southern Colorado Plateau Network (SCPN)*

Natural Resource Report NPS/NRPC/ARD/NRR—2011/372



**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**

## *Southern Colorado Plateau Network (SCPN)*

Natural Resource Report NPS/NRPC/ARD/NRR—2011/372

T. J. Sullivan  
T. C. McDonnell  
G. T. McPherson  
S. D. Mackey  
D. Moore

E&S Environmental Chemistry, Inc.  
P.O. Box 609  
Corvallis, OR 97339

April 2011

U.S. Department of the Interior  
National Park Service  
Natural Resource Program Center  
Denver, Colorado

The National Park Service, Natural Resource Program Center publishes a range of reports that address natural resource topics of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate high-priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

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.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available from Air Resources Division of the NPS (<http://www.nature.nps.gov/air/Permits/ARIS/networks/acidification-eval.cfm>) and the Natural Resource Publications Management website (<http://www.nature.nps.gov/publications/nrpm/>).

Please cite this publication as:

Sullivan, T. J., G. T. McPherson, T. C. McDonnell, S. D. Mackey, and D. Moore. 2011. Evaluation of the sensitivity of inventory and monitoring national parks to acidification effects from atmospheric sulfur and nitrogen deposition: Southern Colorado Plateau Network (SCPN). Natural Resource Report NPS/NRPC/ARD/NRR—2011/372. National Park Service, Denver, Colorado.

## Southern Colorado Plateau Network (SCPN)

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.

There are five parks in the Southern Colorado Plateau Network that are larger than 100 square miles: Canyon de Chelly (CACH), El Malpais (ELMA), Glen Canyon (GLCA), Grand Canyon (GRCA), and Petrified Forest (PETR). In addition, there are 14 smaller parks.

Total annual S and N emissions, by county, are shown in Maps E and F, respectively, for lands in and surrounding the Southern Colorado Plateau Network. County-level emissions of both S and N within the network ranged from less than 1 ton per square mile to between 5 and 20 tons per square mile. In general, annual county emissions of S and N were both less than 5 tons per square mile throughout most of the network. Point source emissions of SO<sub>2</sub> are shown in Map G. Most point sources emitted less than 5,000 tons per year, although there were several that emitted between 5,000 and 20,000 tons of S per year. Point sources of oxidized (nitrogen oxides, NO<sub>x</sub>) and reduced (ammonia, NH<sub>3</sub>) N are shown in Map H. There were several relatively large (larger than 5,000 tons per year) point sources of oxidized N in this network; the point sources of reduced N were small.

Urban centers within the network and within a 300-mile buffer around the network are shown in Map E. There are few population centers within the network; only one is larger than 100,000 people. There are several large cities within the 300-mile buffer around the network boundary, including Denver, El Paso, Phoenix, San Diego, and Los Angeles.

Total S and N deposition in and around the network is 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 was generally less than 2 kg S/ha/yr, with three small areas receiving between 2 and 5 kg S/ha/yr. Total N deposition within the majority of the network ranged from less than 2 kg N/ha/yr to between 2 and 5 kg N/ha/yr. Most of the network received estimated total N deposition between 2 and 5 kg N/ha/yr; one small area in the southwestern portion of the network had estimated N deposition between 5 and 10 kg N/ha/yr.

Land cover in and around the network is shown in Map L. The predominant cover types within this network are shrubland, forest, and grassland/herbaceous.

Land slope within the parks that occur in this network is shown in Map M. Slope varies considerably among the parks. Two of the larger parks (those more than 100 sq. mi.) have average slope less than 10°, whereas terrain in the remainder of the larger parks is steeper, with average slope ranging from 10° to 20° in some HUCs to more than 50° in GRCA. The average slope within the smaller parks ranges from less than 10° in some HUCs to between 30° and 40° in others.

Park lands requiring special protection against potential adverse impacts associated with acidic 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 areas within this network designated as wilderness and Class I. GRCA and PEFO are both Class I. Most of the designated wilderness area is outside NPS jurisdiction.

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 Southern Colorado Plateau Network ranked in the lowest quintile among networks in Pollutant Exposure (Figure A). Emissions and deposition of both S and N within the network are low. However, the network Ecosystem Sensitivity was ranked High, within the second highest quintile among networks (Figure B). This is mainly because there is high relief in much of the park land that occurs in this network, with a considerable length of low-order and high-elevation streams. This network ranked at the bottom of the third quintile in Park Protection, having only moderate amounts of protected lands (Figure C).

In combination, the network rankings for Pollutant Exposure, Ecosystem Sensitivity, and Park Protection yielded an overall Network Risk ranking that was Moderate, below the middle of the distribution among networks (Figure D). The overall level of concern for acidification effects on I&M parks within this network is considered Moderate.

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.

The five I&M parks within the Southern Colorado Plateau Network that are larger than 100 square miles were all ranked in the lowest or second lowest quintile among parks in Pollutant Exposure (Figure E). For the smaller parks, four were ranked Very Low, six were ranked Low, and the other four were ranked Moderate for this theme. There was considerable variation in the Ecosystem Sensitivity ranking. One park (GRCA) was ranked in the highest quintile, while four parks (Aztec Ruins [AZRU], El Morro [ELMO], Hubbell Trading Post (HUTR), and Yucca [YUCH]) were ranked in the lowest quintile. The remaining parks were ranked from Low to High (Table A). For Park Protection, four of the large parks and two of the smaller parks were ranked in the highest (Bamdelier [BAND], GRCA, Mesa Verde [MEVE], and PETR) or second highest (ELMA, GLCA) quintile (Table A). The rest of the parks were ranked in the middle quintile for this theme.

Overall, the Summary Risk ranked one of the large parks (GRCA) and two of the smaller parks as High (BAND and MEVE; Figure H, Table A). The other four large parks and two of the small parks (CACH and Walnut Canyon [WACA]) were ranked Moderate. The remaining 10 parks were ranked Low for Summary Risk (Table A).

<b>Table A.</b> Relative rankings of individual I&M parks within the network for Pollutant Exposure, Ecosystem Sensitivity, Park Protection, and overall Summary Risk from acidic deposition.				
<b>I&amp;M Parks<sup>2</sup> in Network</b>	<b>Relative Ranking of Individual Parks<sup>1</sup></b>			
	<b>Pollutant Exposure</b>	<b>Ecosystem Sensitivity</b>	<b>Park Protection</b>	<b>Summary Risk</b>
Aztec Ruins	Moderate	Very Low	Moderate	Low
Bandelier	Low	High	Very High	High
<b><i>Canyon de Chelly</i></b>	Low	High	Moderate	Moderate
Chaco Culture	Low	Moderate	Moderate	Moderate
<b><i>El Malpais</i></b>	Low	Low	High	Moderate
El Morro	Moderate	Very Low	Moderate	Low
<b><i>Glen Canyon</i></b>	Very Low	High	High	Moderate
<b><i>Grand Canyon</i></b>	Low	Very High	Very High	High
Hubbell Trading Post	Low	Very Low	Moderate	Low
Mesa Verde	Moderate	High	Very High	High
Navajo	Very Low	Moderate	Moderate	Low
<b><i>Petrified Forest</i></b>	Low	Moderate	Very High	Moderate
Petroglyph	Low	Low	Moderate	Low
Rainbow Bridge	Very Low	Moderate	Moderate	Low
Salinas Pueblo Missions	Very Low	Low	Moderate	Low
Sunset Crater Volcano	Low	Low	Moderate	Low
Walnut Canyon	Low	Moderate	Moderate	Moderate
Wupatki	Very Low	Moderate	Moderate	Low
Yucca House	Moderate	Very Low	Moderate	Low

<sup>1</sup> 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).

<sup>2</sup> 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>)

Map B. National map of total N emissions by county for the year 2002. Both oxidized (nitrogen oxides, NO<sub>x</sub>) and reduced (ammonia, NH<sub>3</sub>) 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>)

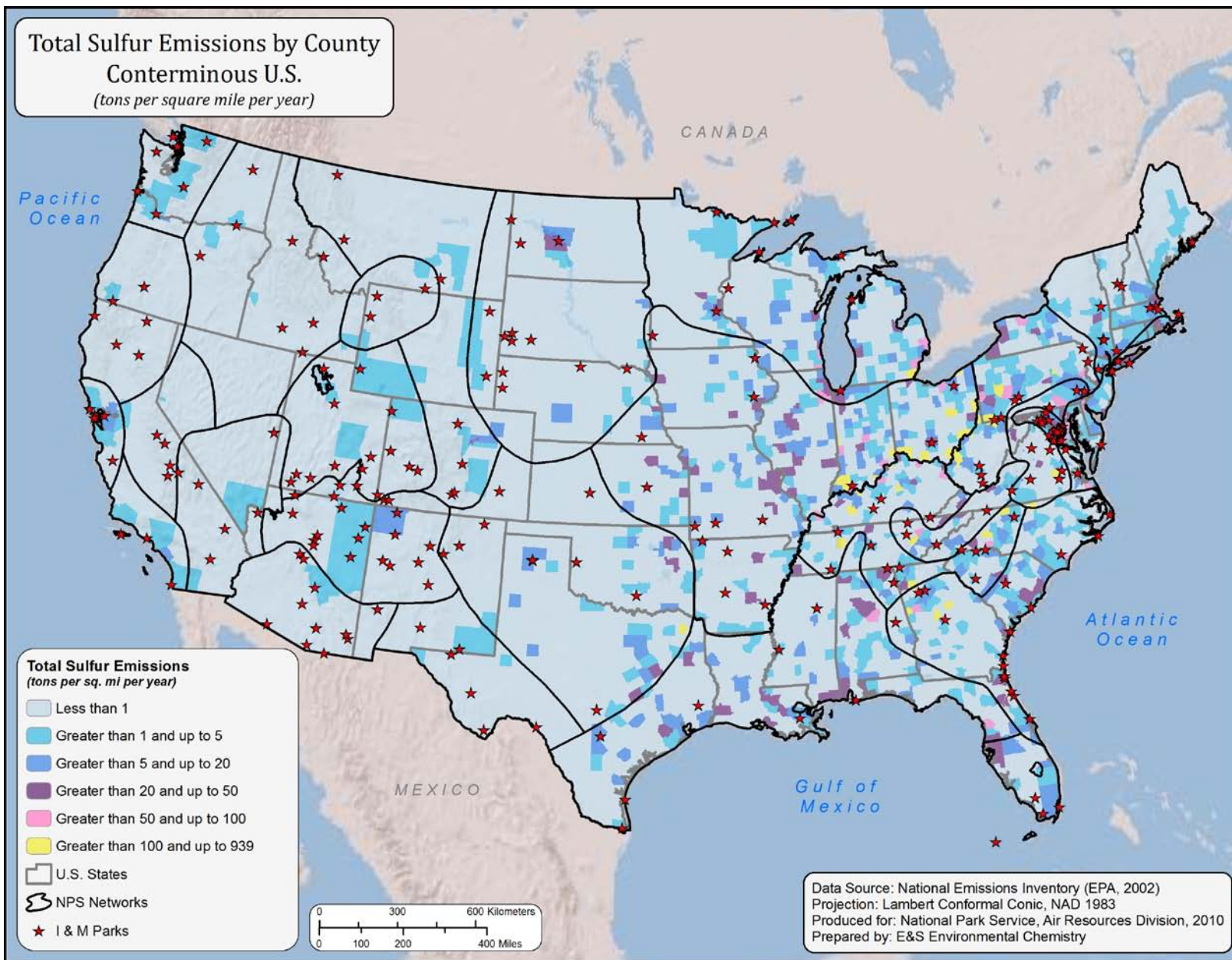
- Map C. Total S deposition for the conterminous United States for the year 2002, expressed in units of kilograms of S deposited from the atmosphere to the Earth surface per hectare per year. For the eastern half of the country, wet deposition values were derived from interpolated measured values from 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<sub>x</sub>) and reduced (ammonia, NH<sub>3</sub>) 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>)
- 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<sub>x</sub>) and reduced (ammonia, NH<sub>3</sub>) N. (Source of data: EPA National Emissions Inventory, <http://www.epa.gov/ttn/chief/net/2002inventory.html>)
- Map G. Major point source emissions of SO<sub>2</sub> for lands surrounding the network. (Source of data: EPA National Emissions Inventory, <http://www.epa.gov/ttn/chief/net/2002inventory.html>)
- Map H. Major point source emissions of oxidized (nitrogen oxides, NO<sub>x</sub>) and reduced (ammonia, NH<sub>3</sub>) 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/ttn/chief/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)



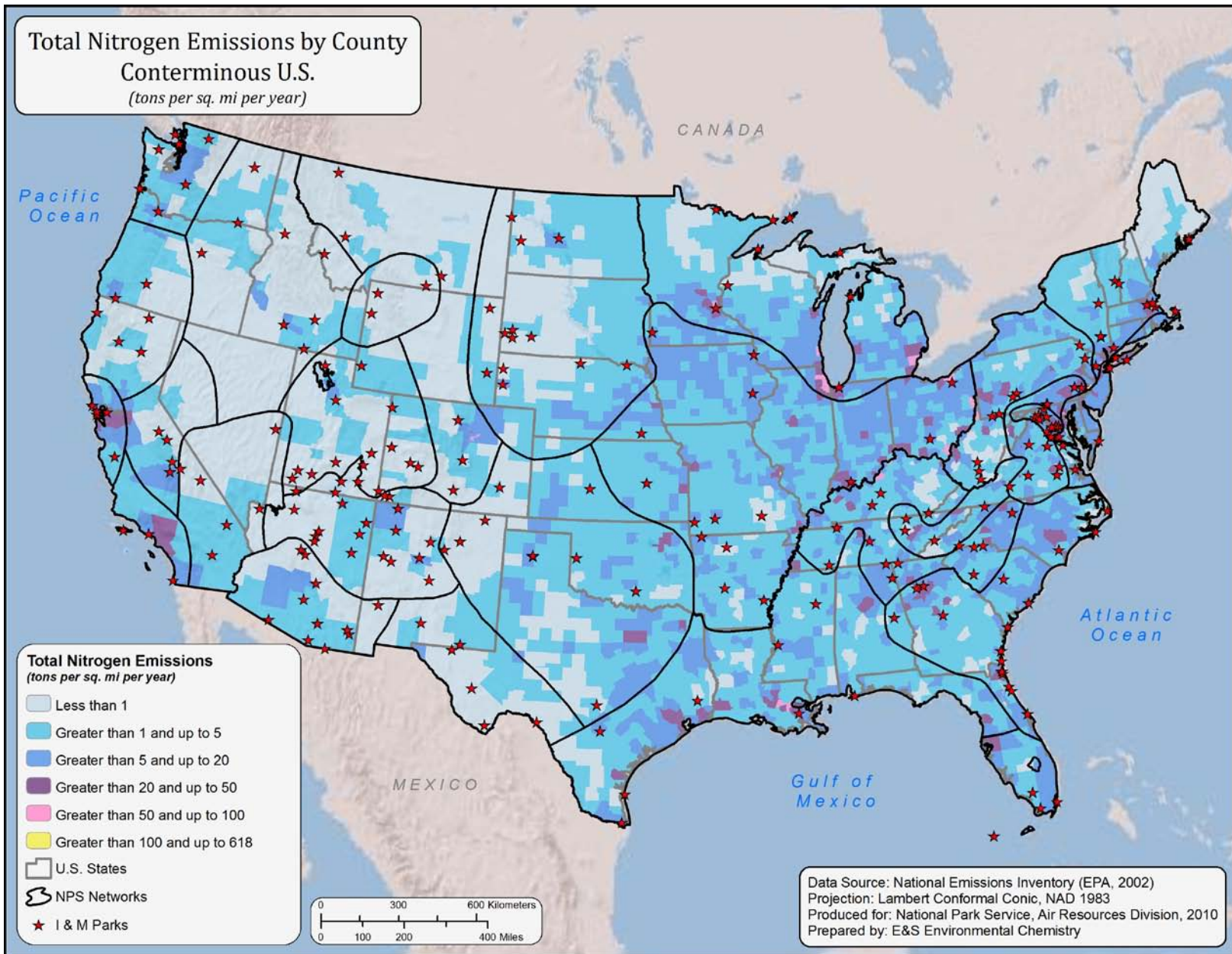
- Map J. Total S deposition in and around the network. Values are expressed as kilograms of S deposited per hectare per year. (Source of data: CMAQ Model wet and dry deposition data for 2002; see information for Map C above for details)
- Map K. Total N deposition in and around the network. Included in the total are wet plus dry forms of both oxidized (nitrogen oxides, NO<sub>x</sub>) and reduced (ammonia, NH<sub>3</sub>) N. Values are expressed as kilograms of N deposited per hectare per year. (Source of data: CMAQ Model wet and 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](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. (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.

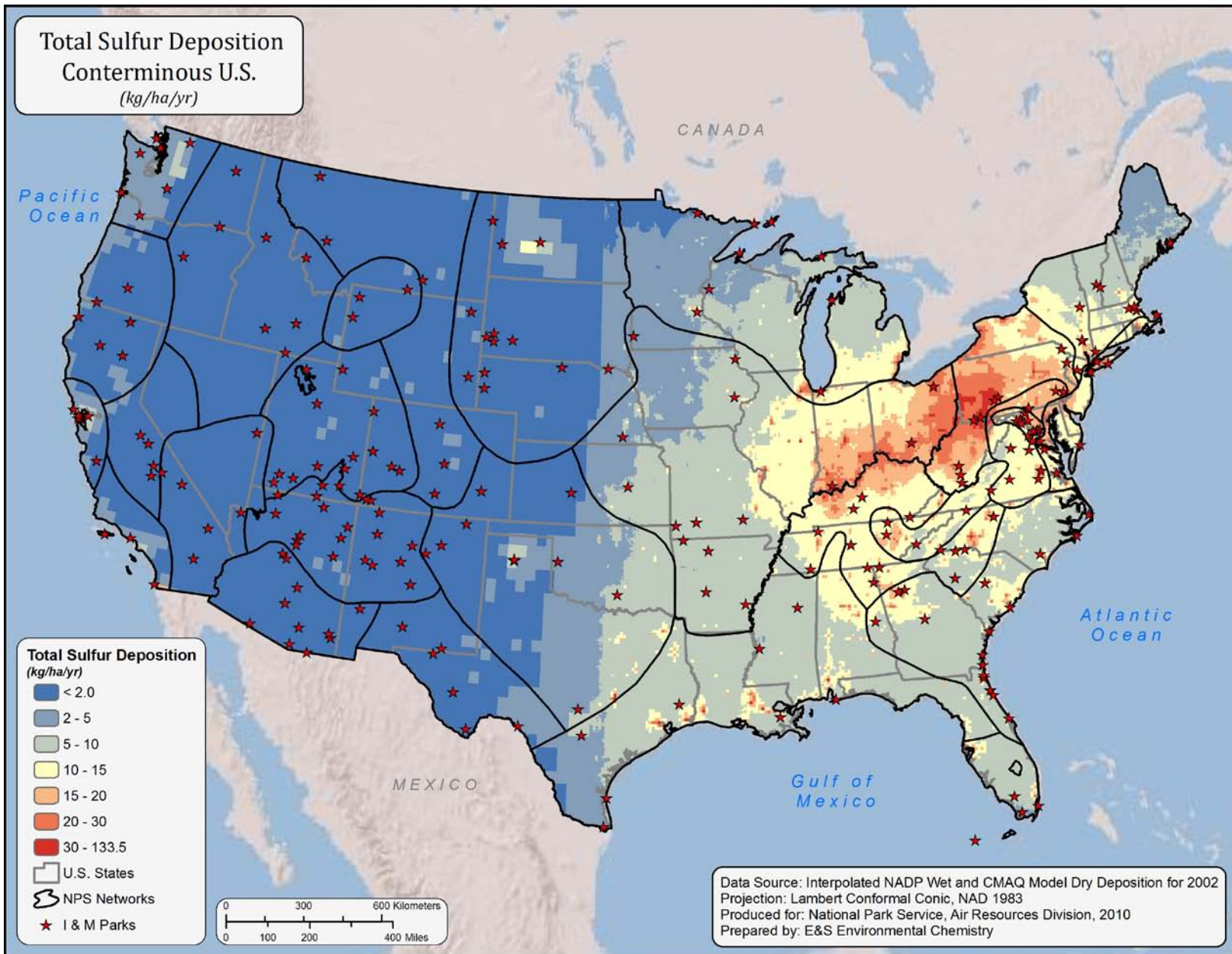
SCP-N-7



Map A

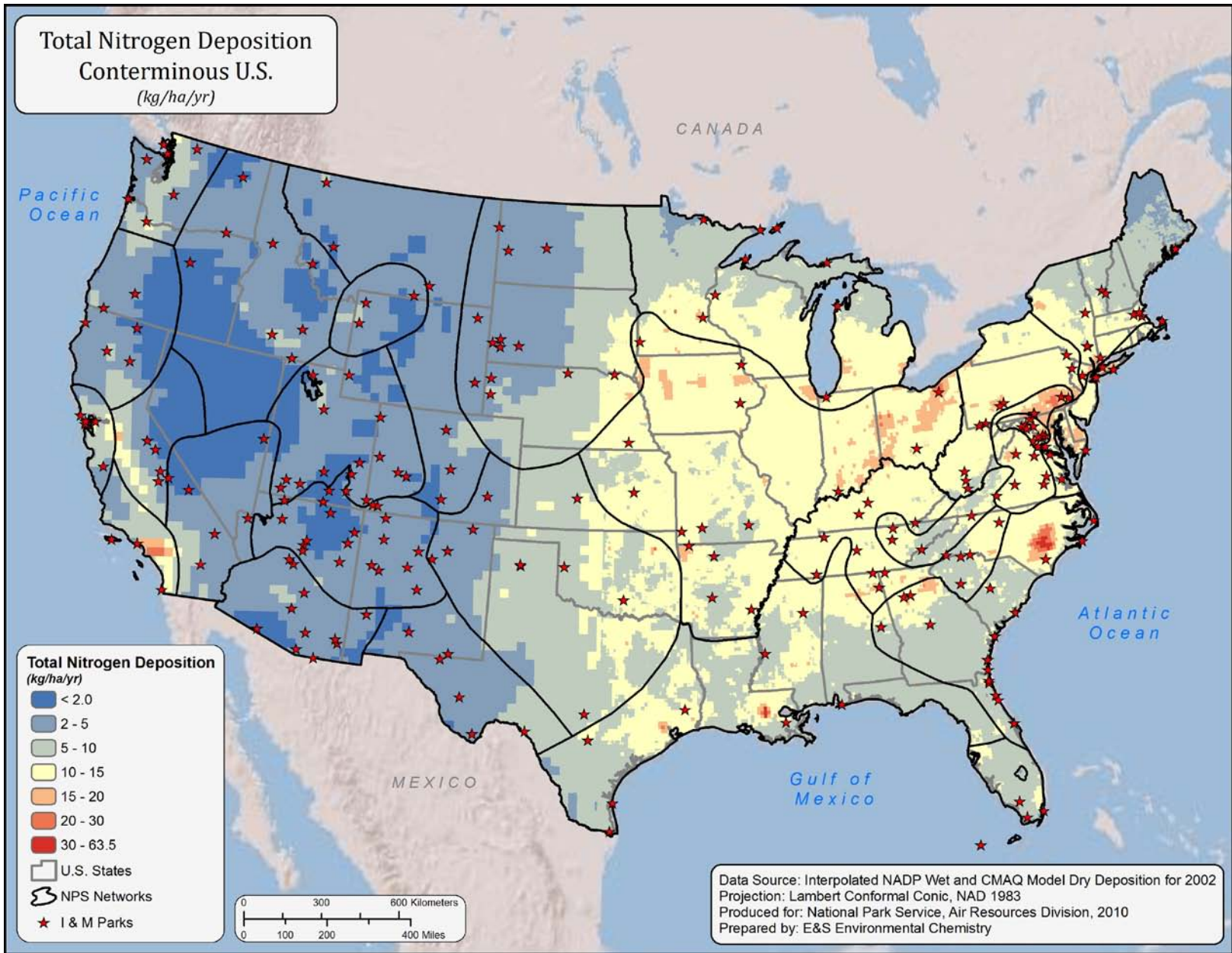


Map B

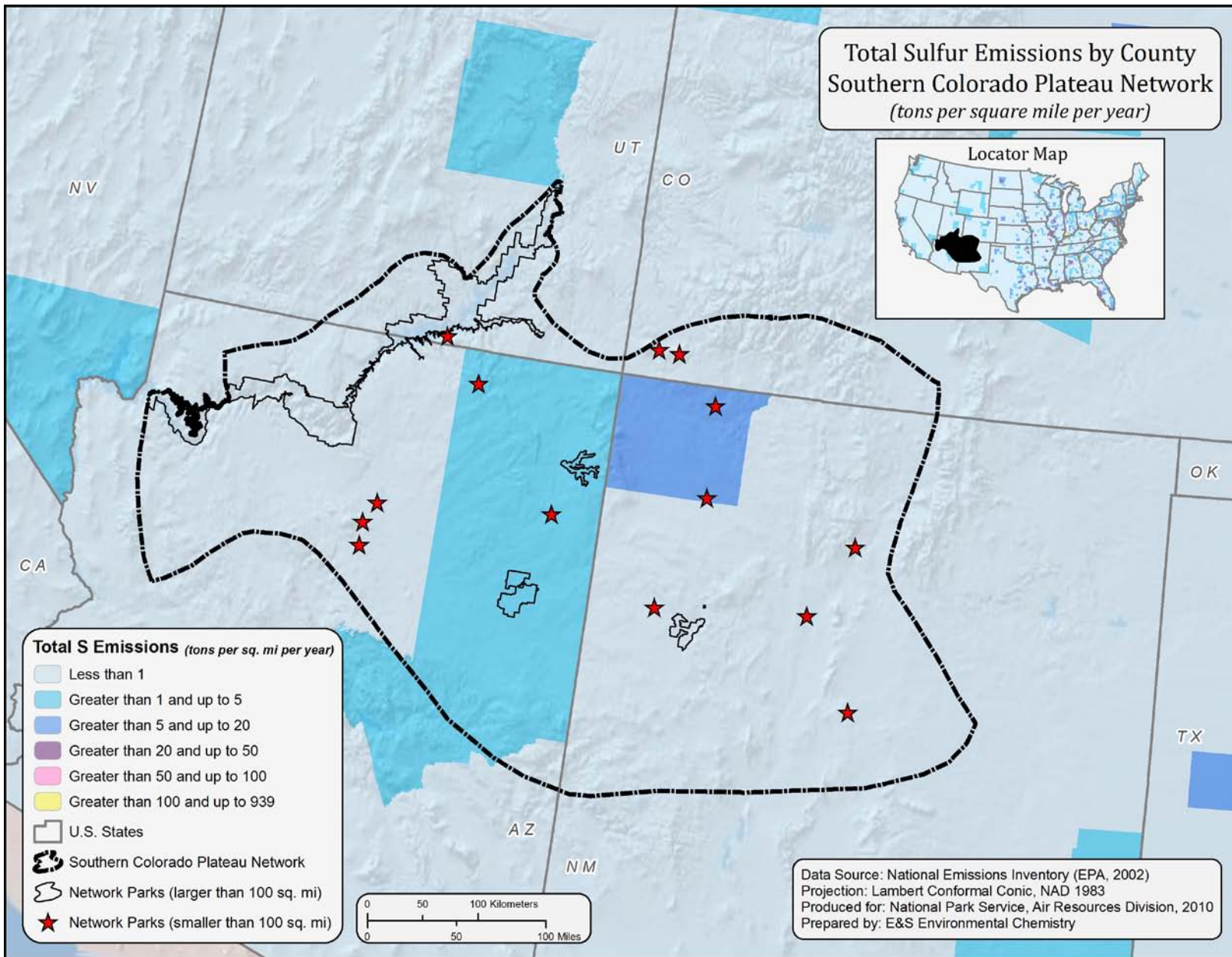


Map C

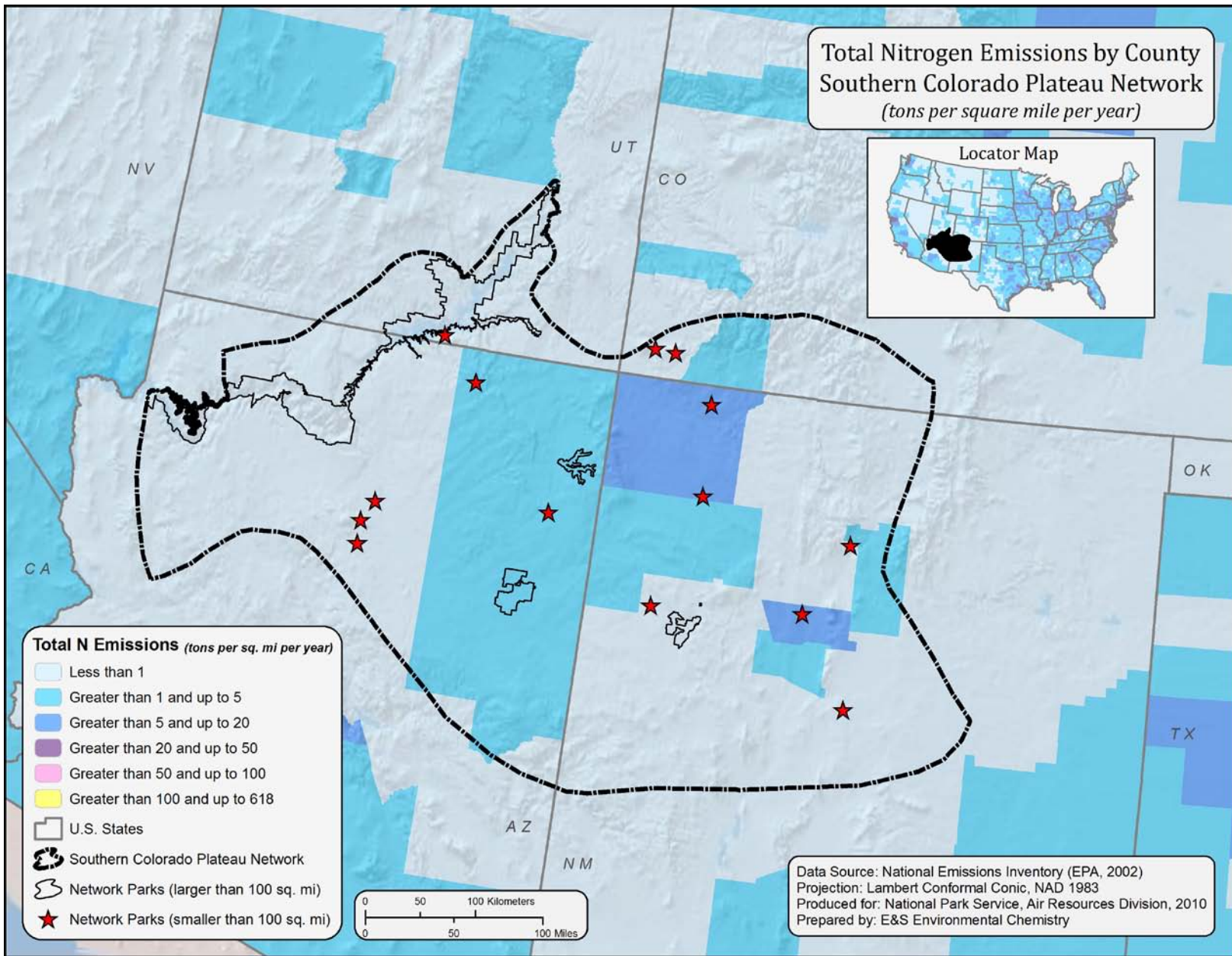
SCPn-10



Map D

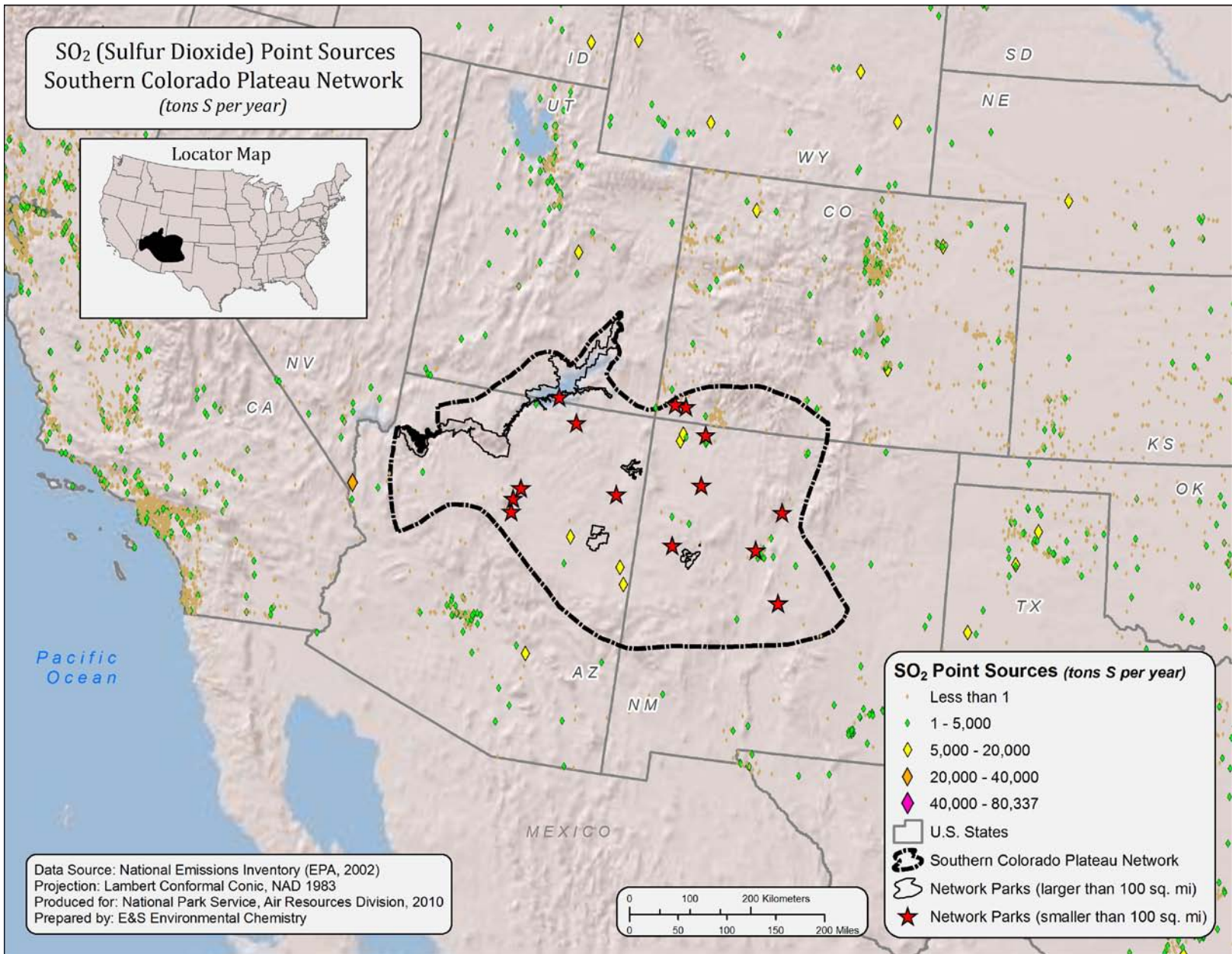


Map E

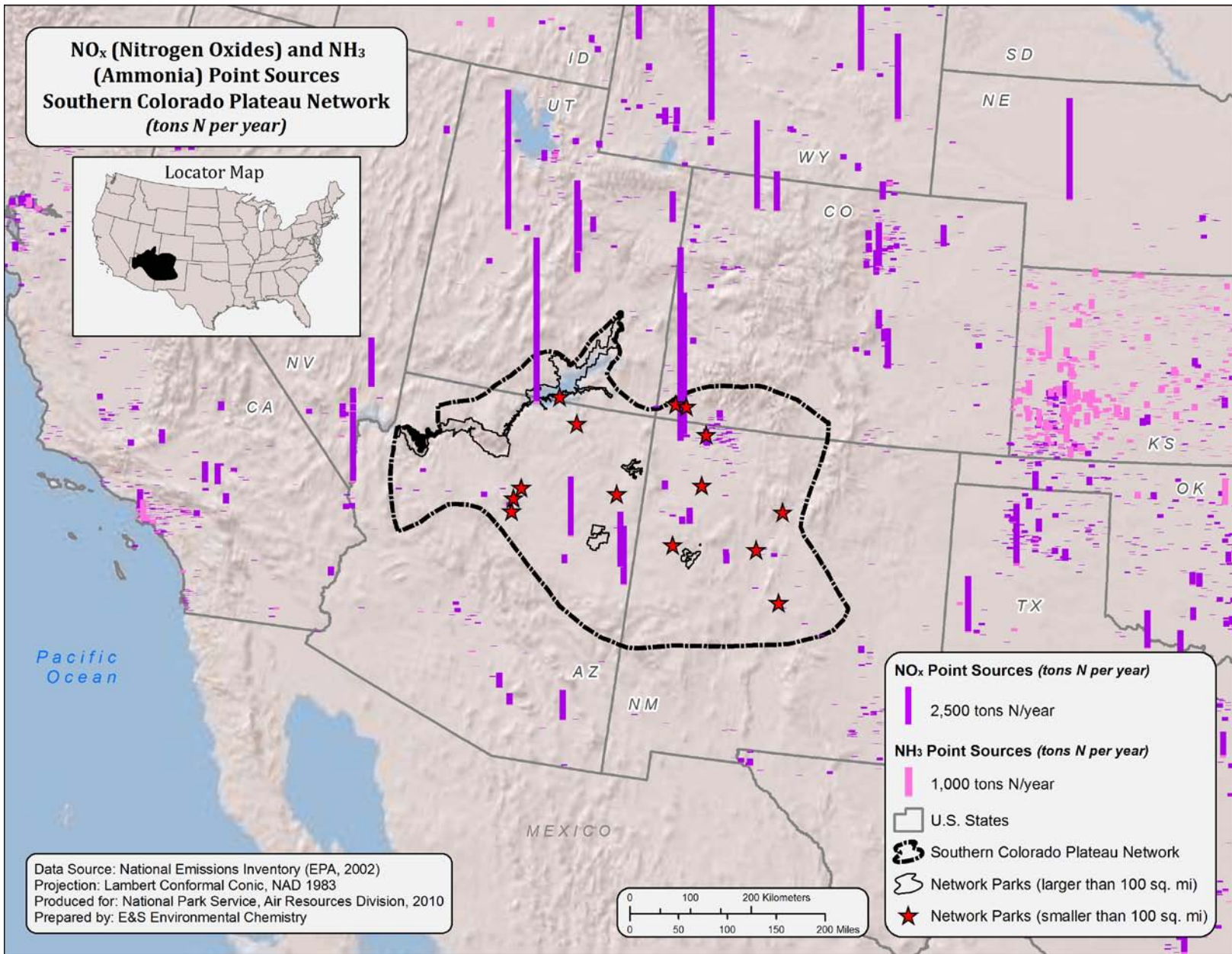


Map F

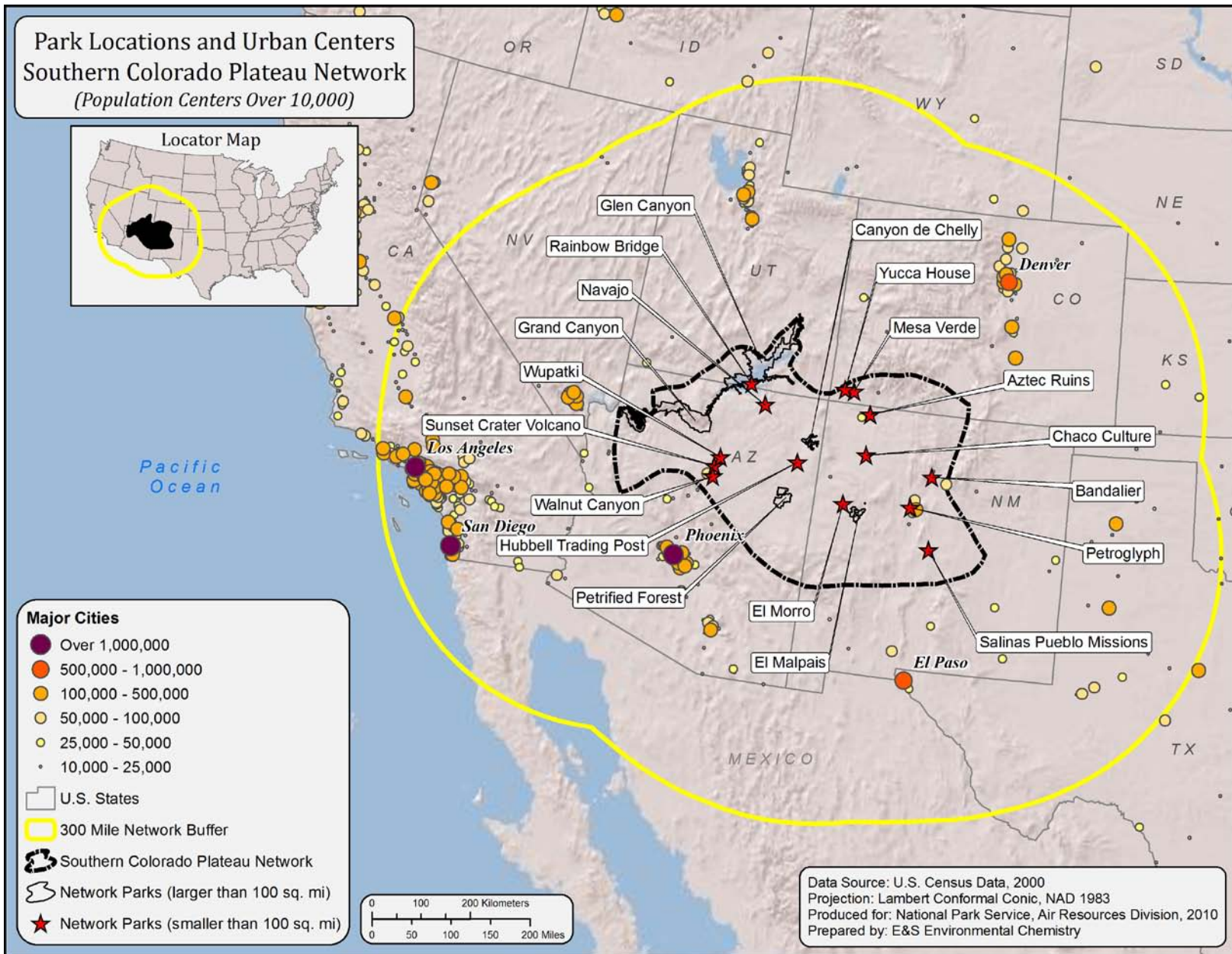




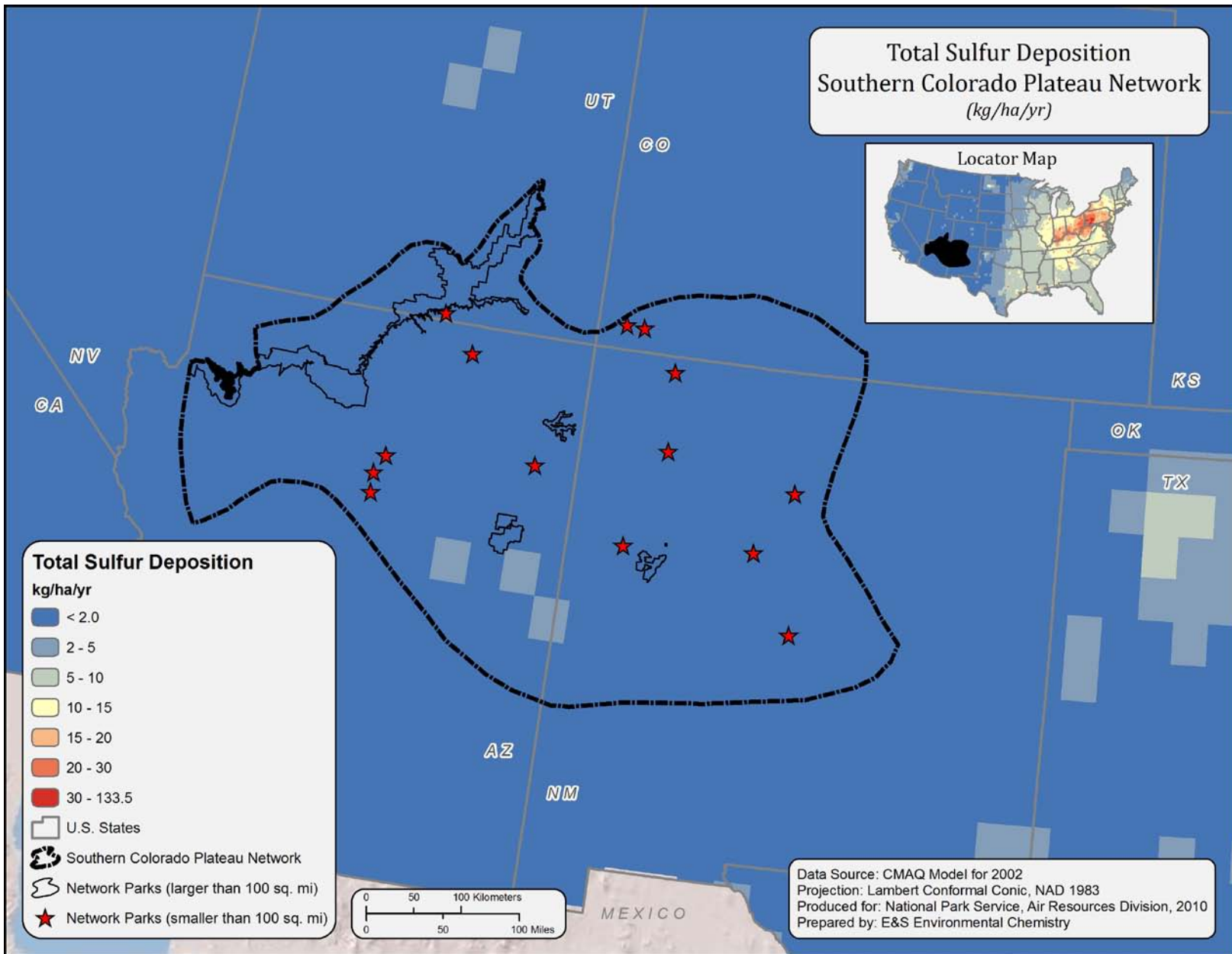
Map G



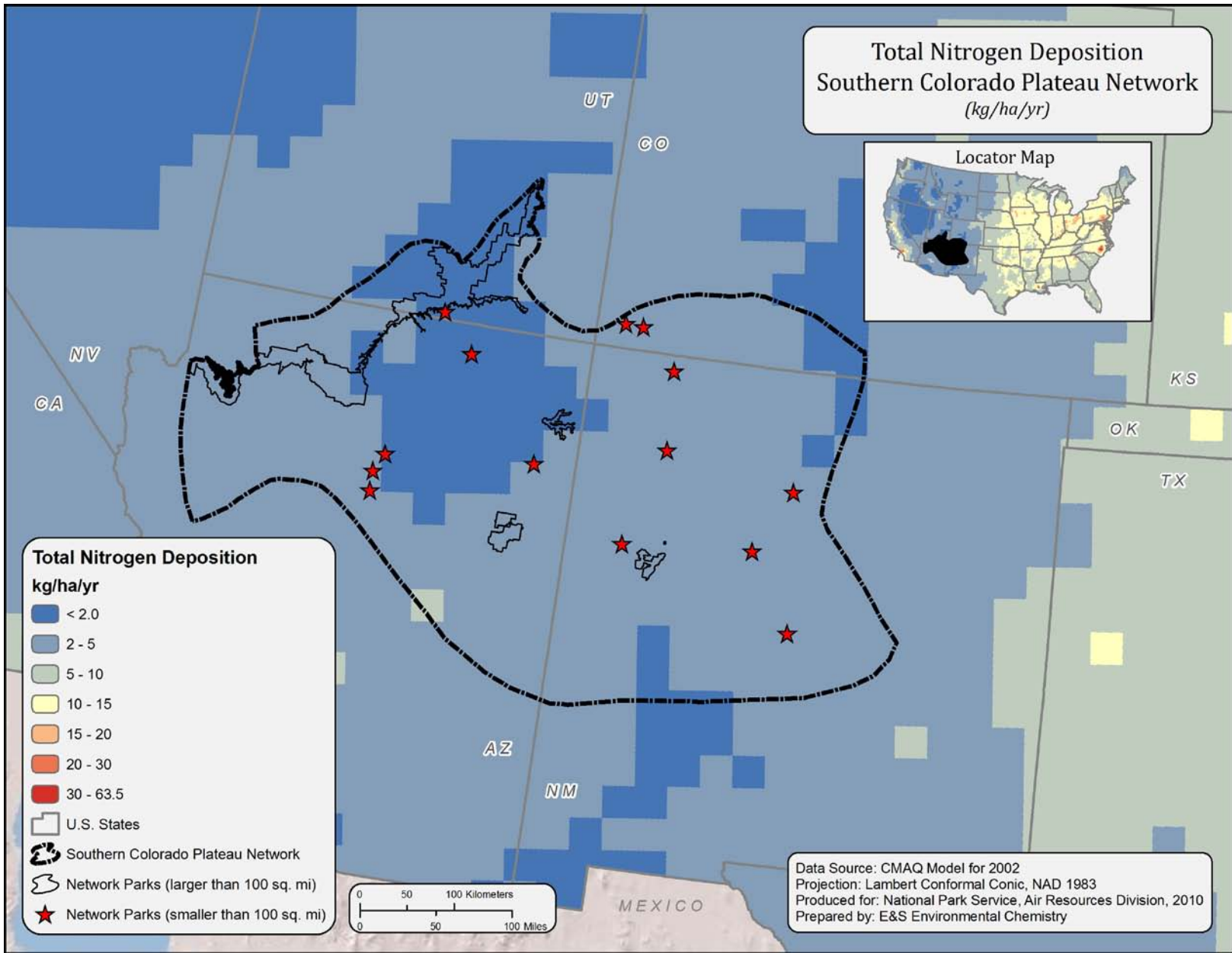
Map H



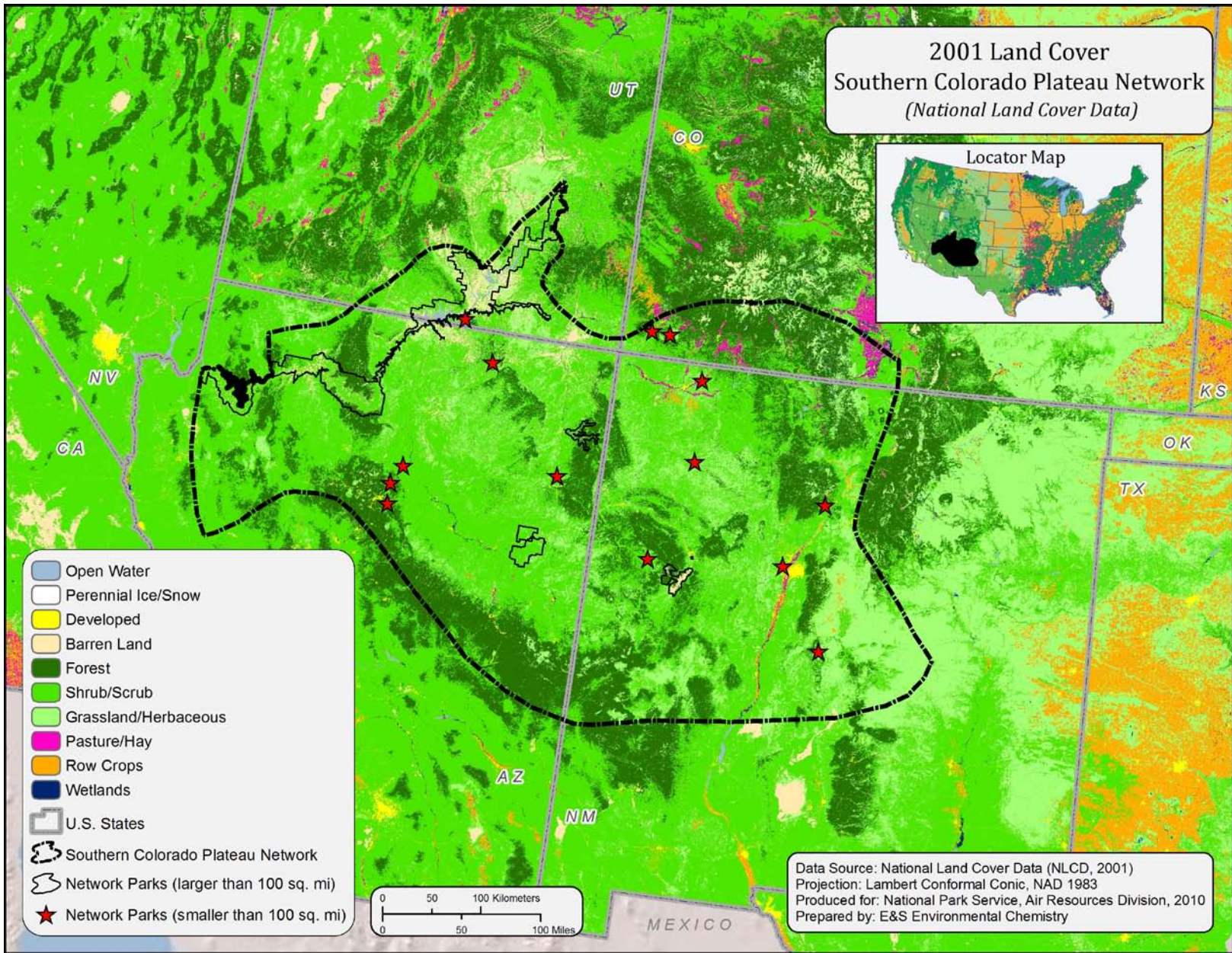
Map I



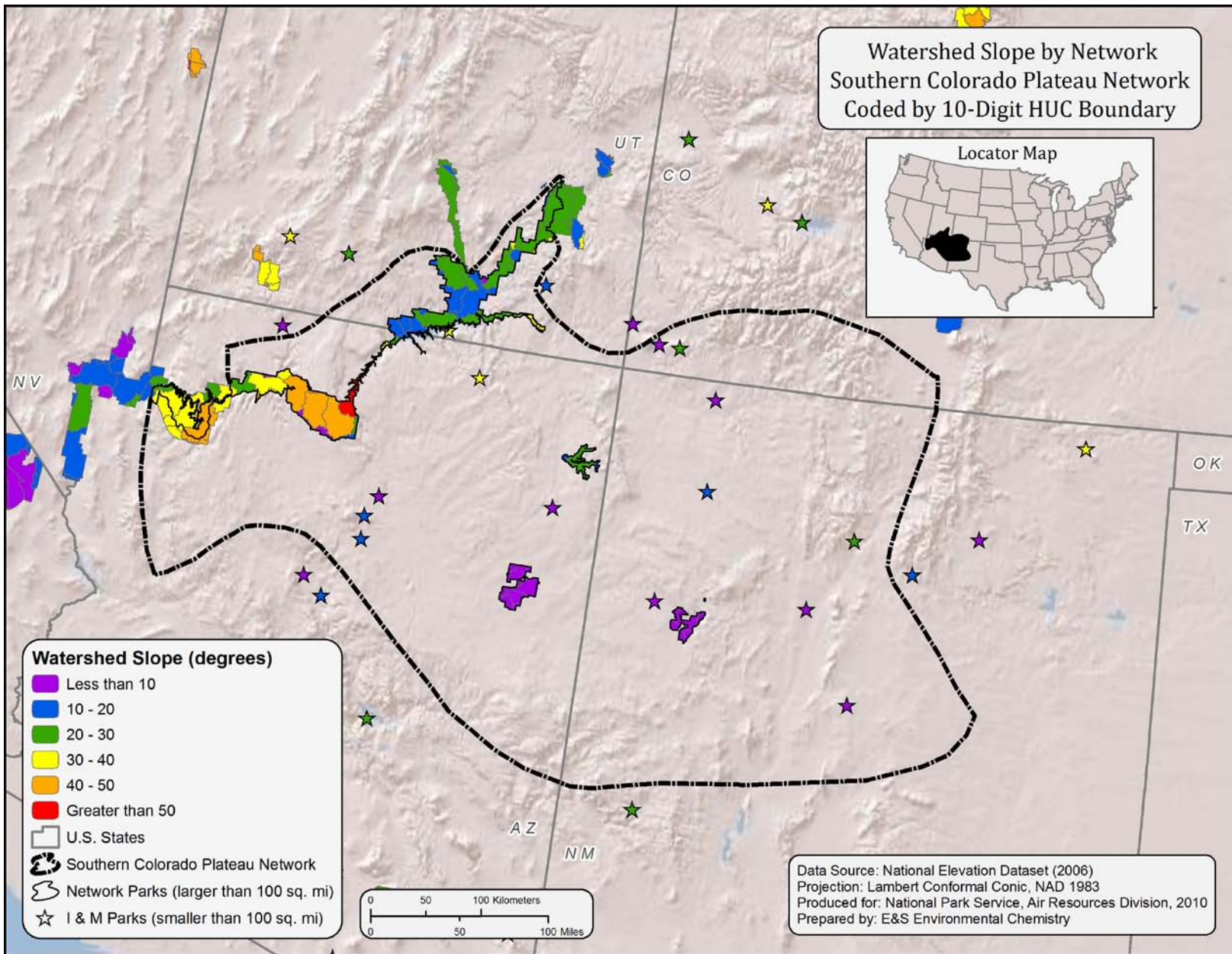
Map J



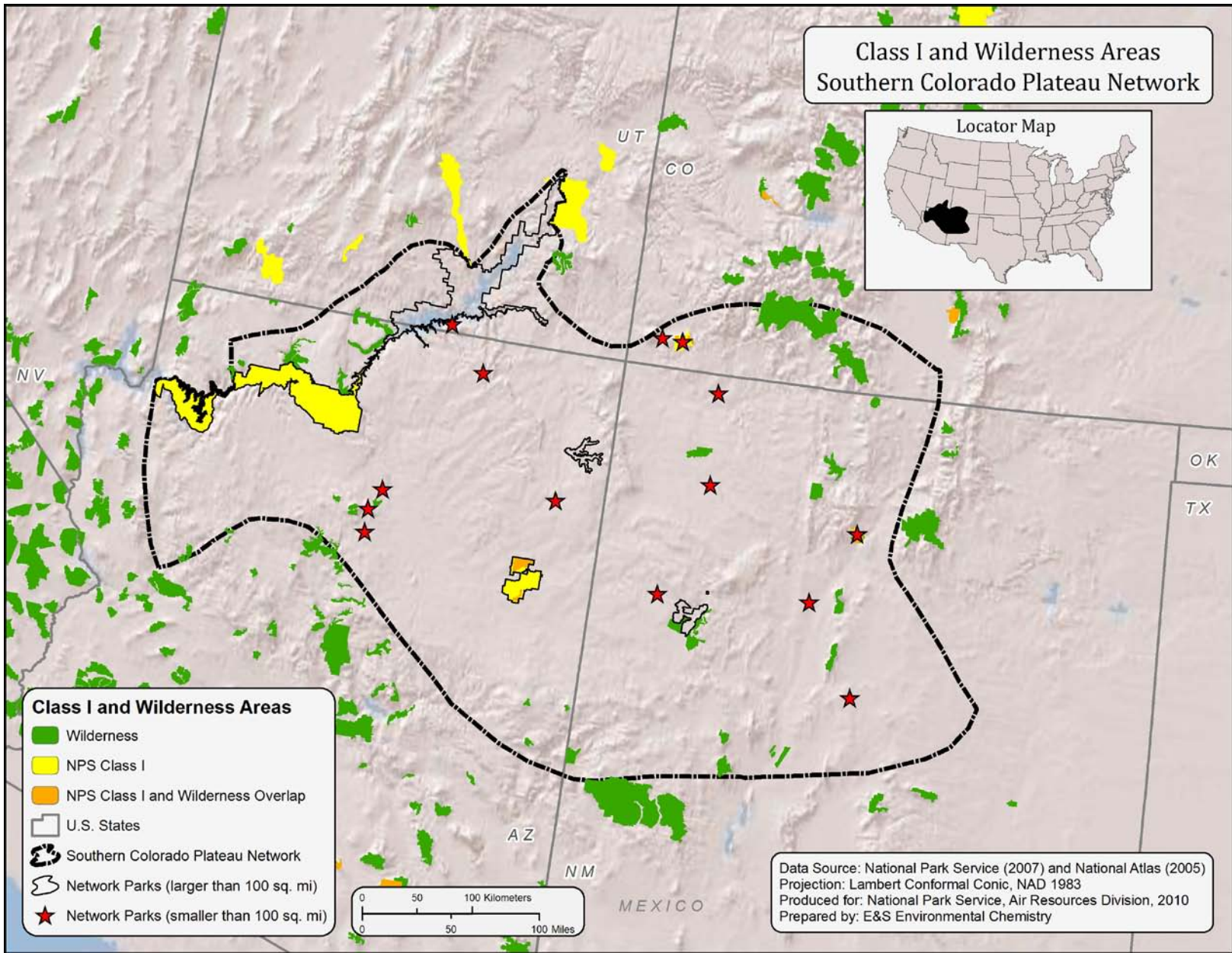
Map K



Map L



Map M



Map N



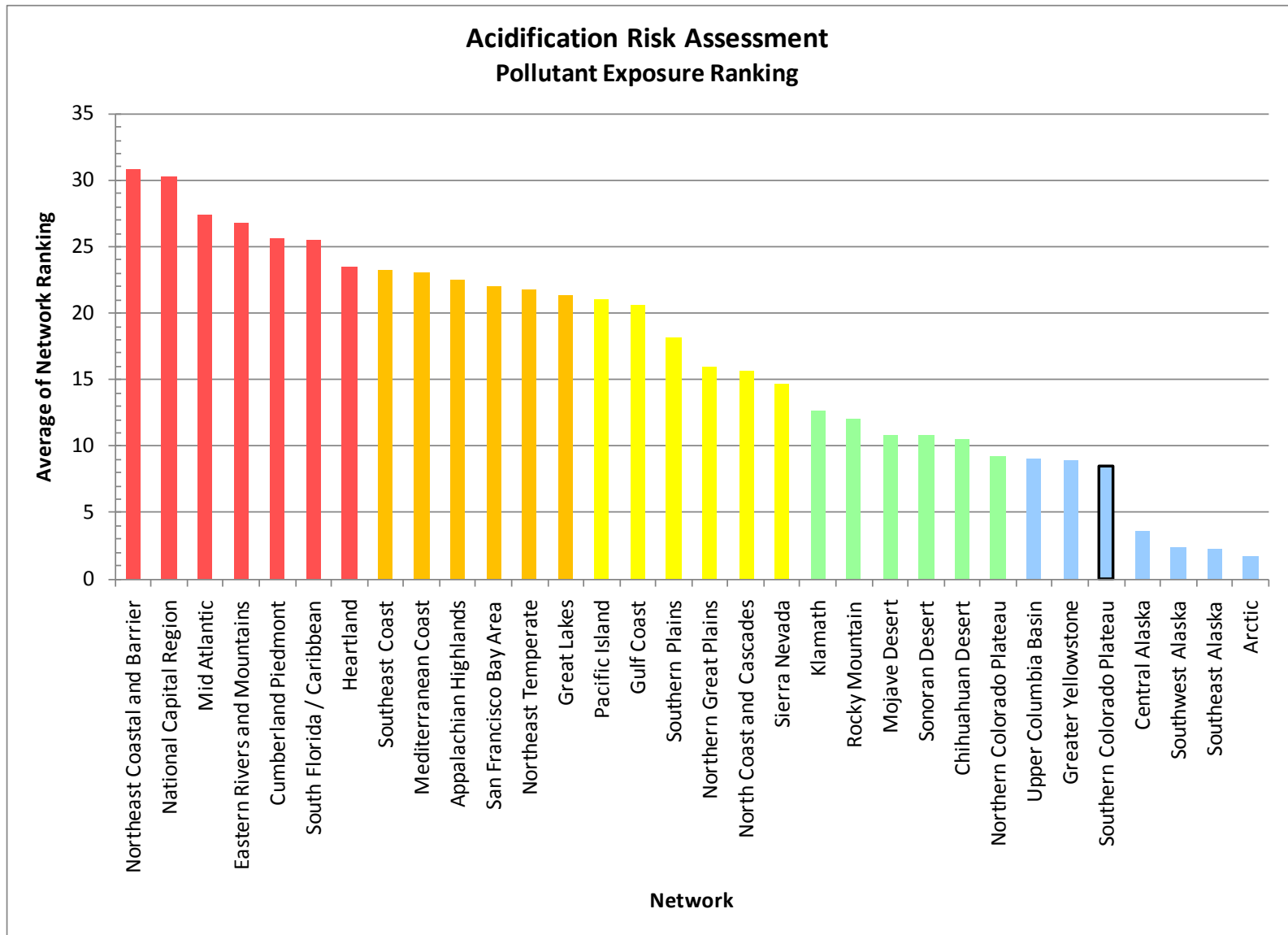


Figure A

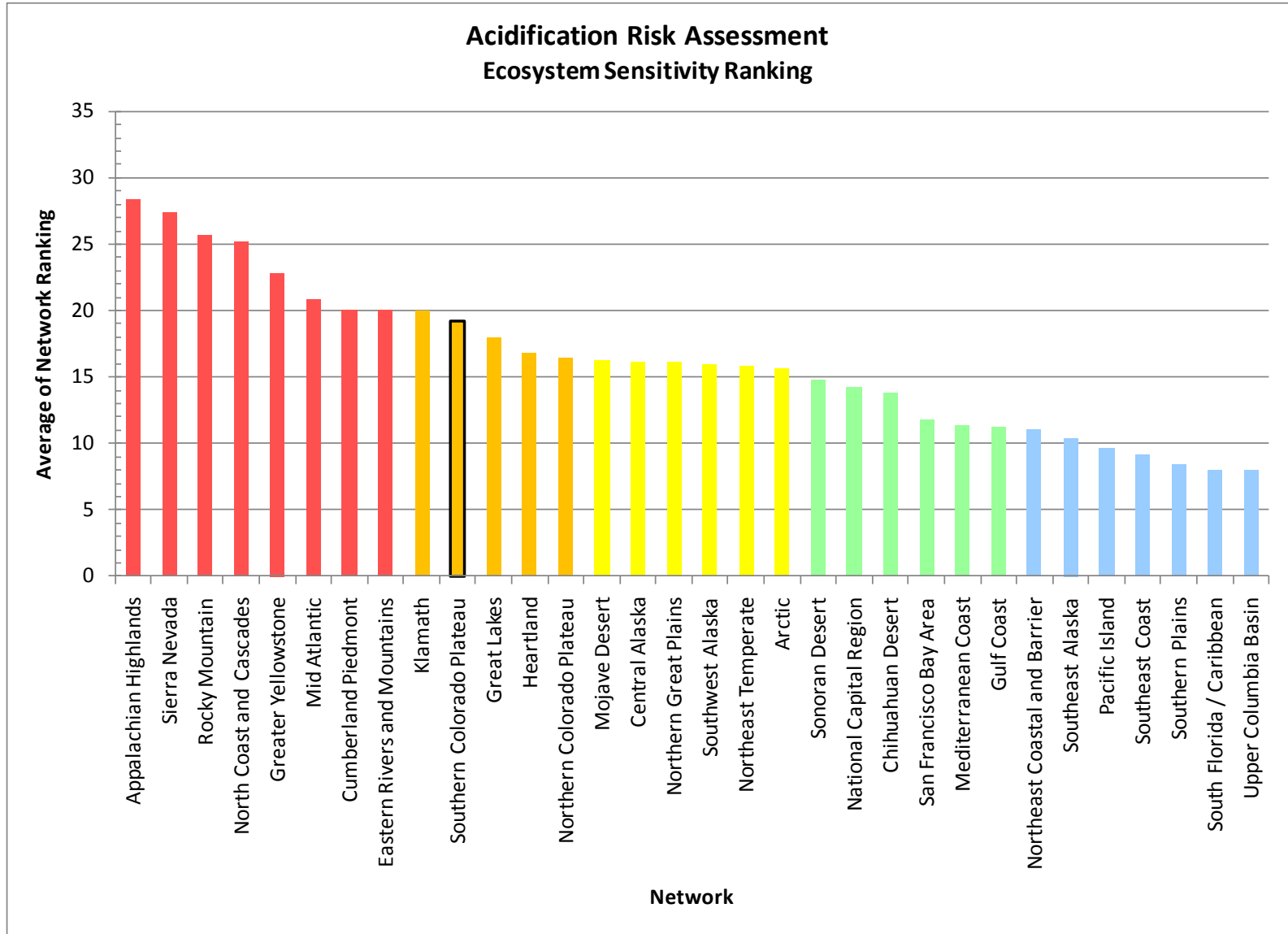


Figure B

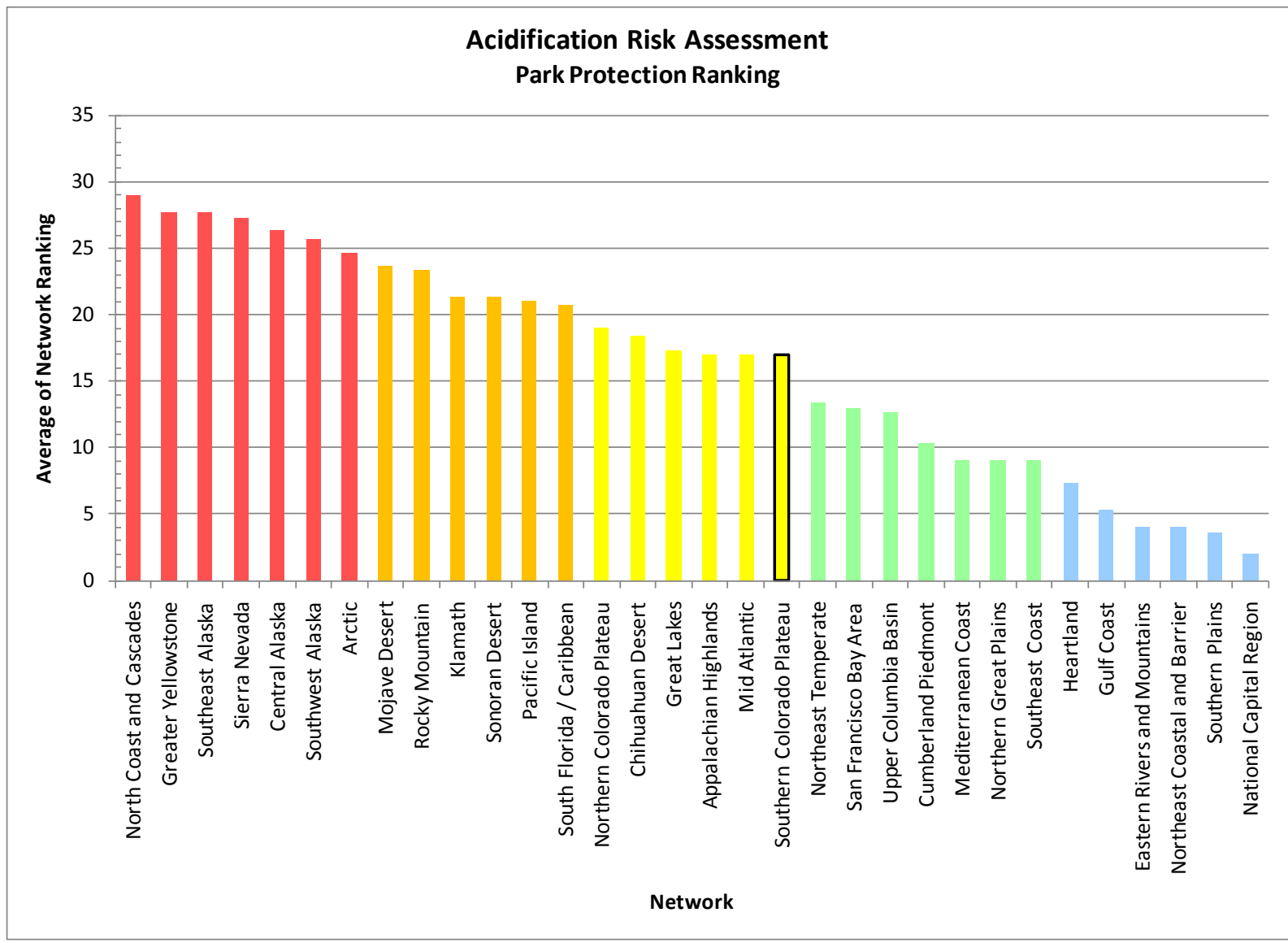


Figure C

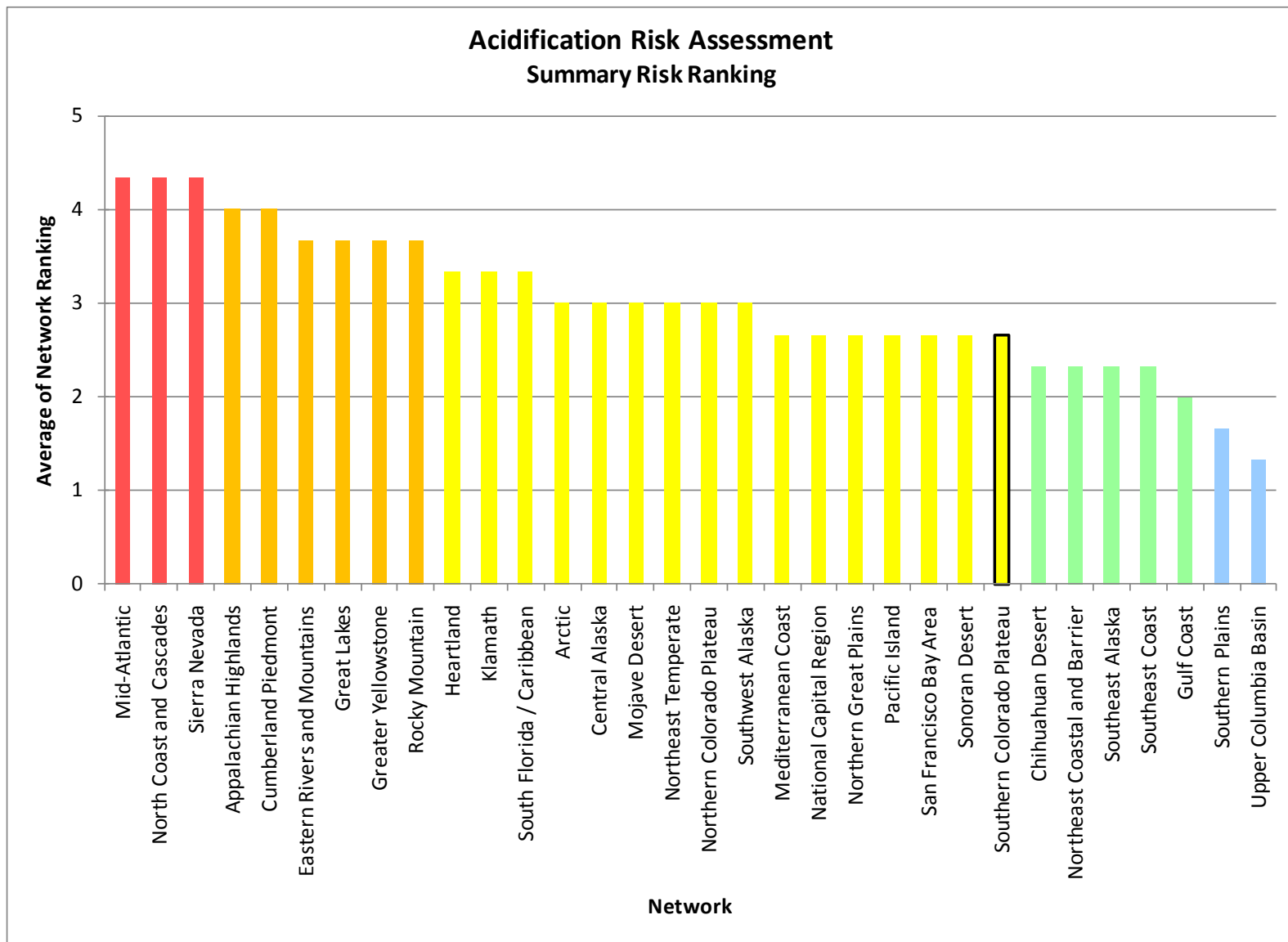


Figure D

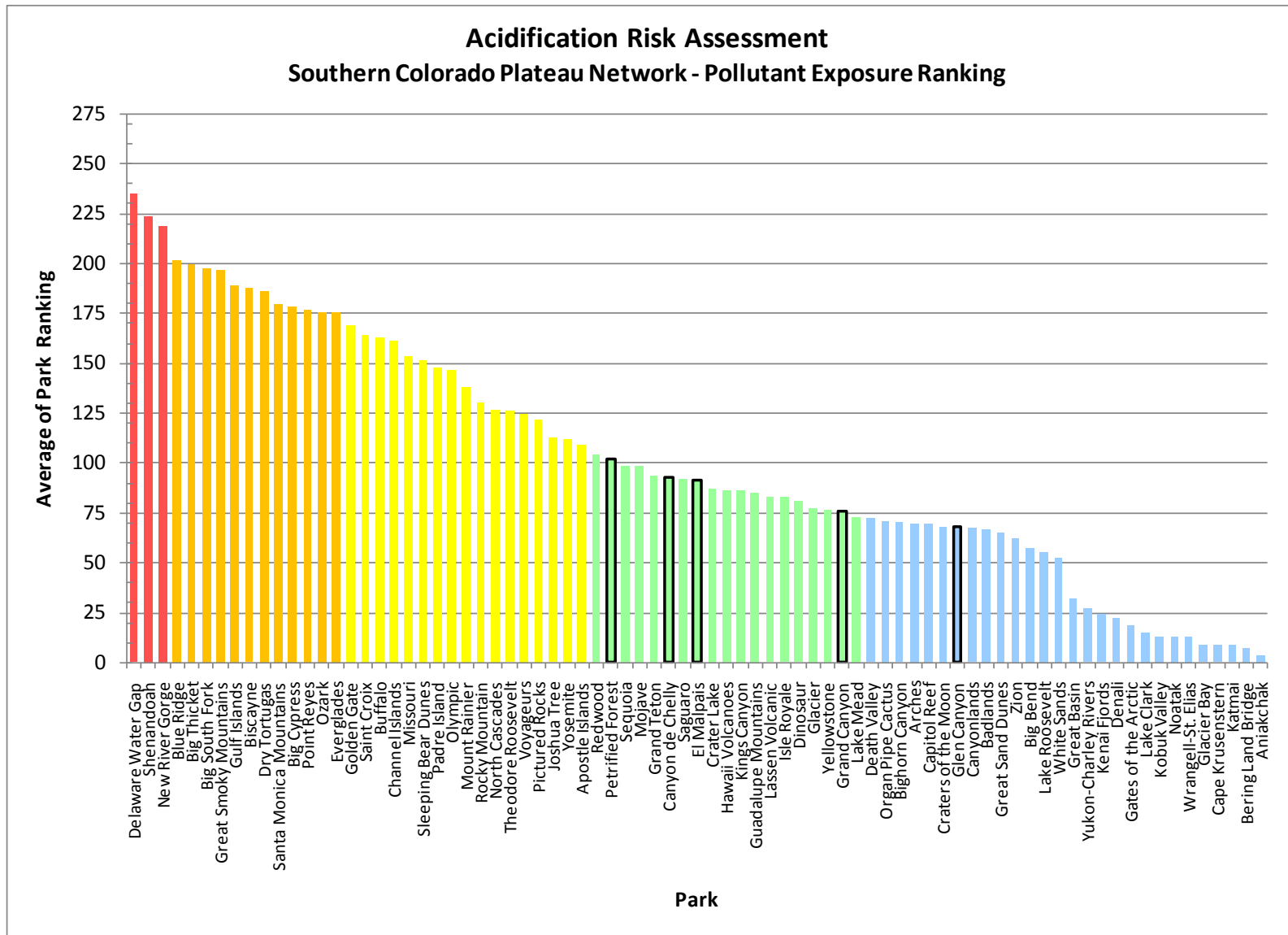


Figure E

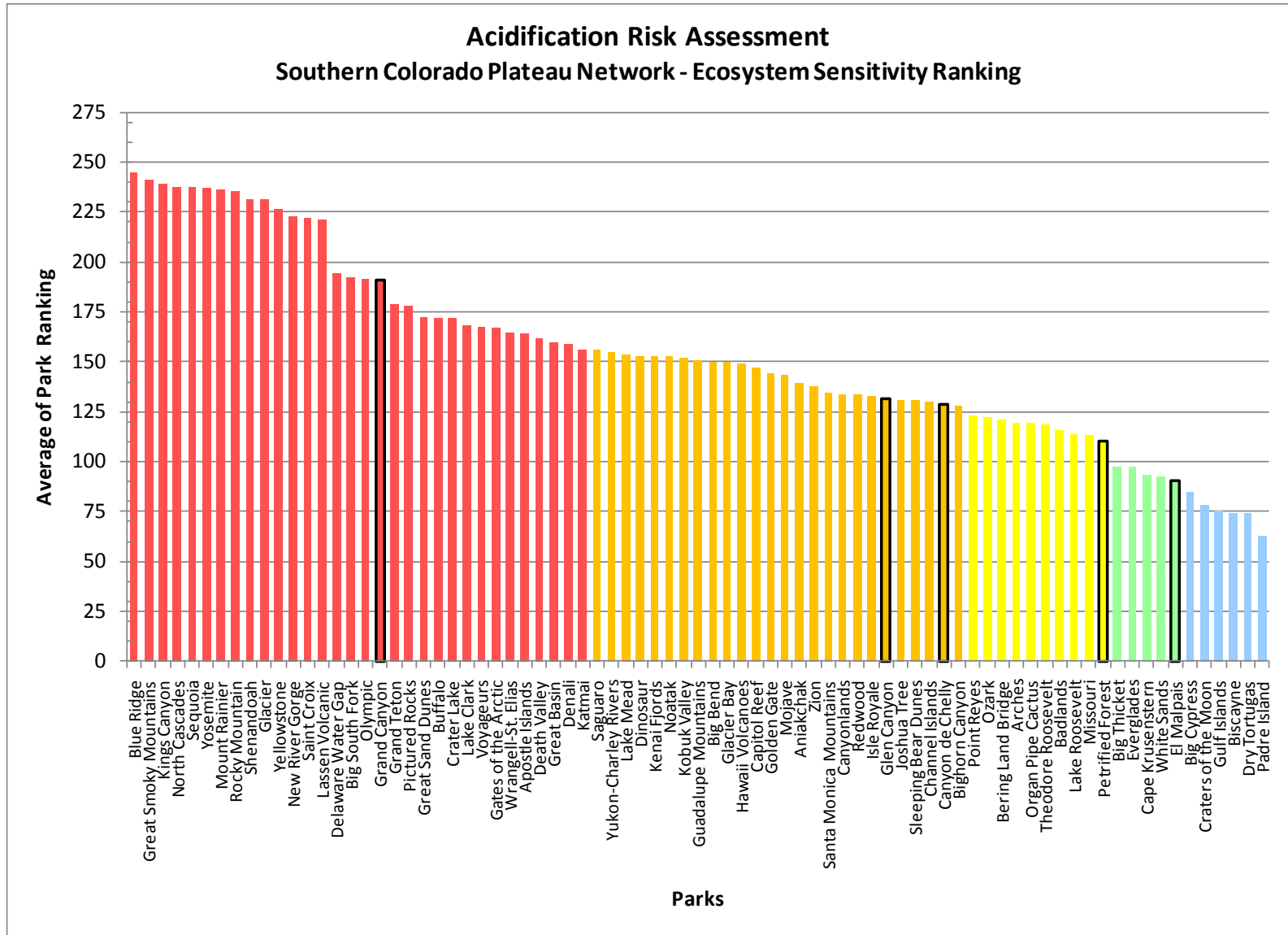


Figure F

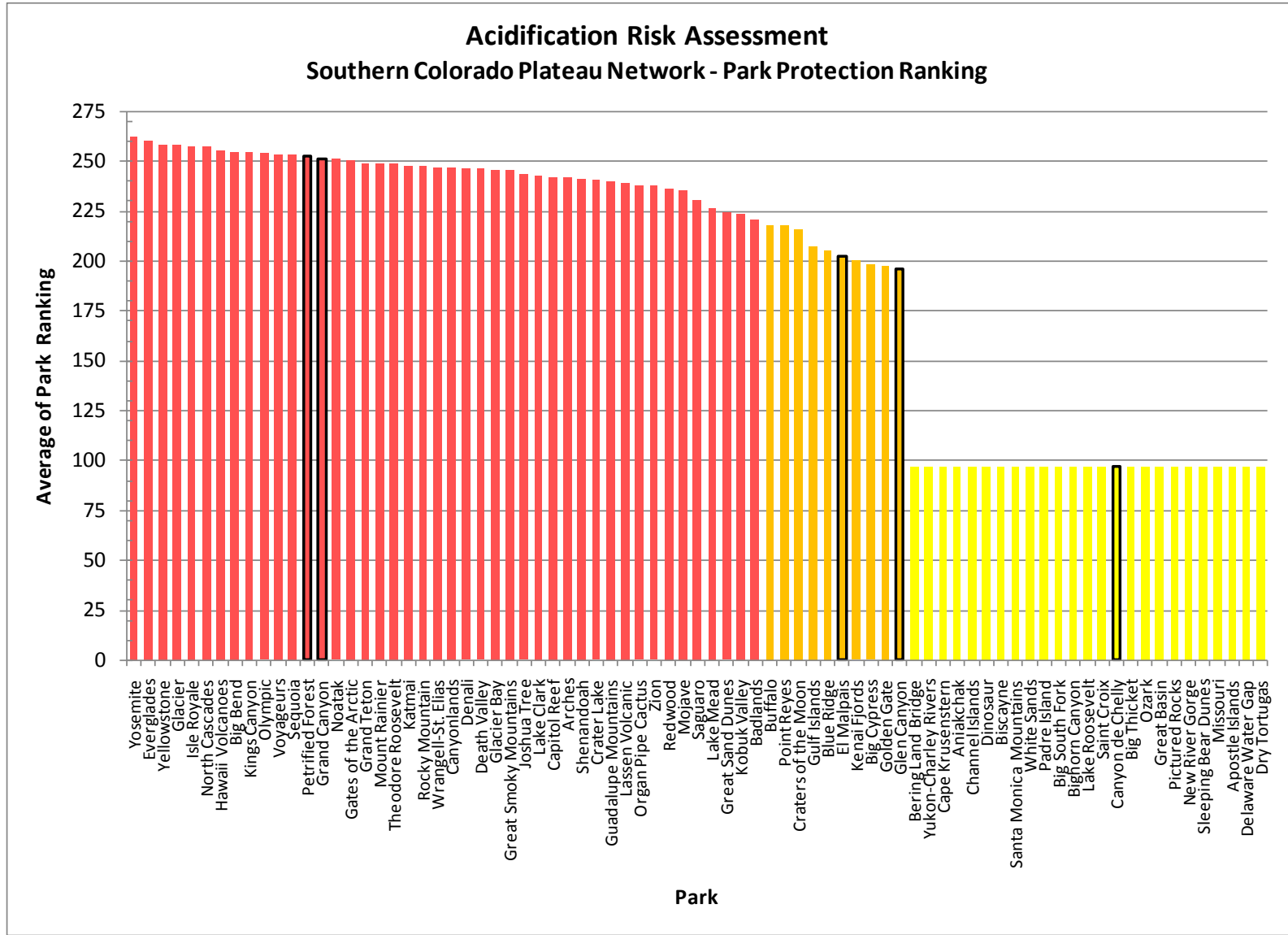


Figure G

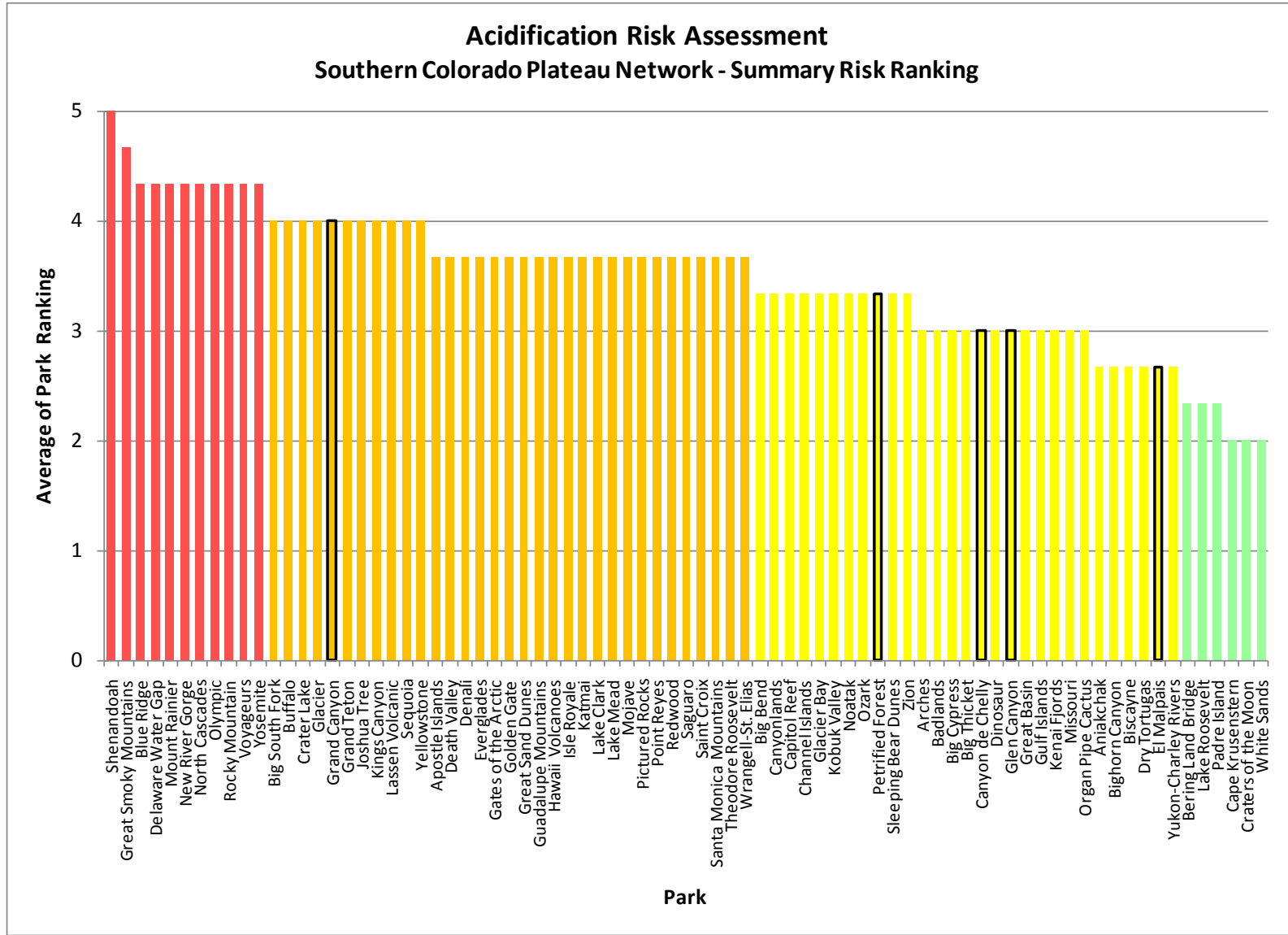


Figure H



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.

NPS 960/107408, April 2011

**National Park Service**  
**U.S. Department of the Interior**



---

**Natural Resource Program Center**

Air Resources Division  
PO Box 25287  
Denver, CO 80225

[www.nature.nps.gov/air](http://www.nature.nps.gov/air)