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Natural Resource Stewardship and Science

Air Quality Monitoring Strategy

Natural Resource Report NPS/NRSS/ARD//NRR—2015/909

ON THIS PAGE
Park staff next to an IMPROVE network monitoring station at Yellowstone National Park.
Photograph courtesy of Yellowstone National Park.

ON THE COVER
Sierra del Carmen at Big Bend National Park.
Photograph courtesy of Big Bend National Park.

Air Quality Monitoring Strategy

Natural Resource Report NPS/NRSS/ARD//NRR—2015/909

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The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are 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.

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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.

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Executive Summary

The US has a long standing commitment to clean, clear air, especially in our national parks. However, many national parks are threatened by elevated levels of air pollution that adversely impact visibility, ecosystems, human health and visitor experience. The National Park Service (NPS) has a responsibility under the Clean Air Act and NPS Organic Act to protect air quality and resources that might be adversely affected by air pollution. Monitoring air quality is critical for carrying out these statutory mandates. On behalf of the NPS, the Air Resources Division (ARD) works with park resource managers and partners to operate an Air Quality Monitoring Program. This program includes participation in several national monitoring networks coupled with data analysis and special studies. These efforts inform mitigation strategies and, in collaboration with our partners, enable the protection of air quality and related values in our national parks by providing baseline information, knowledge of trends, and speciation of pollutants. The data not only benefit national parks, but also state, regional and national partners who rely on the data for regulatory purposes.

Through its own monitors and those of its partners, ARD is able to track conditions and trends at nearly 350 park units, enabling the NPS to be a leader in understanding how air pollution affects scenic views and natural resources. The Monitoring Program produces high quality data, supports in-depth analyses, and provides a consistent measurement record. These data allow for the effective development and implementation of regulations and policies to protect park air quality and the resources that depend on it. As additional benefits, the data and analyses are used to advance the state of the science in air quality research and to provide critical air quality data for use by the greater scientific community.

The objectives of the Air Quality Monitoring Program are to:

1. Document current air quality conditions and track trends using scientifically defensible data,
2. Understand the sources of air pollution affecting air quality in parks, and
3. Identify risks to park air quality and the resources impacted by airborne contaminants.

These objectives are founded on the philosophy that solutions come from a clear understanding of the problem, which is based on scientifically sound data and information, and that together we can achieve the goals of the Clean Air Act and the NPS Organic Act to safeguard our parks for the enjoyment of future generations.

The ability to achieve the monitoring objectives is constrained by technological, logistical and funding limitations. ARD regularly evaluates and optimizes its Monitoring Program within these limitations and within the context of emerging air quality issues. Recently, decreased funding, both from NPS and our partners, has forced compromises in the Monitoring Program and has limited our ability to monitor all relevant pollutants in parks.

The ARD's monitoring strategy guides ARD in managing its Monitoring Program and is aimed at protecting park resources from air pollutant impacts. Risks may be the result of high pollutant

concentrations, long-term loading, or due to particularly sensitive resources. The monitoring strategy defines criteria for sample site selection and identifies what pollutants should be measured. These decisions are made by the ARD in collaboration with park resource managers and partners based on a defined set of considerations. Other strategic factors considered include broad representation of the National Park System within the monitoring networks and providing data to help the NPS proactively identify and respond to new potential threats to park resources. The strategy also describes means to evaluate monitoring capabilities on a network-wide basis and identifies current air quality issues which deserve further attention. ARD will continue to work with parks and other partners to enhance its Air Quality Monitoring Program in order to protect air quality in parks and the resources that depend on it.

Abbreviations

AMNet	Atmospheric Mercury Network
AMoN	Ammonia Monitoring Network
AQRV	Air Quality Related Value
ARD	Air Resources Division
BLM	Bureau of Land Management
CAL	NADP Central Analytical Laboratory
CASTNET	Clean Air Status and Trends Network
FWS	Fish and Wildlife Service
EPA	Environmental Protection Agency
FED	Federal Land Manager Environmental Database
GIS	Geographic Information System
GPMP	Gaseous Pollutant Monitoring Program
IMPROVE	Interagency Monitoring of PROtected Visual Environments
IRMA	NPS Integrated Resource Management Applications
MDN	Mercury Deposition Network
NAAQS	National Ambient Air Quality Standards
NADP	National Atmospheric Deposition Program
NCore	National Core Multipollutant Network
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
NO_X	Nitrogen oxides
NP	National Park
NPS	National Park Service
NTN	National Trends Network
$PM_{2.5}$	Particles less than 2.5 micrometers in diameter

PM_{10}	Particles less than 10 micrometers in diameter
POMS	Portable Ozone Monitoring Systems
QA/QC	Quality Assurance/Quality Control
RHR	Regional Haze Rule
SO_2	Sulfur dioxide
USFS	US Forest Service
USGS	US Geological Survey

Background of NPS Air Quality Monitoring

The National Park System consists of 401 units covering more than 84 million acres. These areas include national parks and monuments, as well as numerous historic sites and scenic areas. Many of these park units are threatened by elevated levels of air pollution that can adversely impact visibility, ecosystems, cultural resources, human health and visitor experience. Under the Clean Air Act and the National Park Service (NPS) Organic Act, the NPS has a responsibility to protect air quality and resources that might be adversely affected by air pollution. Specifically, the Organic Act mandates the NPS to "…conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." In partnership with parks and other agencies, the Air Resources Division (ARD) is dedicated to achieving and maintaining clean air in all units of the National Park System. This involves working with the US Environmental Protection Agency (EPA), states and partners to carry out the following: establish safe pollutant levels through national and regional air quality regulations, monitor air pollution, document impacts, determine the sources of harmful pollutants, facilitate the reduction of harmful levels of pollutants in parks, identify new and emerging issues causing poor air quality, and influence the development of new policies and regulations to address existing and emerging issues. Critical to the accomplishment of these tasks is reliable air quality data.

As part of its responsibilities, the ARD supports and maintains an Air Quality Monitoring Program, which includes participation in several national monitoring networks coupled with data analysis and special studies. Throughout this document, we use the term air quality in a general sense, to designate pollutants and atmospheric processes that could potentially impact park resources; this includes pollutants defined by EPA in the National Ambient Air Quality Standards (NAAQS)[1] as well as airborne contaminants such as mercury and air toxics. The purpose of the Monitoring Program is to develop the comprehensive information needed to aid the NPS in protecting the air quality and related values of units of the National Park System. This information must be of high quality so that it is defensible in scientific and regulatory settings. The monitoring networks document current air quality conditions and, with long-term measurements, track the trends of air pollutants that affect park resources. Data collected from the Monitoring Program inform the NPS about air quality within the national parks and ultimately allow for better protection of park resources, thus serving a critical role in the air resource management program of ARD.

NPS air quality monitoring consists of monitoring stations in almost 70 national parks across the country. Some stations have been in operation since the 1970's. In addition to measurements within the parks, ARD partners with state and federal agencies to maximize spatial coverage, monitoring capabilities, and cost efficiencies, so that interpolated data can be used to derive conditions and trends for nearly 350 park units. All data collected within the monitoring networks are carefully

[1] The EPA sets two kinds of NAAQS: "primary" focused on protecting human health, and "secondary" focused on protecting public welfare, like visibility and ecosystem resources.

validated and are accessible to park staff and the public. Beyond collection and processing of data, the ARD also analyzes the measurements and communicates these results in order to inform park managers on issues germane to air quality and related values. ARD further strives to inform and educate staff and the public on risks associated with poor air quality. Although the monitoring data are collected within specific national parks, data collected throughout the networks provide critical information for assessing regional, national, and global air quality, and these data also are widely used by other agencies and scientific organizations.

The NPS Air Quality Monitoring Program has three primary focus areas: visibility, gaseous pollutants, and atmospheric deposition (wet and dry); meteorological data are also collected at many of the monitoring sites. Each of these components involves participation in one or more national monitoring networks, in-depth data analyses, and implementation of and coordination with atmospheric and/or ecological special studies. The monitoring networks are described briefly here, with a more detailed description, including a summary of cost saving measures taken to date, in Appendix A.

Visibility monitoring is designed to evaluate pollutants that affect visibility in our national parks as well as providing data and analyses that aid in the implementation of EPA's Regional Haze Rule (RHR). The IMPROVE (Interagency Monitoring of PROtected Visual Environments) program is the primary monitoring network for visibility, with supporting data provided by the optical and scene monitoring networks. The IMPROVE network evaluates the presence and persistence of particles in the atmosphere.

Certain national parks and wilderness areas were defined as Class I areas under the Clean Air Act amendments of 1977.[2] These areas were afforded special air quality protections, including visibility protections in all but two Class I areas. All but one of the visibility protected Class I areas (Bering Sea Wilderness) are represented by an IMPROVE monitoring site. IMPROVE modules collect $PM_{2.5}$ (particles less than 2.5 micrometers in diameter) and PM_{10} (particles less than 10 micrometers in diameter) samples, with the $PM_{2.5}$ samples analyzed for chemical composition. These data are then used to calculate haze levels and estimate visibility. Chemical composition analysis is crucial to understanding what pollutants are responsible for visibility impairment, and thus aids in identifying effective emission reduction strategies.

Gaseous pollutant monitoring focuses on measurements of ozone and meteorological parameters. These measurements were originally designed to determine compliance with EPA's NAAQS and to provide data that could be linked to ecological effects. Most of the NPS-operated gaseous monitoring stations are part of the Clean Air Status and Trends Network (CASTNET).

[2] Under the Clean Air Act, Class I areas consist of international parks, national parks larger than 6000 acres and wilderness areas and national memorial parks larger than 5000 acres that were in existence as of August 7, 1977. A total of 158 Class I areas exist in the US, with the NPS managing 48 of them.

Deposition monitoring strives to estimate total deposition, including both wet and dry components. Sulfur, nitrogen, and mercury species are the primary pollutants of concern. NPS participates in two national atmospheric deposition monitoring networks: the National Atmospheric Deposition Program (NADP) for wet deposition, and CASTNET, which measures ozone, as stated above, and also estimates dry deposition of sulfur and nitrogen species. Both networks are designed to track changes in deposition chemistry and to facilitate relative comparisons between different sites nationally. NPS, EPA and others use these data to relate those changes over time and relative levels between sites to emissions and ecosystem effects.

In contrast to long-term routine monitoring that provides information on the conditions and trends of air pollutants, the ARD often initiates special studies to address specific questions about the sources of air pollutants in national parks and the ecological effects of those pollutants on natural resources, and to further develop and improve field and laboratory methodologies. Special studies are short-term and intensive by design and typically include various partners.

One of the greatest challenges in managing a national program of this scope is balancing competing interests for limited financial resources, especially as priorities and funding levels change. This has been particularly true in recent years as the NPS Air Quality Monitoring Program has faced shrinking budgets. Such impacts have been exacerbated as other agencies involved in the monitoring networks in which the NPS participates have faced similar financial pressures. The ARD has worked hard with partners to minimize the impact of funding constraints by maximizing efficiencies in all aspects of the networks and forging partnerships with other agencies. To date, cost savings for the Monitoring Program have been realized by curtailing efforts aimed at reducing measurement uncertainty and by reducing the size and scope of the networks (see Appendix A). Unless new and less expensive monitoring methods are developed, any future savings needed will require reducing the number of pollutants and/or parameters measured, scaling back participation in collaborative networks, and/or reducing the number of sampling sites in the NPS networks. Future cuts also may require foregoing addressing new and important emerging issues. The impacts of such reductions are profound, potentially restricting the ability of the ARD and park resource managers to protect air quality and the resources that depend on it. Even with static funding levels, operation of the monitoring networks faces diminished support due to rising analytical costs, costs associated with maintenance of aging instrumentation, and the need to shift funds to address emerging issues, such that flat funding is equivalent to eroding monitoring capabilities.

Objectives of the NPS Air Quality Monitoring Program

The ARD aids park managers in improving air quality in national parks to be protective of natural and cultural resources as well as staff and visitor health. For effective air quality management, the monitoring networks must provide accurate measures of air pollutant levels, and related analyses must characterize the sensitivity of resources to air pollutants. Further, a clear understanding of the causes of elevated levels of pollutants is needed for developing effective mitigation strategies. The ARD also tracks the effectiveness of air resource management strategies and identifies emerging threats in order to be proactive in resolving them. Finally, to successfully manage air quality issues in parks, the ARD must work with park resource managers and partners to ensure the public are informed and engaged. To aid in these activities and the effective implementation of the Air Quality Monitoring Program, the following objectives have been identified.

- Document current air quality conditions and track trends using scientifically defensible data.
  - Determine air quality conditions present in or representative of all national parks;
  - Identify violations of NAAQS and exceedances of ecological thresholds;
  - Track progress toward national and NPS air quality goals;
  - Estimate response in pollutant levels to air quality regulation; and
  - Identify emerging air quality problems.
- Understand the sources of air pollution affecting air quality in the parks.
  - Provide data to help determine the contributions of various pollutants, source regions and source types;
  - Identify physical and chemical processes driving air quality; and,
  - Collect sound scientific evidence to support the development of meaningful mitigation strategies and provide input to development of air quality regulations.
- Identify risks to park air quality and the resources impacted by airborne contaminants.
  - Develop and evaluate dose-response relationships for sensitive resources;
  - Establish and evaluate thresholds/critical loads/target loads; and,
  - Identify and address emerging issues.

To successfully meet these objectives the air quality monitoring networks must contain the following fundamental characteristics:

1. **Continuity of measurements.** Long-term data sets provide the underpinning framework for the NPS to identify and quantify the important processes controlling air quality in park units and are essential for documenting how air quality is changing over time. Long-term measurements also allow for assessment of how changes in emissions and implementation of control strategies affect the amount and type of air pollutants in parks.

2. **High temporal and spatial resolution.** High resolution data are critical for understanding sources, transport and chemical transformations of pollutants and for effectively implementing models to better capture larger scale processes.
3. **Robust sample collection and analysis.** Quality control measures ensure the networks provide robust data sets for use in regulatory, planning and permitting actions. Data analysis is essential for translating the large quantities of raw data into useful information that allows the ARD to advance park protection. High quality data sets also are utilized as part of national and international scientific efforts to understand and characterize air quality and air pollution impacts.
4. **Inclusion of survey monitoring, special studies and seasonal measurements.** These studies provide detailed information needed to clearly identify sources of air pollutants and impacts to natural resources in specific park units.

When all of these criteria are met, the monitoring data can be effectively coupled with modeling tools that encompass dynamical, photochemical and emission processes to provide a clear understanding of the processes that control air quality in national parks. Such data products not only benefit national parks, but also help to guide state, regional, and national regulatory agencies that have enforcement responsibilities, provide factual data for legislative efforts, and help to advance our fundamental understanding of the science that governs air quality.

Monitoring Strategy

The NPS Air Quality Monitoring Program is administered by the ARD. The ARD is a national office, and, as such, places a very high priority on service-wide needs, recognizing that the National Park System is made up of 401 individual units as well as regional and national offices. While this strategy provides a high level overview, its implementation will be accomplished through specific monitoring network and site-specific evaluations, considering the goals and purposes of each network. Those goals and purposes, and their relative priority, must also be reconciled between networks. Collaboration and communication with our park and regional partners are keys to making this strategy and its implementation successful; however, the final decisions about the NPS Air Quality Monitoring Program rest with the ARD and its management team.

To fully meet the objectives of the Monitoring Program would require long-term monitoring using robust measures of all potential pollutants at all parks and at high temporal resolution. This is impractical because of constraints related to cost, available technology and logistics. Compromises must therefore be made. The goal of the monitoring strategy is to optimize the Air Quality Monitoring Program to best meet the objectives within existing constraints. The monitoring strategy is intended to be flexible, so that the same approach will be utilized whether budgets are contracting or expanding and should be responsive to changing resource needs.

The first component of the strategy is the upfront identification of considerations for selection and maintenance of sampling sites and measured pollutants and parameters of the NPS monitoring networks. These considerations are focused on the most critical needs of the NPS and are aimed at identifying what pollutants will be measured and where. Related to these considerations, the second component of the strategy provides a network-scale approach to evaluate the Air Quality Monitoring Program and to identify mechanisms for enhancing our current monitoring capabilities. The final component of the monitoring strategy describes timely air quality issues that directly impact national parks.

Considerations

The following questions are aimed at examining existing/potential monitoring sites or measured pollutants. The questions are broken into three categories: primary, secondary, and logistical considerations. Primary considerations are deemed to be of greatest importance. Secondary considerations are also taken into account, and in some cases multiple secondary considerations may outweigh a primary consideration. Finally, several logistical constraints are noted which often play a deciding role in determining site selection and pollutants measured. For each site, all of these factors are considered, as well as potential unique circumstances which may not be listed here. Final decisions to address the contraction or expansion of the networks will be made in collaboration with park resource managers and ARD partners.

- **Primary Considerations**
    - Can (are) the data be(ing) used by the NPS to influence decisions by regulatory agencies?
    - Do documented violations in NAAQS or exceedances in critical loads or other thresholds exist?

  - Are park resources at risk?
  - Are park resources particularly sensitive to pollutants?
  - Are we relying on the monitors for regional/spatial coverage?
  - Does the monitor have an established long-term record of data collection and would removal of the site be detrimental to regional tracking of trends?
  - Is the park a Class I area?
- **Secondary Considerations**
  - Does the park have significant natural resources, as determined by the Inventory and Monitoring Program?
  - Is there a new potential threat to park resources?
  - Are multiple pollutants measured at one site?
  - Are the data important to the park for internal uses?
  - Are existing monitors within the parks adequate to meet our objectives?
  - Can costs be reduced by seasonal monitoring without jeopardizing regulatory function?
  - Are researchers using the data to support their work and is that work germane to park protection?
- **Logistical Considerations**
  - Are there site constraints related to access, power, or staffing of the site?
  - Who is funding the site?
  - Do other monitors exist in the area that could be used?
  - Is park staff supportive of current and/or new monitoring initiatives?
  - Are existing monitors in ideal locations within the parks?
  - Have there been advances in monitoring that allow us to measure new or existing threats?
  - Is there a possibility to share operation of the monitor with a non-NPS entity?

Although it is our goal to have comprehensive monitoring for all parks, either with monitors in the park or nearby, we note here some of the reasons we do not monitor certain pollutants in certain locations. These include areas where resources are not at risk for a given pollutant, where baseline concentrations have been established and there are no known air quality issues, where sources have been effectively controlled, where redundant measurements are being made, and where it is either not cost-effective or logistically viable to make measurements.

Evaluation of Existing Air Quality Monitoring Networks

As part of ARD’s commitment to protecting park resources, we regularly evaluate all components of our Air Quality Monitoring Program. The goals of these assessments are to:

- Identify gaps and overlaps among current monitoring networks;
- Identify pollutants of concern which are not currently monitored;

- Identify opportunities for development and refinement of analytical methods;
- Evaluate innovative monitoring methods to establish more cost-effective monitoring options;
- Assess whether NPS objectives are being met through participation in partnerships; and
- Identify all areas where efficiencies can be gained in the Air Quality Monitoring Program.

Network and site evaluations are conducted on an ongoing basis by the ARD and through the steering committees of the networks in which NPS participates. To some extent, these evaluations are driven by practical considerations, such as the annual federal budgeting process, but also by changes in available technology and by obtaining better information related to emerging issues through special studies. More thorough evaluations are carried out for each of the networks typically every few years. Each network evaluation is unique and generally includes participation from NPS partners. Park and regional input is also sought for these assessments. In all cases, the assessments are meant to ensure that NPS objectives are being met. In previous years, the results of these efforts have been formalized at different levels, and only in some cases were results widely distributed (e.g., IMPROVE, as described below). For future evaluations, it is ARD's goal to better communicate these results with parks and regional staff. A key aspect of these assessments is the belief that every monitoring site adds important information locally, regionally and nationally. As such, any park or region that may be impacted by a proposed change to the network will be consulted before any decisions are finalized.

Network evaluations have allowed the monitoring networks to evolve over time and have led to the current monitoring configuration. For example, special studies have shown the importance of ammonia to total reactive nitrogen deposition for sensitive ecosystems. To quantitatively account for ammonia, a cost effective method for measuring ammonia in remote locations was developed, and in 2010 the Ammonia Monitoring Network (AMoN) became an official part of the NADP program. More recently, there is evidence that energy development operations in the Bakken region of North Dakota are adversely impacting air quality in Theodore Roosevelt and other national parks. A special study is underway at the time of this writing to understand these potential impacts, and as part of this study the ARD is assessing whether additional air quality monitoring is needed to track potential changes in these parks. Finally, in response to potential budget cuts over the past eight years, the IMPROVE monitoring program has conducted two extensive network evaluations. This process involved establishing a number of network criteria to rank the monitoring sites to determine which sites would have the least impact on national particulate matter and haze monitoring and compliance with the RHR. The entire process was guided by a working group consisting of federal, state and other personnel. As a result of these evaluations, several monitoring sites have been discontinued and other cost saving changes have been implemented. An overview and history of each of the monitoring networks is provided in Appendix A.

Although the networks are regularly evaluated and modified, numerous measurement gaps exist which limit our ability to meet all of our stated objectives. Some examples of gaps in current monitoring include measurements of air toxics, measurements of all components of nitrogen deposition, the need to use interpolated data for some parks rather than direct measurements,

measurements at higher time resolution, and measurements of precursors of ozone and particulate matter.

While the NPS maintains a robust Air Quality Monitoring Program, opportunities exist to enhance current monitoring capabilities without impacting the existing monitoring networks. Examples of current and future considerations include:

- Co-location of instrumentation at “core” measurement sites focused on method development and measurement inter-comparisons;
- Collaboration with universities/outside agencies by providing infrastructure for air quality research in parks aimed at supplementing monitoring data;
- Utilization of air quality models to augment observations with spatial, temporal, and compositional information when lacking direct measurements;
- Utilization of remote sensing for extended spatial and temporal coverage for analysis when lacking direct measurements; and,
- Co-location of ecosystem monitoring at areas currently instrumented for air quality monitoring.

Future Priorities

Over the past two decades, the NPS has focused on regional scale air pollutants such as particulate matter, ozone and deposition, all of which will remain areas of concern into the foreseeable future. However, new challenges are emerging in air quality that must be considered when planning for the future. For example, oil and gas development and production operations near many park units are rapidly increasing along with the need to better characterize related emissions and influence future oil and gas emission control strategies. Other timely issues include:

- Linking air chemistry and deposition to develop critical load thresholds for ecosystem impacts;
- Agricultural emissions;
- Wildfires, prescribed burns and smoke;
- Mercury and toxics emissions and cycling; and,
- Greenhouse gases and climate.

Current NPS air quality monitoring provides data relevant for each of these issues. However, targeted monitoring of a more comprehensive suite of parameters is needed to carry out a well-integrated assessment of the impacts of each of these issues to park air quality and related values. The results of such assessments could motivate changes to the Air Quality Monitoring Program as it currently exists. Complicating any of these efforts is the fact that rising background levels of pollutants have resulted from world-wide anthropogenic emissions, raising the complex issue of how to deal with domestic emission control strategies when increased atmospheric pollutant loading results from long range transport.

Uses of Data

The information that the ARD collects through monitoring and special studies is used in a variety of ways; such as, tracking the status of air quality and air quality related value (AQRV) conditions and trends in parks; evaluating emission sources and mitigation strategies; supporting policy and regulatory planning decisions made by state and federal air regulatory agencies; addressing air quality in park planning; providing data for university and government researchers outside of NPS; and providing outreach and education opportunities. Parks and partners also use these data for a variety of planning activities not explicitly listed. Here we highlight some of this work, as it has had widespread impacts on the parks as well as in the scientific and policy arenas.

Assessment of Conditions and Trends of Air Quality and AQRVs in Parks

The ARD uses the monitoring data to assess conditions and trends for visibility, ozone, sulfur and nitrogen deposition, and mercury levels in parks. Special studies data allow the NPS to understand how air pollutants are currently impacting park air quality and AQRVs. ARD uses the data to determine the effect of pollutants on visibility, sources contributing to visibility impairment in parks, ozone exposure levels and impacts to vegetation and humans, critical loads and effects on aquatic and terrestrial resources, and the extent of mercury contamination in fish and wildlife. These data help the NPS and the public understand which parks are at highest risk for impacts, and where conditions of park air quality and AQRVs are declining or improving. From the air quality monitors that are in parks and the many state and local monitors near parks, ARD is able to report on conditions and trends at nearly 350 national park units.

Evaluation of Emission Sources and Mitigation Strategies

Monitoring data are critical to fulfilling our role under the Clean Air Act to “preserve and enhance the air quality and AQRVs” in national parks. Under the Act, the NPS is required to review new sources of air pollution and determine potential impacts to park resources. In addition, National Environmental Policy Act (NEPA) documents often require assessment and disclosure of air quality and air pollution impacts from sources outside parks. Monitoring data from networks and special studies are used to define current air quality conditions in parks and identify where pollutant levels impair visibility, cause foliar injury, pose a risk to humans, or exceed critical loads. An understanding of current and past conditions in parks provides a baseline to assess how new emission sources could impact air quality and AQRVs in parks, and informs our recommendations for source mitigation measures or pollution control equipment to address adverse impacts.

Support of Policies and Regulations to Protect Air Quality in Parks

Monitoring in and near parks provides a record of air quality that supports regulatory applications including, but not limited to, the evaluation of visibility trends for purposes of the RHR, demonstration of attainment or nonattainment of current NAAQS, and development of future regulations. The monitoring data are also important for assessing the success of regulatory programs, providing vital feedback and measures of accountability on air quality regulations. For example, NADP and CASTNET have helped to track the successful acid rain programs that have reduced emissions and deposition of sulfur and reactive nitrogen that damage sensitive parks and other areas.

The EPA conducts a science and policy assessment every five years to determine whether air quality standards to protect health (primary standards) and ecosystems (secondary standards) should be established or updated. Monitoring data provided by the NPS on ozone, nitrogen oxides (NO_x) and sulfur dioxide (SO_2) concentrations, deposition, and effects on visibility, soils, waters, and plants are a critical component of these periodic assessments. For example, ozone and vegetation data from Sequoia and Yosemite NPs have been used to document the concentrations at which ozone pollution causes damage to Ponderosa pine trees. Stream acidification and aquatic and terrestrial eutrophication monitoring and research projects sponsored by the ARD provide evidence informing the EPA's assessments of whether existing air pollution limits are adequate to protect sensitive natural ecosystems nationwide. The ARD provides a synthesis of all relevant air quality and air pollution effects monitoring in national parks to the EPA for developing secondary ozone, NO_x and SO_2 standards. Operation and maintenance of NPS monitoring networks within the EPA Quality Assurance (QA) and Quality Control (QC) guidelines is vital to using these sites to assess policy and regulatory decisions and pollution reduction initiatives.

NPS and Other Agency Planning

The ARD assists parks and other agencies in planning activities to ensure that air pollution impacts are adequately identified and addressed. Measuring pollutant levels in parks provides vital information for evaluating internal and external actions that affect air quality and resources sensitive to air pollution in national parks. Air quality data are often used in NPS NEPA analyses to define current air quality conditions and trends to provide a baseline and context for changes predicted from proposed projects.

Air quality data are also used in a variety of park planning documents: Park Foundation Documents, State of the Park Reports, Natural Resource Condition Assessments, and Resource Stewardship Strategies. Park Foundation Documents identify a park's resources, values, and history as well as resource condition, opportunities, threats, and planning and analysis needs. These documents serve as blueprints to effectively manage parks to protect resources and allow for visitor enjoyment. State of the Park Reports and Natural Resource Condition Assessments assess current and desired conditions of air quality and related resources while a Resource Stewardship Strategy describes how to make progress toward desired conditions through management goals.

NPS monitoring data also support the planning, permitting and regulatory decisions of other federal and state agencies. For example, when the Bureau of Land Management (BLM) plans for fossil fuel leasing and development, NPS monitoring data are used to determine the current condition and trends against which any additional future impacts may be evaluated. These evaluations allow NPS to influence and support mitigation decisions of other agencies to protect park resources.

Model Development and Evaluation

Air quality models are routinely used in regulatory decisions (e.g., NAAQS attainment determinations, regional haze plans, and multi-state pollutant reduction strategies) and federal agency planning decisions (e.g., BLM oil and gas Resource Management Plans and project development NEPA documents). Monitoring data are used to evaluate and improve the performance of air quality models. Model runs must be demonstrated to meet EPA performance criteria (i.e., how well the model predicts pollutant concentrations) before emissions control options can be evaluated. Monitoring data are also used to predict future air pollutant concentrations based on model predicted changes. The more robust the monitoring data that can be used in the model evaluation, the more reliable the model outputs and future projections on which to base agency decisions.

Outreach and Education

Many of the key stories about the importance of clean air in parks use air monitoring data in interpretive materials and programs at the park level. For example, wayside exhibits focused on the visibility impacts of haze are common in many parks. Air quality stories are often integrated in interpretive talks about sensitive environments or changing land use patterns around a park. These stories provide opportunities to engage visitors in park stewardship because the actions that they take at home can make a difference for park air quality. Real time air quality data also support visitor center exhibits at a number of parks where current meteorological and ozone data are displayed alongside a current scenic image of the park.

Current air quality data and scenic images are also displayed on NPS webpages. There are 19 air quality webcams in parks that display images that update every 15 minutes, along with hourly meteorological, ozone, particulate matter, and visual range data as available. These sites received over 9 million page views in 2013, far outpacing the visitation for any other NPS nature and science webpage. Many virtual park visitors use these webpages to stay connected with their favorite national parks from a distance or to check on conditions before making a trip to a nearby national park.

Air quality health advisories for ozone and particulate matter are based on forecasts as well as monitoring data (e.g., AIRNOW). Web and park based advisories are an important way of informing park staff and visitors about the potential health impacts of poor air quality. Hawaii Volcanoes NP has additional health concerns because of SO_2 emissions from ongoing volcanic activity. Real time SO_2 and particulate monitoring data are critical to protecting staff and visitors at the park.

Conclusions

Clean, clear air is critical to ecosystem health, protection of resources and the visitor experience at all national parks. To protect air quality, the ARD has maintained an active Air Quality Monitoring Program since the 1970's, measuring pollutants and assessing their impacts on park resources. The Air Quality Monitoring Program consists of participation in monitoring networks, data analysis, and special studies. The monitoring networks focus primarily on characterizing visibility, ozone, and atmospheric deposition in parks. Special studies and data analysis are carried out to understand the causes of air pollution and the impacts on natural resources in specific park units, and to refine monitoring techniques. Combined, the various components of the Air Quality Monitoring Program have allowed the NPS to protect park resources by influencing regional and national air quality regulations. Additionally, the monitoring data have been used extensively to support park planning and outreach efforts and to achieve a better understanding of air quality from a local to global scale.

The ARD maintains a leadership role in protecting air quality in natural areas throughout the US by utilizing the data sets generated from the monitoring networks. To do so, the Monitoring Program has evolved over time, forging new partnerships with federal, regional and state agencies to improve spatial coverage, monitoring capabilities, and cost efficiencies. The ARD has been proactive in incorporating new analytical techniques into its monitoring networks, striving to make the best and most cost effective measurements while maintaining consistent long-term records. As with many federal programs, decreased funding in recent years coupled with rising costs have impacted all facets of the monitoring networks, resulting in less rigorous quality control measures, a reduction in the number of stations, measurement gaps, and termination of measurements.

The ARD has developed this monitoring strategy to help guide the Air Quality Monitoring Program into the future. This strategy identifies considerations for selection of sampling sites and measured pollutants. Considerations are focused on protecting park resources by identifying, understanding, and working to reduce levels of pollutants in all parks. The strategy also describes approaches to evaluate and enhance monitoring capabilities on a network-wide basis and identifies current air quality issues which deserve further attention.

The ARD will continue to make scientifically sound measurements of those air pollutants that impact parks and invest the necessary time and expertise to analyze the monitoring data and clearly communicate these results so that park managers and policy makers can make informed decisions. In implementing the monitoring strategy, it is our goal that the Air Quality Monitoring Program will remain a robust and invaluable entity for the NPS well into the future.

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Appendix A. Overview and History of Monitoring Networks

The quantities and figures presented in this discussion represent the state of the networks as of the time of this writing. Updated information can be found through the web links in each section.

Visibility

IMPROVE

The degradation of visibility is among the most easily recognizable effects of air pollution in the atmosphere. Under the Clean Air Act, Congress recognized that visibility is a resource to be valued and preserved now and for future generations, and set forth a national goal that calls for “the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class I federal areas which impairment results from manmade air pollution.” Federal Land Management agencies such as the NPS were assigned, “the affirmative responsibility to protect the air quality related values of Class I lands.” The RHR further expanded this affirmative responsibility by requiring monitoring in locations representative of the 156 visibility-protected federal Class I areas. The NPS Visibility monitoring network is driven by this mandate. To this end, NPS participates and serves a leadership role in the IMPROVE network, which collects visibility data in Class I areas across the country, with a focus on tracking progress toward the goal of returning visibility to natural conditions by 2064. IMPROVE is a cooperative effort led by representatives from the NPS, EPA, US Forest Service (USFS), US Fish and Wildlife Service (FWS), BLM, National Oceanic and Atmospheric Administration (NOAA), and several interstate air quality management organizations.

Visibility degradation is caused by the scattering and absorption of light by particles and gases in the air. For the RHR, visibility is determined using the Deciview haze index, which is inversely related to visual range and can be calculated from measurements of speciated particle composition concentrations. The IMPROVE network provides these speciated aerosol measurements using a robust sampling system and well established analytical techniques (Hand et al., 2011). Data from the IMPROVE network are used to establish current visibility conditions in Class I areas, to identify chemical species and emission sources responsible for existing anthropogenic visibility impairment, and to document long-term trends for assessing progress toward the national visibility goal. Additionally, analyses of the spatial, temporal, and interspecies patterns in these concentrations have been used to explore and verify hypotheses such as impacts from smoke and Saharan dust, and to uncover monitoring and data analysis issues.

The IMPROVE particle monitor consists of four independent sampling modules that collect 24-hour samples on filters every third day. Three modules (A, B, and C) collect only fine particles ($PM_{2.5}$), while the fourth (module D) collects both fine and coarse particles (PM_{10}). Data from all of the modules are used to calculate visibility metrics. Module A is equipped with a Teflon® filter that is analyzed for $PM_{2.5}$ gravimetric fine mass, elemental concentration, and light absorption. Module B is fitted with a Nylasorb (nylon) filter and analyzed for the anions sulfate, nitrate, nitrite, and chloride using ion chromatography. Module C utilizes a quartz fiber filter that is analyzed by thermal optical reflectance (TOR) for organic and light absorbing carbon. Module D is fitted with a PM_{10} inlet and utilizes a Teflon filter to determine PM_{10} aerosol mass concentrations gravimetrically. These filters are retrieved once a week, typically by park staff. Filters are then sent to contracted laboratories for physical and chemical analyses. All data are available on the Federal Land Manager Environmental Database (FED) 6-9 months after the filters are collected (http://views.cira.colostate.edu/fed/).

The NPS and the EPA first began long-term visibility monitoring at select national parks in 1979; IMPROVE was established as a national visibility monitoring program in 1985. The IMPROVE network initially was funded by the NPS and consisted of 30 monitoring sites primarily located in national parks, 20 of which began operation in 1987. IMPROVE network operations were fully implemented in March 1988. About 40 additional sites, most in remote areas, that used the same instrumentation, monitoring, and analysis protocols (called IMPROVE protocol sites) began operation prior to 2000 and were separately sponsored by individual federal or state organizations. Many of the early sites also included optical monitoring with a nephelometer, a transmissometer, and/or color photography to document scenic appearance (described further below).

Beginning in 1998, the EPA provided support to expand the IMPROVE network in order to provide the representative speciated particle monitoring required under the RHR for each of the 156 mandatory federal Class I areas where visibility is an important attribute (with the exception of Bering Sea Wilderness), expanding the number of sites to 159. At its peak, the IMPROVE network had 176 sites in 2004. This number has decreased due to funding cuts, and the current network includes 164 sites across the country (see Figure 1), 53 of which are in national park units.

In addition to a reduction in the number of IMPROVE sites, a number of other cost savings measures have been implemented in recent years: a reduction in site maintenance by field technicians to every other year; a reduction in enhanced QA/QC measures; a reduction in the number of collocated samplers that are used to better quantify measurement precision; removal of quartz backup filters, another QC tool, and replacement with field blanks; and skipping one week of sampling for the entire network at Christmas. Although these cuts have resulted in significant cost savings and have improved efficiencies, continued cuts aimed at QC measures are expected to impact data quality. As such, future cuts will likely result in a reduction in sampling sites, which will impact implementation of the RHR and RHR State Implementation Plans. Such changes to the network may be required even without funding cuts, as an increase in funding is needed simply to keep pace with rising analytical costs. Beyond just keeping up with costs, further funding increases would strengthen the network by allowing reimplementation of enhanced QC measures, potential expansion of the network, better characterization of artifacts, further investigation into reduction of uncertainty in the IMPROVE equation (used to relate speciated particle concentrations to visibility), and additional measurements which impact aerosol concentrations and visibility in parks.

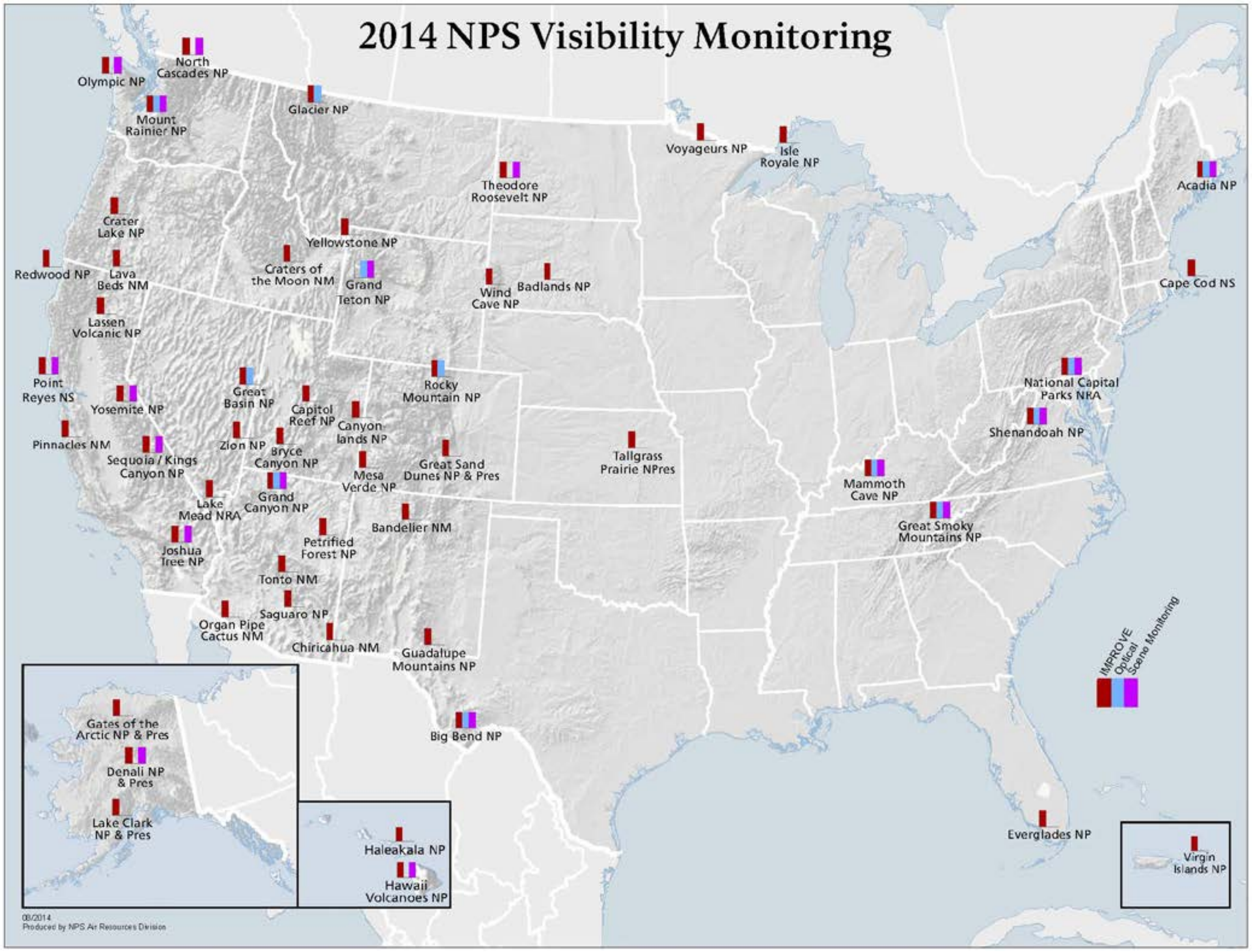

Figure 1. Map of Visibility and Particle Monitoring Sites in National Parks as of September 2014.

Optical

Although IMPROVE speciated particle measurements are related to visibility metrics through aerosol hygroscopicity and Mie theory, the NPS directly measures aspects of visibility through optical measurements and scene monitoring at a subset of the IMPROVE sites. Optical monitoring is conducted using an Optec NGN-2 integrating nephelometer, which was specifically designed for in-situ measurement of aerosol scattering (Molenar, 1997). The optical measurements serve as a quality assurance check for IMPROVE, in that measured and reconstructed scattering should be equivalent. The nephelometers have the added benefit that they run continuously and provide higher time resolution data, allowing for an examination of diurnal variability in visibility and short-term visibility impairing events.

Currently there are 12 nephelometers in operation (Figure 1) in the National Park System. The Optec NGN-2 open air nephelometer uses a unique integrating open-air design to measure total ambient light scattering coefficients for all particles sizes at an effective wavelength of 550 nm. Because of the open-air design, relative humidity and temperature of the air sample are essentially unchanged, so that the aerosol is negligibly modified when brought into the optical measuring chamber. Nephelometer data are available on the FED website (http://views.cira.colostate.edu/fed/). NPS partners with the USFS to share nephelometers and other optical equipment. A contractor is responsible for managing the optical network, maintaining instruments and software, and quality control, while NPS personnel are responsible for routine operation of the NPS sites.

Optical measurements have been conducted since 1986. Historically, optical measurements included both nephelometers and transmissometers (Optec LPV-2), which measure the irradiance of a light source after the light has traveled over a finite atmospheric path (1-15 km). Due to budgetary constraints, shifting priorities, and the relatively intensive data processing required, the NPS transmissometers have been phased out, with the last transmissometer shut down in 2007. While the nephelometer network is still in place, these instruments are now more than 20 years old and parts are becoming difficult to replace, as they are no longer manufactured. For this network to continue, replacement nephelometers are needed, likely within the next 5 years.

Scene Monitoring

Monitoring of scenic views is accomplished using digital cameras to document the visual impact of regional and layered hazes as a function of aerosol concentrations. Scene monitoring has the added benefit of displaying real time park imagery to the public through the ARD website (http://www.nature.nps.gov/air/WebCams/). Scene monitoring is more in line with the simple definition of visibility; scene characteristics include observer visual range, scene contrast, color, texture, and clarity, and have the distinction that they are also dependent on scene and lighting conditions.

Early scene monitoring was accomplished using automated 35-mm camera systems. At each camera site a spectrum of images associated with varying haze levels have been digitized and are available from the IMPROVE website (http://vista.cira.colostate.edu/IMPROVE/). These early camera systems have been replaced with webcams that take still photographs and upload these images to the ARD web page every 15 minutes at 18 parks across the country (Figure 1). Real-time data for visual range, weather, ozone, and PM also are included on the website to provide a snapshot of air quality in the park. Captured images qualitatively document the visible effects of uniform and layered hazes on unique vistas. Densitometer measurements of the calibrated digital imagery can yield relative radiance fields that can be used to calculate visibility indices. Alternatively, relative contrast measurements can be derived from the digital images and if calibrated against the nephelometer scattering data can be used to derive quantitative visibility metrics. Digital images can also be used to determine variations in vista color, texture and form.

Future cuts to this network will likely result in fewer active webcams, while increases in funding will allow for more webcams across the national park system. Additional funding may also allow for implementation of a night sky webcam network. This latter effort is currently in the testing phase, and has been shown to provide spectacular images of the night sky.

Gaseous Pollutants

The Gaseous Pollutant Monitoring Program (GPMP) determines ozone levels in national parks. Ozone is measured at elevated levels in many NPS units and can affect the health of visitors and staff, as well as sensitive vegetation. As of September 2014, the locations of NPS ozone instruments, along with state supported sites in parks, are shown in Figure 2. Although the focus of the GPMP is to measure ozone, several enhanced sites also include measurements of carbon monoxide, sulfur dioxide and oxides of nitrogen (NO, NO_2, NO_x and NO_y). A comprehensive suite of meteorological parameters are also measured at each site. The hourly meteorological data collected at these sites have been useful in understanding both the climatological and short-term weather conditions associated with various air quality conditions in NPS units. For example, knowledge of prevailing winds and their seasonal and diurnal variations can help with understanding the transport of air pollutants into the parks. Similarly, knowledge of temperature, moisture, and precipitation patterns can help with understanding the chemistry and deposition that impact air pollution levels.

There are numerous other gaseous pollutants that affect resources within the national park system and that are of interest to the NPS because they relate to physiological, morphological, or histological injury to park biological resources or to global climate change (e.g., other photochemical oxidants, nitrogen compounds, and toxic organic compounds). As air quality issues arise at park units, additional parameters may be added to better understand the processes affecting the air quality at a particular park unit.

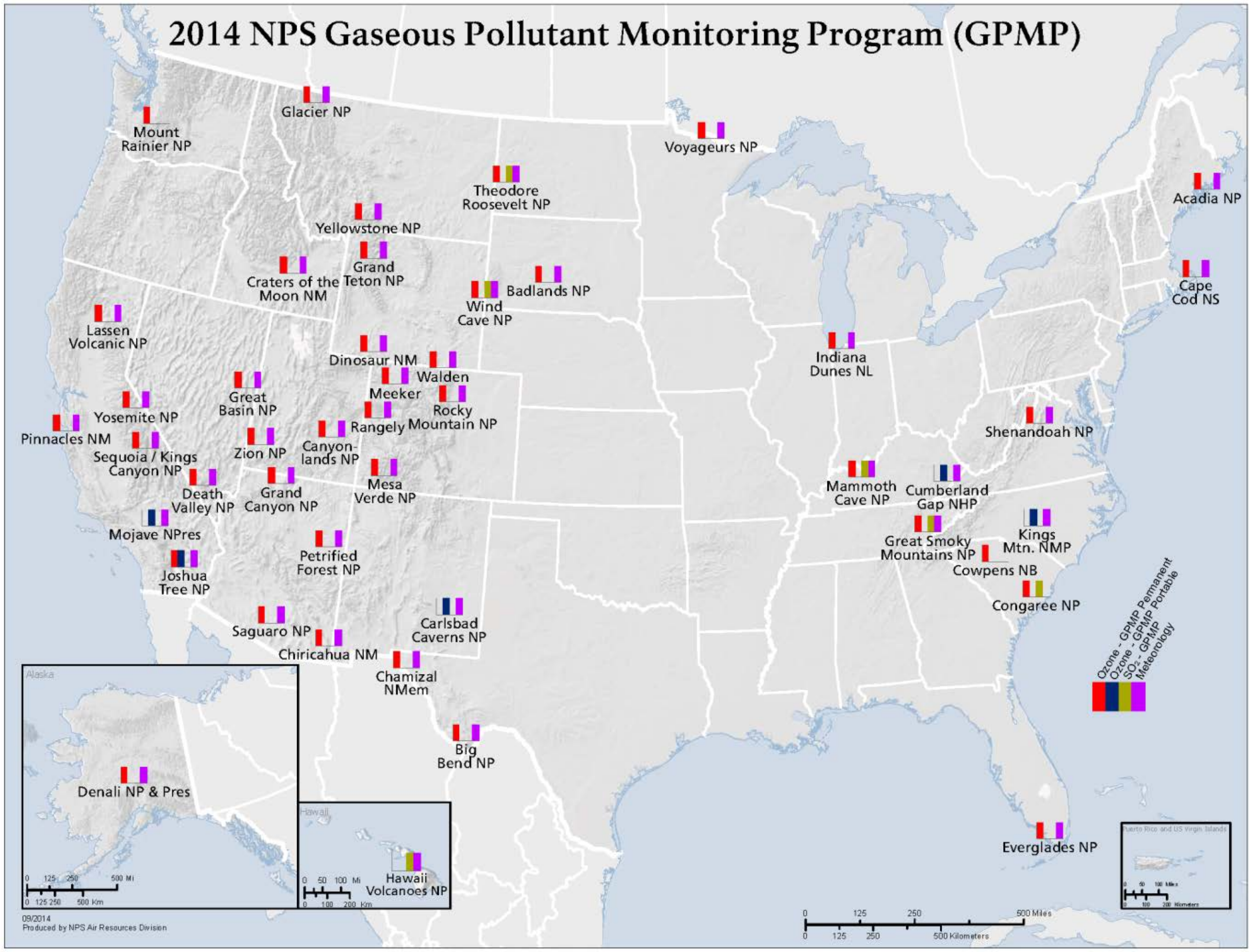

Figure 2. Map of the NPS Gaseous Pollutant Monitoring Program as of September 2014.

From a historical perspective, the NPS GPMP was effectively comprised of two types of stations, "trends" and "baseline" (Ray et al., 1998). "Trends" stations were strategically located throughout the US and were to be maintained indefinitely, pending funding, to serve as the primary source of air quality information to guide NPS air resource management decisions. Data from the "trends" network served to characterize the spatial and temporal distributions and trends of key air quality indicators on a network wide basis. These data have been used to characterize the range of values for air quality indicators, the extent to which these indicators are influenced by anthropogenic activities (internal or external to the parks), and whether any observed changes are attributable to natural variation or anthropogenic activities. A large number of the GPMP ozone monitoring stations now have over 20 years of trend data, making them some of the longest records in the US.

Early on, a fewer number of "baseline" stations were also operated with the primary purpose of documenting existing air quality levels for shorter periods (typically 3-5 years), after which time the instruments would be re-deployed to other NPS areas. The ultimate goal of the "trends and baseline" strategy was to establish existing conditions in nearly all 48 NPS Class I areas by the year 2000 and to subsequently re-visit each of the baseline sites at 5-10 year intervals to determine how air quality levels have changed with time. While the concept of "trends" stations still currently exists, the "baseline" monitoring concept was never fully implemented because of costs, and has relied on spatial interpolations using Geographic Information System (GIS) mapping in conjunction with targeted monitoring for relatively short time periods.

Short-term survey monitoring for ozone is typically carried out with portable ozone monitoring systems (POMS; Figure 2). The POMS are most often operated seasonally over a 3-5 year time period, effectively replacing the "baseline" monitoring concept. POMS are deployed to document the current air quality and evaluate impacts on the park unit. It is sometimes necessary to re-deploy measurements at a later date to evaluate how air quality has changed with time. To date, parks with significant natural resources, as determined by the Inventory and Monitoring Program, have been considered for monitoring; however, all parks may be considered as eligible candidates for air quality and pollutant monitoring. To date, 38 park units have operated POMS since 2002. Some years, as many as 15 POMS were in operation at various parks. Moreover, some park units have used the POMS in order to have collocated monitors or monitor at multiple sites within a single park unit. The greatest advantage of the POMS is that it is an easily deployable, low power system. Typically, the POMS are operated during the summer ozone season; however, some units are operated year round. For example, a 2 year study was recently conducted at Dinosaur National Monument using the POMS to investigate the impact of oil and gas production operations on ozone levels in the region. After 2 years of POMS measurements, the portable unit was replaced by a permanent, reference method analyzer for long-term regulatory measurements. As part of our goal to disseminate information in a timely fashion, data sets are posted monthly to publically accessible web sites as soon as the data are quality controlled, typically one month after the measurement period. Real time gas phase and meteorological data (1-hour averages) are available to the public at the following site: http://www.nature.nps.gov/air/data/current/index.cfm. Additionally, raw data are available upon request via a password protected web site in near real time. Finally, the historical archive can be found at the following site: http://ard-request.air-resource.com/.

As overall funds have decreased to support monitoring efforts, ARD has become increasingly more dependent on partnerships with other monitoring networks in order to maintain high spatial and temporal resolution of pollutants such as ozone. In some instances, this includes data from state sponsored monitoring programs, but the primary partners for ARD for ozone are CASTNET and the National Core (NCore) Multipollutant Network.

CASTNET is a national air quality monitoring network designed to provide data to assess trends in air quality, atmospheric deposition, and ecological effects resulting from changes in air pollutant emissions. ARD operates 25 CASTNET sites within national parks and Class I areas. CASTNET provides long-term monitoring of air quality in rural areas to determine trends in regional atmospheric nitrogen, sulfur, and ozone concentrations and deposition fluxes of sulfur and nitrogen pollutants in order to evaluate the effectiveness of national and regional air pollution control programs. While NPS ozone monitors have always been operated in a regulatory manner, it is worth noting that in 2011 all other CASTNET ozone monitors became compliant with the requirements in the Code of Federal Regulations.

NCore is a multi-pollutant network that integrates several advanced measurement systems for particles, pollutant gases and meteorology. Most NCore stations have been operating since the formal start of the network on January 1, 2011. Currently, the NCore network consists of 80 sites, of which 63 are urban and 17 are rural, a few of which are in parks (e.g., Great Smoky Mountains and Acadia NPs). The NCore focus is such that monitoring sites incorporate continuous monitoring of multiple pollutants that can be used with modeling to better understand transport issues. The ARD has partnered with the EPA and is now participating in the NCore network with park resource managers at Great Smoky Mountains NP assuming operations of the site at the park. The large spatial scale and high temporal resolution of the NCore network is beneficial to further understanding the drivers of air quality in park units.

With current overall fiscal constraints, the present monitoring network has had reductions in the number of monitoring sites, an inability to replace aging and dated equipment, and reductions in quality assurance programs. If the NAAQS for ozone is lowered, it will be essential for the NPS to maintain its current level of monitoring, and there will likely be a need to expand the GPMP network to include new sites of concern. New funding could help facilitate this expansion while also enabling aging equipment to be updated.

Atmospheric Deposition of Nitrogen, Sulfur, and Mercury

Air pollutants are deposited into the environment by wet deposition (rain, snow, and fog) and dry deposition (via settling, impaction, and adsorption) where they can harm ecological resources, including water quality, soils, plants, and animals. Nitrogen and sulfur compounds can cause the acidification of soils, lakes, and streams. Although nitrogen is an essential plant nutrient, excess nitrogen in soils and surface waters may also cause unwanted fertilization and alter plant community composition. Mercury can also be deposited from the atmosphere and bioaccumulate in the food chain. This can cause behavioral, neurological, and reproductive effects in fish, birds, and wildlife. The NPS participates in two national monitoring networks in order to obtain information on wet and dry atmospheric deposition: NADP and CASTNET.

Wet Deposition

The NADP measures atmospheric deposition and studies its effects on the environment. The NADP/National Trends Network (NTN) is a nationwide, long term precipitation monitoring network that began monitoring in 1978 with 22 sites and grew rapidly in the early 1980s. The expansion was due to the implementation of monitoring under the National Acid Precipitation Assessment Program, the purpose of which was to improve understanding of the causes and effects of acidic precipitation. Today, the network has over 250 sites spanning the continental US, Alaska, Puerto Rico, the Virgin Islands, and one site in Argentina. Of these 250 sites, 34 are located in national parks and are funded by ARD (Figure 3). Another 8 are located in parks but are funded by other partners. NADP data are widely used and were cited in over 150 peer-reviewed publications in 2013.

The NADP is a cooperative effort among many different groups, including the NPS, US Geological Survey (USGS), EPA, US Department of Agriculture-National Institute of Food Administration, State Agricultural Experiment Stations, NOAA, USFS, FWS, BLM, and numerous universities and other governmental and private entities.

Precipitation samples at each site are collected weekly and analyzed for pH, specific conductance, and sulfate, nitrate, ammonium, chloride, calcium, magnesium, potassium, and sodium concentrations by the NADP Central Analytical Laboratory (CAL) in Champaign, IL. Stringent quality assurance programs enhance data accuracy and precision. More information on these programs and the monitoring data can be found on the NADP/NTN website at http://nadp.isws.illinois.edu.

The NPS participates in other sub-networks of NADP as well, including the Mercury Deposition Network (MDN), the Atmospheric Mercury Network (AMNet), and the Ammonia Monitoring Network (AMoN), which are described below.

Dry Deposition

The CASTNET complements the NADP/NTN. Nearly all of the CASTNET sites are collocated or near an NTN site. Together, these two monitoring networks provide data necessary to estimate long-term temporal and spatial trends in total deposition (wet and dry). Currently, CASTNET operates 90 sites throughout the contiguous United States, Alaska, and Canada, providing a large spatial scale for measurements. Of these, 25 are located in national parks (Figure 3).

CASTNET is managed and operated by EPA's Clean Air Markets Division in cooperation with the NPS and other federal, state and local partners. The network was established under the 1990 Clean Air Act Amendments to assess the trends in acidic deposition resulting from emission reduction programs, such as the Acid Rain Program, NO_x Budget Trading Program, and the Clean Air Interstate Rule.

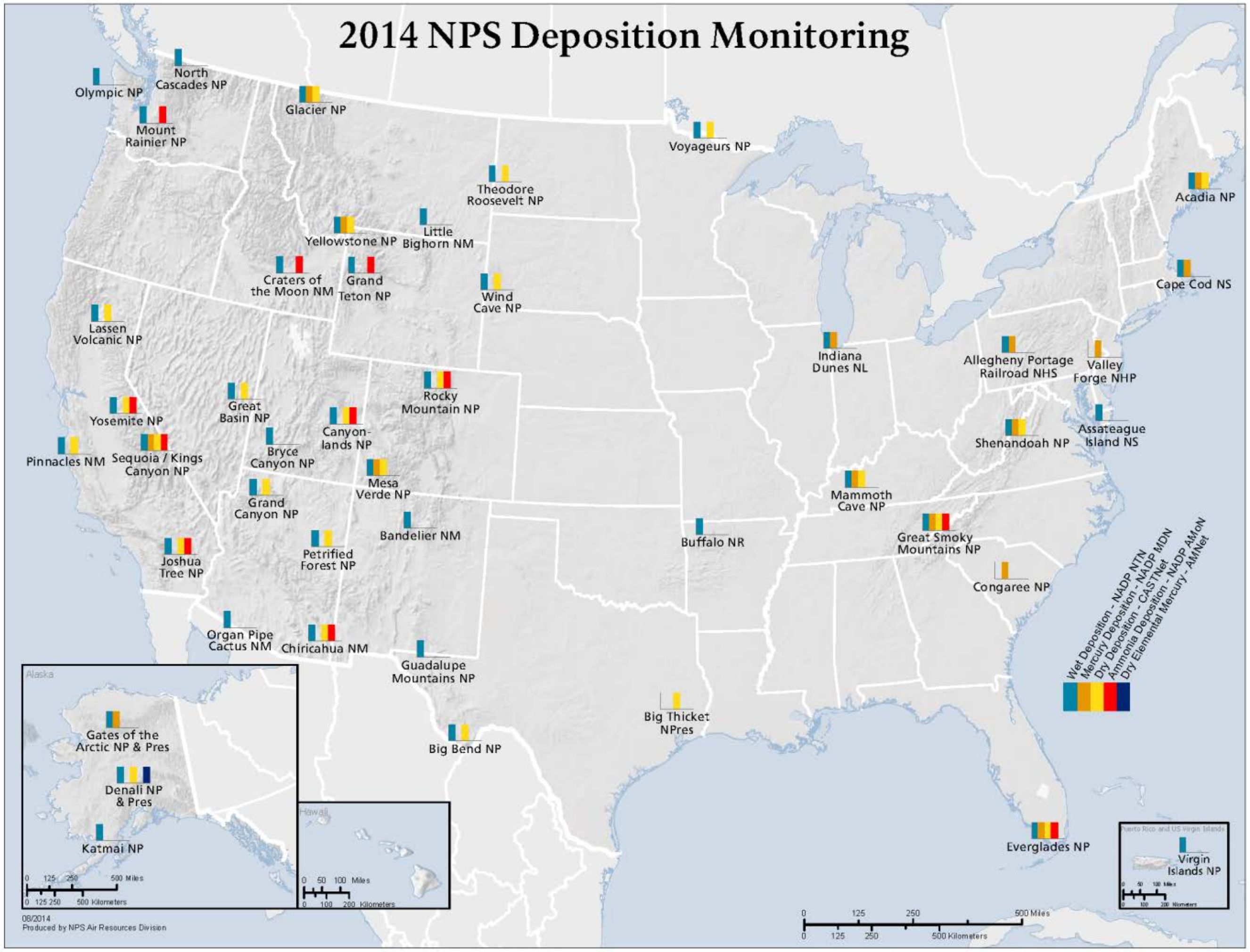

Figure 3. Map of the NPS Deposition Monitoring Sites as of September 2014.

CASTNET measures weekly ambient concentrations of sulfur dioxide, sulfate, nitric acid, nitrate, and ammonium with a 3-stage filter pack under a controlled flow rate. As mentioned above, continuous ozone concentrations are also measured at all CASTNET sites. Meteorological measurements, including temperature, wind speed and direction, sigma theta, solar radiation, relative humidity, precipitation, and surface wetness, are made at only the NPS CASTNET sites. More information on this network and the monitoring data can be found on the CASTNET website: http://epa.gov/castnet/javaweb/index.html.

In the last decade, the importance of ammonia to dry nitrogen deposition was recognized and, in 2010, the AMoN joined NADP. The network now comprises about 50 monitoring sites across the country, 10 of which are located in national parks (Figure 3). AMoN uses passive samplers that are collected every two weeks and do not require electricity or a data logger. Samplers are returned to the NADP CAL for chemical analysis and data are available on the NADP website.

Mercury Deposition

Wet and dry mercury deposition is measured by two sub-networks of NADP. MDN, which measures wet deposition, joined the NADP in 1996, and currently has over 100 sites in the US and Canada, with 15 sites in national parks (Figure 3). MDN samples are analyzed for total mercury and some for the more toxic methyl mercury on a weekly basis by the NADP Mercury Analytical Laboratory, in Seattle, WA. The AMNet joined NADP in 2009 and has 21 sites that measure atmospheric concentrations of mercury species (gaseous oxidized, particulate-bound, and elemental mercury) with an automated continuous measuring system. Denali National Park and Preserve is the only park that participates in this network and measures elemental mercury only. Data are collected with standardized methods, quality assured, and archived in a password protected data base on the NADP website.

Regional Deposition Monitoring

Five national parks participate in the USGS Rocky Mountain Snowpack Survey, measuring nitrogen, sulfur and mercury compounds in the seasonal snowpack at 60 high-elevation sites in the Rockies since 1993 (http://co.water.usgs.gov/projects/RM_snowpack). Other monitoring has included passive and surrogate surface mercury measurements at four parks in California and Nevada from 2010-2012 (Wright et al., 2014), throughfall measurements at three Pacific Northwest parks from 2005-2007 (Fenn et al., 2013), mercury in litterfall at three parks in the eastern US from 2007-2009 (Risch et al., 2011), and cloud water chemistry at Great Smoky Mountains National Park from 2005-2012 (EPA, 2012).

History and Future of Deposition Monitoring

As with all the networks, deposition monitoring has at times expanded and at other times contracted. The most recent major expansions included adding NADP/NTN sites during the Natural Resource Challenge of 2003, and adding NADP/AMoN sites in 2010. From 2007 to 2009, almost all of the NPS NADP sites replaced their aging rain gages with new digital rain gages. In times of decreasing budgets, several sites have been closed (8 NADP, 8 CASTNET, and 2 MDN), and funds transferred to parks to support monitoring duties have been reduced. New funding opportunities could be used to expand the network to new sites of concern. For example, NADP was recently added in GRTE for concerns about nitrogen deposition, and NADP and CASTNET were recently added to DINO for concerns related to the expansion of oil and gas production. Funding support is also needed in order to transition research grade measurements into those that may be applied in routine monitoring networks.

Special Studies

In contrast to long-term routine monitoring that provides information on the conditions and trends of air pollutants, the ARD initiates special studies to answer specific questions about the levels of pollutants and deposition in national parks, as well as their origin, fate and effects on ecological systems and visibility. Special studies are short-term and intensive by design. These studies often involve the assessment and refinement of existing field, laboratory and modeling methodologies to better understand and decrease uncertainties and/or costs. New monitoring and modeling methods may also be developed to provide new methods to measure pollutants suitable for inclusion in routine monitoring programs and to better simulate the fate of these pollutants. The ARD has participated in numerous special studies in parks across the country since the late 1970's (Figure 4; Appendix B, Table 1; see also http://vista.cira.colostate.edu/improve/Studies/Specialstudies.htm; and http://www.nature.nps.gov/air/studies/index.cfm). The following sections provide some examples of these types of studies.

Source Apportionment

Managing air quality in the parks requires an understanding of the origin of excess levels of pollutants. Source apportionment is thus a central issue in many ARD special studies. These studies include measurements of key aerosol and gaseous species at multiple locations surrounding the park of interest. Receptor and source oriented models are used to help analyze and interpret these data to investigate the sources and transport of pollutants. Receptor models directly use the collected data in and near the NPS unit. These methods use statistical analyses to identify patterns in the measured data that are related to source contributions. Measurements of aerosol and gaseous concentrations and deposition are also used to evaluate the skills of source-oriented models such as regional chemical transport models. Hybrid models that combine the results of both receptor modeling and chemical transport models can also be used to refine modeled source attribution estimates.

One of the earliest source attribution studies was the Pacific Northwest Regional Aerosol Mass Apportionment Study (PANORAMAS), carried out in 1984. This cooperative monitoring study, aimed at documenting levels and sources of visibility impairment in the Pacific Northwest, identified smoke as a major contributor to visibility impairment. Since then, numerous special studies have explored smoke impacts on air quality (e.g., the Yosemite Aerosol Characterization Study: YACS), including laboratory studies where detailed chemical composition measurements have been made of smoke generated from the most relevant fuels for wildfires and prescribed burns in the United States (e.g., Biogenic Smoke Study; Fire Lab at Missoula Experiments; FLAME I, II, and III; Levin et al., 2010). Other focused special studies have been implemented to better characterize the physical and optical properties of aerosols causing haze (e.g., Southeast Aerosol and Visibility Study: SEAVS). These data have been instrumental in developing the IMPROVE equation and in radiation transfer models and global models for radiation balance simulations and climate change.

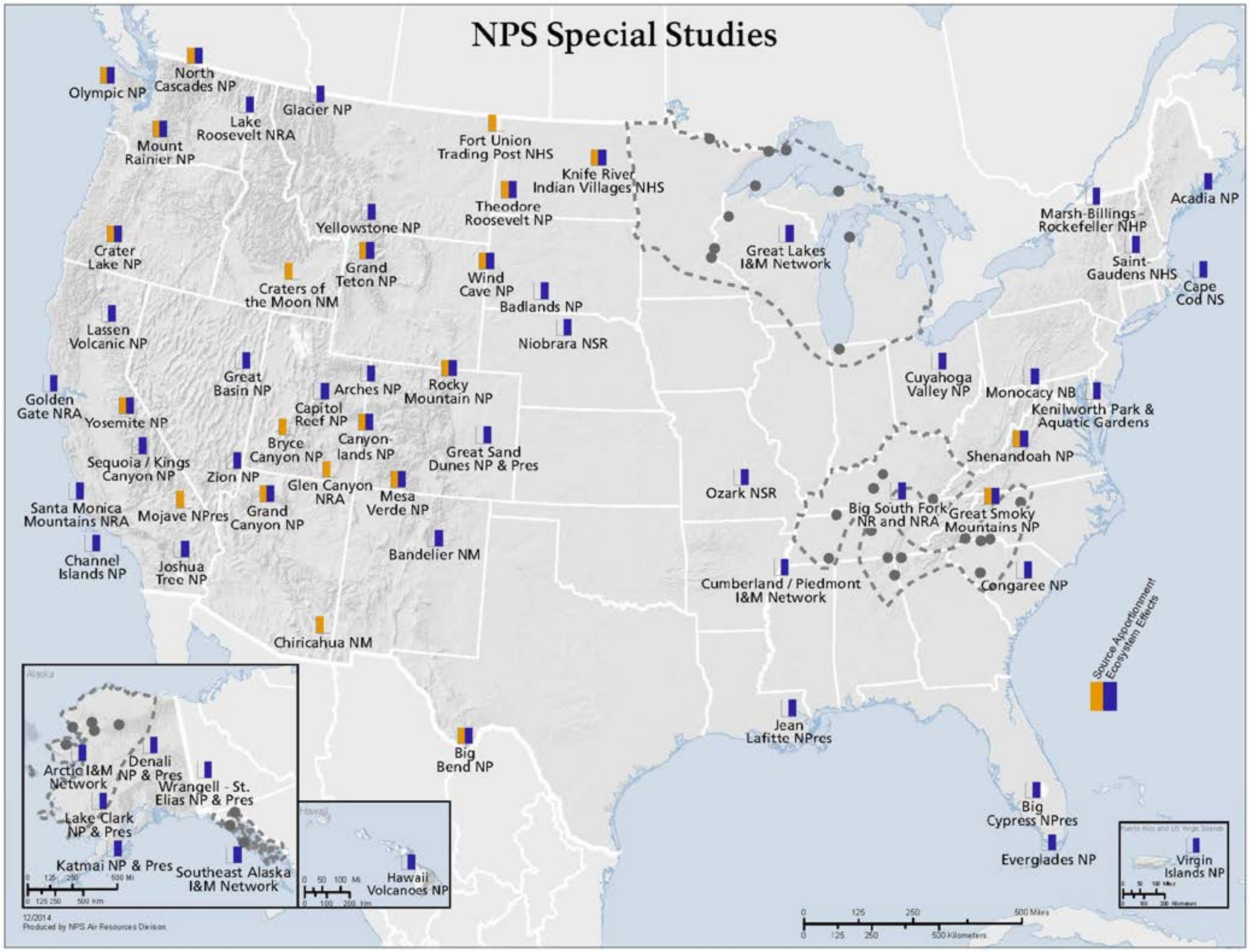

Figure 4. Map of Sites for Special Studies. In the figure, studies are broken into the broad categories of Source Apportionment and Ecosystem Effects; special studies which do not fall into either of these broad categories are not included in the figure. The gray circles represent parks that participated in special studies often through their role in the Inventory and Monitoring Network (separated by region). Many special studies also included specific objectives related to visibility, deposition, gaseous pollutants, and method development.

Other studies have focused more on anthropogenic emissions. Studies such as the Winter Haze Intensive Tracer Experiment (WHITEX), Measurement of Haze and Visual Effects (MOHAVE), and the Pacific Northwest Regional Visibility Experiment (PREVENT) were instrumental in developing source-receptor relationships that linked emissions from large coal-fired power plants to haze in national parks. The Big Bend Regional Aerosol and Visibility Observational (BRAVO; Hand et al., 2002) study identified the relative contributions of Mexico and large source regions to haze in Big Bend National Park, while the Rocky Mountain Atmospheric Nitrogen and Sulfur Studies (ROMANS I and II; Benedict et al., 2013) and the Grand Teton Reactive Nitrogen Deposition Study (GrandTReNDS; Prenni et al., 2014) helped to determine the composition and form of nitrogen deposition in Rocky Mountain and Grand Teton NPs, respectively, and the link between nitrogen deposition and source emissions of reactive nitrogen such as ammonia and NO_x. More recent studies have focused on oil and gas development and the related impacts in the Bakken region near Theodore Roosevelt National Park and in Rocky Mountain National Park.

Ecosystem Effects

The ARD participates in and initiates studies that assess the effects of air pollutants on soils, surface waters, vegetation, and wildlife in units of the national park system (e.g. Eagles-Smith et al., 2014). Pollutants affect park ecosystems in the following ways: ozone can cause injury and growth reductions in trees and other plants; nitrogen and sulfur deposition can change soil and water chemistry, affecting plant nutrient availability and damaging aquatic biota; nitrogen deposition can also act as a fertilizer, often favoring non-native plant species; and toxic contaminants such as mercury, pesticides, and industrial by-products can be deposited in park ecosystems where they can bioaccumulate to toxic levels in fish and other wildlife. In addition, these pollutants can act synergistically causing multi-stressor impacts to natural areas.

Researchers and NPS managers work together in parks to develop a better understanding of how pollutants move through ecosystems, and to determine the locations, magnitude, and types of risks to resources posed by these pollutants. Special studies assessing ecological effects of air pollutants usually last from 1-3 years, but sometimes can take place over longer timeframes. Projects often involve partnerships with other federal agencies such as the USFS or USGS, or universities.

Examples of recent special studies evaluating air pollution impacts to national park resources include studies over a large spatial scale, such as the Appalachian Trail MEGA-Transect Atmospheric Deposition Effects Study, which examines soils, surface waters and plants along ridge top areas in the eastern US to evaluate their condition and vulnerability to future additional damage; and a nationwide assessment of mercury in dragonfly larvae which tasked citizen scientists with collecting field samples to help identify patterns and risk of mercury accumulation in park ecosystems. Examples of more local-scale studies include an assessment of how nitrogen deposition may foster establishment of invasive weeds in the southern California Santa Monica Mountains; and exploring how atmospheric deposition of nitrogen in Grand Teton National Park may be changing aquatic biota in alpine lakes. Results from these studies are made available to the public through the NPS Integrated Resource Management Applications (IRMA) system, and include project final reports, and peer-reviewed journal articles (https://irma.nps.gov/App/Portal/Home).

Appendix B. Special Studies led or funded by ARD

Table 1. Special Studies led or funded by ARD. The authors note that this table is not all inclusive, but rather highlights many of the studies in which ARD has participated.

Special Study	Year(s)	Participating Parks
Assessing the Effects of Nitrogen Deposition on High-Elevation Plant and Soil Communities	2012 – present	MORA, NOCA, OLYM
Assessing the Impact of Mercury Bioaccumulation in Cumberland Piedmont Park Units	2007 – 2009	ABLI, BISO, CUGA, MACA
Assessing the Risk of Nitrogen Deposition to Natural Resource Units in the Four Corners Region of Colorado and Utah	2014 – present	MEVE, ARCH
Assessment of Nitrogen Deposition and its Possible Effects on Alpine Vegetation in Grand Teton National Park	2006 – 2007	GRTE
Atmospheric Deposition in Complex Terrain: Scaling Up to the Landscape at ACAD and GRSM	2002 – 2003	ACAD, GRSM
Atmospheric Deposition of Inorganic Nitrogen in Grand Teton NP: Determining Biological Effects on Algal Communities in Alpine Lakes	2009 – 2012	GRTE
Atmospheric Nitrogen Deposition Assessment in the Santa Monica Mountains NRA and the Effects on Weed Invasion	2011 – present	SAMO
Bakken Air Quality Study	2013 – 2014	FOUN, KNRI, THRO
Big Bend Regional Aerosol and Visibility Observational Study (BRAVO)	1999	BIBE
Characterize Aquatic AQRVs Potentially Affected by Atmospheric Deposition and Develop Long-Term Monitoring Protocols to Track and Refine the AQRVs at Mount Rainier and North Cascades	2004 – 2005	MORA, NOCA
Critical Loads for Atmospheric Deposition in the Sierra Nevada	2007 – 2009	SEKI, YOSE
Determine Adaptive Potential of Mojave Desert Plants to Nitrogen Deposition and Invasion at Joshua Tree National Park	2010 – 2014	JOTR
Determine Critical Nitrogen Levels on Growth, Litter Persistence and Germination of Plants at Joshua Tree NP	2007 – 2009	JOTR
Determine Critical Nitrogen Loads to Boreal Lake Ecosystems using the Response of Phytoplankton	2008 – 2011	ACAD, ISRO
Determine Sensitivity of High Elevation Lakes to Nitrogen Deposition through Nutrient Enrichment Experiments	2013 – present	MORA, NOCA, OLYM
Determine Spatial and Elevational Distribution of Atmospheric Nitrogen Deposition in Soils	2011 – 2014	BIBE

Table 1. Special Studies led or funded by ARD. The authors note that this table is not all inclusive, but rather highlights many of the studies in which ARD has participated.

Special Study	Year(s)	Participating Parks
Determine the Impacts of Aluminum Toxicity and Calcium Loss on Threatened High-Elevation Spruce Fir in Great Smokies NP	2007 – 2009	GRSM
Develop Screening Procedures and Sampling Protocols for Assessment of Deposition-Sensitive Surface Waters in the Rocky Mountains	2005	GLAC, GRSA, GRTE, ROMO, YELL
Dragonflies, Mercury, and Citizen Scientists in Parks	2014 – present	ACAD, BICY, CACO, CHIS, DENA, GRSM, MABI, MACA, NOCA, ROMO, SACN, SAGA
Effects of Atmospheric Nitrogen Deposition on Sagebrush Steppe Vegetation Dynamics at Upper Columbia Basin Network Parks	2009 – 2012	CRMO
Effects of Atmospheric Pollutants on Invasibility of Panne Vegetation by Invasive Plants at Indiana Dunes National Lakeshore	2004 – 2007	INDU
Evaluating Effects of Nitrogen Deposition and Ambient Ozone on an Invasive Plant in the National Capital Region	2008 – 2011	NCRO
Front Range Air Pollution and Photochemistry Éxperiment (FRAPPÉ)	2014	ROMO
Grand Teton Reactive Nitrogen Deposition Study (GrandTReNDS)	2011	GRTE
Great Smoky Mountains Ammonia Study	2004	GRSM
Impacts of Anthropogenic Nitrogen Deposition on Weed Invasion, Biodiversity and Fire Cycles at Joshua Tree NP	2003 – 2005	JOTR
Impacts of Atmospheric Nitrogen and Climate Change on Desert Ecosystems in Big Bend NP	2003 – 2005	BIBE
Impacts of Sediment Microbial Community Structure on Mercury Methylation at Congaree NP	2005 – 2006	CONG
IMPROVE Coarse Mass Speciation Study	2003 – 2004	GRCA, GRSM, MORA, SEKI
IMPROVE Reduced Nitrogen Study	2011 – 2012	BAND, CHIR, GLAC, MEVE ROMO, WICA, YELL
Long-term Data on Alpine Plants: Is Atmospheric Nitrogen Affecting Species Composition in Rocky Mountain and Glacier NPs?	2005 – 2007	GLAC, ROMO
Measurement of Haze and Visibility Effects (MoHaVE)	1992	GRCA

Table 1. Special Studies led or funded by ARD. The authors note that this table is not all inclusive, but rather highlights many of the studies in which ARD has participated.

Special Study	Year(s)	Participating Parks
Mercury in Fish from 21 Western and Alaskan National Parks	2008 – 2012	CARE, CRLA, DENA, GLAC, GLBA, GRBA, GRCA, GRSA, GRTE, LACL, LAVO, MEVE, MORA, NOCA, OLYM, ROMO, SEKI, WRST, YELL, YOSE, ZION
Methylmercury Exposure of Songbirds in Mercury-Sensitive Landscapes of Voyageurs NP	2012 – 2014	VOYA
Modeling the Timeline for Acidification from Excess Nitrogen Deposition in Rocky Mountain NP	2002 – 2004	ROMO
Monitoring Air Quality in the Southeast Alaska Network: Linking Ambient and Depositional Pollutants with Ecological Effects	2008 – 2010	GLBA, KLGO, SITK
Navajo Generating Station Visibility Study (NGS)	1990	GRCA
NPS-wide Studies of Mercury in Biota, including regional studies	2008 – 2014	ACAD, BIBE, CACO, CARE, CRLA, CUVA, DENA, GLAC, GLBA, GOGA, GRBA, GRCA, GRSA, GRSM, GRTE, JELA, KEAQ, KNRI, LACL, LAVO, MABI, MACA, MEVE, MONO, MORA, NIOB, NOCA, OLYM, OZAR, PIRO, ROMO, SACN, SAGA, SEKI, VOYA, WRST, YELL, YOSE, ZION
Ozone Injury Survey at Rocky Mountain NP	2006	ROMO
Ozone Pollution Damage to Growth and Physiology of Native Trees and Wildflowers in Great Smoky Mountains NP	2002	GRSM
Pacific Northwest Contaminant Mapper		CRLA, LARO, LAVO, MORA, NOCA, OLYM, SEKI, YOSE
Pacific Northwest Regional Aerosol Mass Apportionment (PANORAMAS)	1984	CRLA, CRMO, MORA, OLYM
The Pacific Northwest Regional Visibility Experiment (PReVEnt)	1990	MORA, NOCA, OLYM
PERCEPTION Visibility Study	1979	CANY, GRCA, MEVE

Table 1. Special Studies led or funded by ARD. The authors note that this table is not all inclusive, but rather highlights many of the studies in which ARD has participated.

Special Study	Year(s)	Participating Parks
Park Research and Intensive Monitoring of Ecosystems Network (PRIMENet)	1996 – 2004	ACAD, BIBE, CANY, DENA, EVER, GRSM, GLAC, HAVO, OLYM, ROMO, SHEN, SEKI, THRO, VIIS
Remote Sensing of Ozone Uptake in Ponderosa and Jeffrey Pine Forests in Sequoia, Kings Canyon, and Yosemite NPs	2002 – 2003	SEKI, YOSES
Research on Operations Limiting Visual Extinction (RESOLVE)	1983 – 1985	MOJA
Rocky Mountain Atmospheric Nitrogen and Sulfur Studies (ROMANS I and II)	2006, 2008, 2009	ROMO
Rocky Mountain Snowpack Survey	1993 – present	GLAC, GRSA, GRTE, ROMO, YELL
Shenandoah Visibility Study	1991	SHEN
Songbirds as Indicators of Mercury in National Park Ecosystems	2012 – 2013	GRTE, MORA, YOSE
The Southeastern Aerosol and Visibility Study (SEAVS)	1995	GRSM
Studies of Contaminants in Fish from Western Parks, including regional studies	2002 – 2013	CARE, CRLA, DENA, GAAR, GLAC, GLBA, GRBA, GRCA, GRSA, GRTE, LACL, LAVO, MEVE, MORA, NOAT, NOCA, OLYM, ROMO, SEKI, WRST, YELL, YOSE
Sub regional Cooperative Electric Utility, Department of Defense, National Park Service, and EPA Study (SCENES)	1984 – 1989	CANY, GRCA, MEVE
The Effects of Ozone and Climate on Tree Growth, Water Use, Soil Moisture Content, and Streamflow in Great Smoky Mountains NP	2001 – 2003	GRSM
The Impact of Atmospheric Nitrogen Deposition on Lichen Communities in Yosemite NP	2010 – 2012	YOSE
Western Airborne Contaminants Assessment Project (WACAP)	2002 – 2007	BAND, BIBE, CRLA, DENA, GAAR, GLAC, GLBA, KATM, LAVO, MORA, NOAT, NOCA, OLYM, ROMO, SEKI, WRST, YOSE
Winter Haze Intensive Tracer Experiment (WHITEX)	1987 – 1990	BRCA, CANY, GLCA, GRCA

Table 1. Special Studies led or funded by ARD. The authors note that this table is not all inclusive, but rather highlights many of the studies in which ARD has participated.

Special Study	Year(s)	Participating Parks
The Yosemite Aerosol Characterization Study (YACS)	2002	YOSE

Shenandoah National Park. Photograph courtesy of Shenandoah National Park.

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