Critical Loads and Levels: Leveraging Existing Monitoring Data

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Abstract—*A snapshot of current air quality in the National Parks and Wilderness areas of the US is presented based on data from the 165 site Interagency Monitoring of Protected Visual Environments, or IMPROVE program, and other relevant air quality monitoring programs. This snapshot is provided using the VIEWS web service, an on-line web-based data warehouse, analysis, and delivery system for visibility and atmospheric aerosols. The relevance of these data to inform development of a proposed new program of Critical Loads and Levels will be discussed.*

Introduction

In the United States, land management agencies such as the USDA Forest Service and various Department of Interior agencies (National Park Service, National Fish and Wildlife Service, Bureau of Land Management, and others) have responsibility to manage the country's natural resources. These land managers are authorized through specific legislation to monitor various aspects of the resources they manage. However, monitoring the potential effects of air pollution on these natural resources is a relatively new challenge and one that invokes a shared responsibility between land managers, and state and federal environmental agencies. One result of this is uneven monitoring with variable coverage and quality between components. A recent National Research Council (NRC) report, Air Quality Management in the United States (National Research Council 2004, p. 11), identified "Protecting Ecosystem Health" as one of seven major air quality challenges facing the United States in the coming decade. Specifically the NRC report states:

"Although mandated by the Clean Air Act, the protection of ecosystems affected by air pollution has not received appropriate attention in the implementation of the act. A research and monitoring program is needed that can quantify the effects of air pollution on the structure and function of ecosystems. That information can be used to establish realistic and protective goals, standards, and implementation strategies for ecosystem protection."

In this paper we review some of our experiences in protecting ecosystems from air pollution effects over the past 27 years since passage of the 1977 Amendments to the Clean Air Act. These Amendments formally addressed protection of some of the nation's ecosystems by designating 156 mandatory Class 1 Areas (federally managed wilderness and national parks above certain minimum sizes that existed when the Act passed). For Class 1 areas, federal land managers are given an "affirmative responsibility" to protect their "air quality related values (including visibility)." Land managers have responded with a number of different monitoring activities. Many involve inventory of the resources and are site, region, and agency specific. Only one monitoring network, IMPROVE, collects national, multi-agency, quality controlled data actually used in the regulatory process. As such IMPROVE represents an example of the type of monitoring the NRC report requests. However, before reviewing IMPROVE and its data, we will briefly review air pollution effects on ecosystems identifying the components needed to develop critical levels and loads for their protection.

Conceptual Models of Air Pollution Impacts on Ecosystems

The USDA Forest Service, in response to the Clean Air Act, developed a conceptual model of air pollution impact on the Class 1 areas they manage (Fox and others 1989). This included an early effort to identify key monitoring activities needed for identifying and documenting the condition of Class 1 area "air quality related values" (Fox and others 1987). Recently, an interagency Federal Land Manager Air Quality Related Values WorkGroup (FLAG) reviewed, revised, and updated the early conceptual model (http://www.fs.fed.us/r6/aq/natarm/Flag_final.pdf).

The conceptual model of Class 1 area air pollution impacts, as originally conceived, focused on:

- *visibility* (aerosol concentrations in and around the Class 1 areas);
- *ozone*, the only one of the nationally established "criteria" pollutants known to impact vegetation at concentrations routinely measured in Class 1 areas, and;
- *sulfur and nitrogen deposition* because of both their potential for acidifying surface waters and soils as well as their nutrient value.
- Certainly there are additional aspects of air pollution that have an impact, particularly deposition of metals and concentrations of "toxic" air pollutants; however, they tend to be isolated and site specific and so require special attention on a case by case basis.
- At any rate the original conceptualization has proven robust. It is similar to the framework developed by the UNECE Convention on Long-range Transboundary Air Pollution and the International Cooperative Programme (ICP) it has spawned (ICP 2004). The ICP has taken the concept further by developing and mapping so called *critical levels* and *critical loads*. *Critical levels* and *critical loads* are determined on an ecosystem basis, considering ecosystem specific biology and biogeochemistry as well as sensitivities in conjunction with ambient concentrations and deposition levels. Critical values are defined as threshold levels above which significant aspects of the ecosystem may not be sustainable. Obviously, there are mixes of both science and value judgment that must go into quantifying *critical loads* and *critical levels*. Setting these numerical values is not the subject of this paper.

Here we wish to consider a general procedure that has been used in Europe (fig. 1, IPC 2004.) In this procedure, there are clear needs for data capable of providing statistically accurate spatial and temporal patterns of air

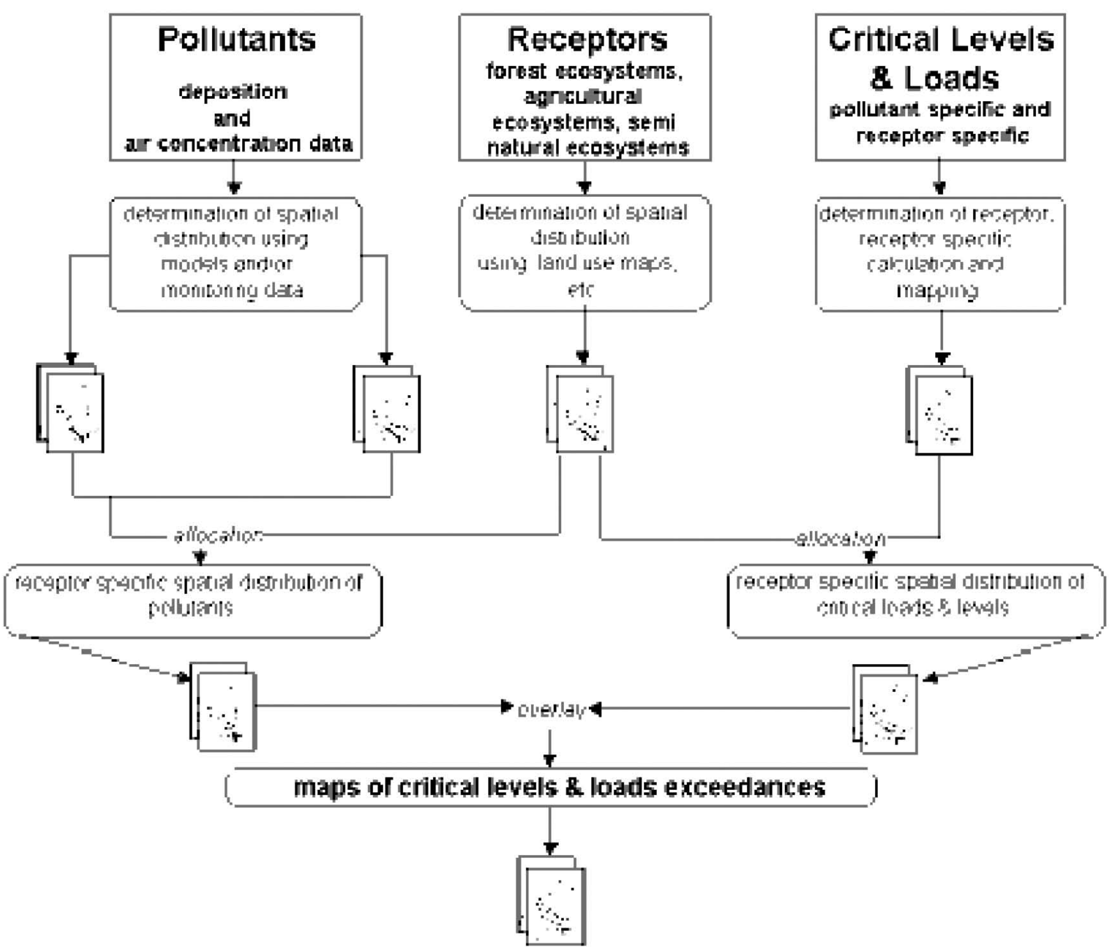

Figure 1. The steps in constructing critical loads and levels as employed by the UNECE's ICP (ICP 2004).

pollution, data providing equivalently accurate spatial maps of ecosystems and land cover, and conceptual models able to link pollution levels with specific ecosystems impact mechanisms.

In this paper we will focus only on the first of these three requirements, namely the air quality monitoring data that are currently available in the United States. We will briefly review the current status of rural air quality in the United States, presenting a snap shot of present data from the IMPROVE, NADP, and ambient air quality networks. But first, to provide this snap shot, we will use the capabilities and resources of the VIEWS, which will be presented in some detail. Finally we will present a brief discussion of the relevance of this type of data to enhanced ecosystem impact monitoring and specifically, to the implementation of a US version of the ICP critical loads monitoring.

Views

The Visibility Information Exchange Web System (VIEWS) mission is to facilitate the analysis and use of aerosol and atmospheric pollution data in a public web-based environment to improve understanding and knowledge about air quality and its improvement. VIEWS is supported collaboratively by five RPOs that assist regional bodies of states and tribes in their efforts to address regional air quality problems in general and the EPA's Regional Haze Rule in particular. VIEWS provides custom data products based primarily on IMPROVE data and designed to assist states in the regulatory process. Also available from VIEWS are supporting datasets of general interest to regional haze impacting National Parks, Wilderness areas, and other scenic areas.

To support the RPOs data requirements, the VIEWS web site is designed to provide organized, comprehensive, and convenient access to data and data products relevant to the Regional Haze Rule and general visibility issues. This information can be accessed by users in an ad-hoc manner and can be returned in a variety of formats, including graphically and as formatted text files. Most data products obtained from the VIEWS web site are generated dynamically from the VIEWS database.

Behind the scenes VIEWS supports a robust and efficient SQL database system designed to acquire and manage large amounts of air quality data. To date, datasets from IMPROVE and over 20 other monitoring programs are included. All data in VIEWS have undergone a series of integrity checks and are described by common metadata and data structure. This 'data homogenization' process produces a truly integrated database optimized for efficient retrieval and meaningful comparisons.

The Visibility Information Exchange Web System (VIEWS) home page, http://vista.cira.colostate.edu/views, is shown in figure 2. Below the VIEWS logo are quick links to data resources and information, such as user's guides, news and bulletins, and a current dataset inventory. The left-hand navigation bar provides links to the main web site sections. Descriptions of the content and capabilities of the main VIEWS sections are presented following the top-down organization of the left hand navigation bar.

Data and Metadata

The data and metadata section provides access to the integrated air quality datasets and related metadata in VIEWS. These resources are available via links from the *All Data* section or via the interactive *Metadata* and *Query Wizard* tools. The *Metadata Browser* is an interactive graphical browser used to display monitoring site locations and land features in a web-based Geographical Information System (GIS). This tool provides a map with zoom and pan capabilities, high-resolution geographical layers, and provides tabular metadata for single or multiple monitoring sites. The Metadata Browser incorporates the *active layer* concept common to GIS applications in which the user can select monitoring sites from an active geographical layer. For example, if the active *Counties* layer is selected, clicking on the map within a given county will select metadata for all sites in that county. Unique to VIEWS is the ability to select a Class I area and display metadata for the representative IMPROVE monitoring sites, even if that site is not physically within the Class I area boundaries. In its tabular output, the Metadata Browser provides links to the *Site Browser* tool. The Site Browser contains detailed monitoring site metadata, links to topographic maps, and photographs of many IMPROVE sites.

The *Query Wizard* tool allows users to retrieve data by selecting a subset of monitoring sites, measured parameters, and time ranges from the VIEWS integrated database. Users are provided options to download data and metadata from multiple monitoring programs and select from a variety of output formats, including text files and charts.

The *ASCII Data* page provides links to a variety of files containing raw IMPROVE aerosol data and associated metadata. These data are provided in simple text format to allow easy access to relevant information.

The *Annual Summary* section of VIEWS provides access to data products in support of states' requirements to comply with the Regional Haze Rule. These

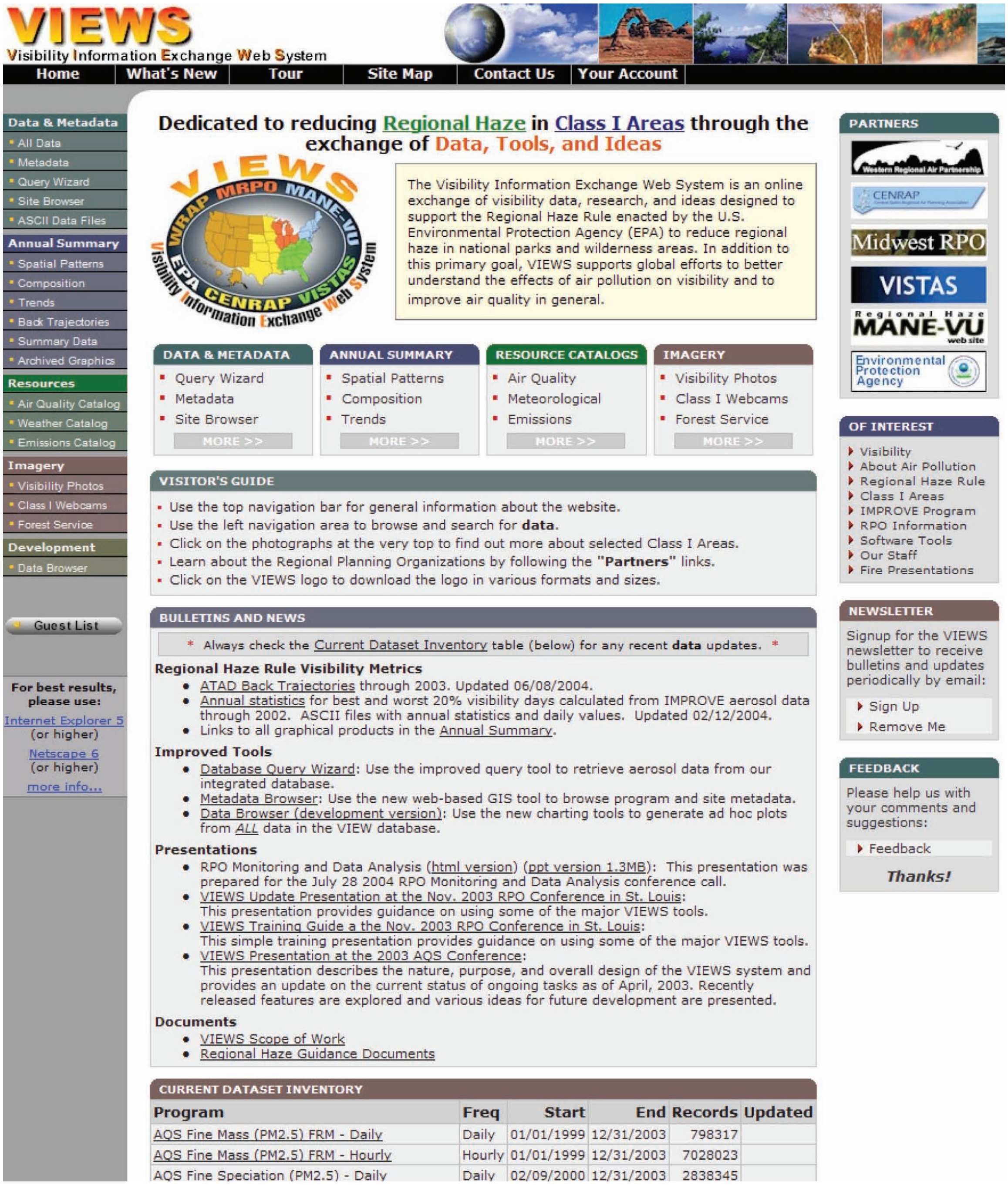

Figure 2. VIEWS home page.

data products include graphical summaries based on IMPROVE aerosol data. The *Annual Summary* data products are updated on a yearly basis as each complete year of IMPROVE data become available. Calculated visibility metrics catered to the Regional Haze Rule include the annual and 5-year mean of the best and worst 20 percent visibility days expressed in deciviews. Other parameters available from the Annual Summary are annual and seasonal means and a host of measured and calculated parameters based on IMPROVE aerosol data. Annual Summary data products are available via a series of graphical interfaces. These interactive web pages display visualizations of aerosol spatial patterns, composition information for specific data aggregations, trend lines of annual and multi-year time periods, and back-trajectories to indicate air mass source regions during specific days and haze events.

Rural Air Quality in the US

The primary data resource for VIEWS is the IMPROVE network. IMPROVE, the Interagency

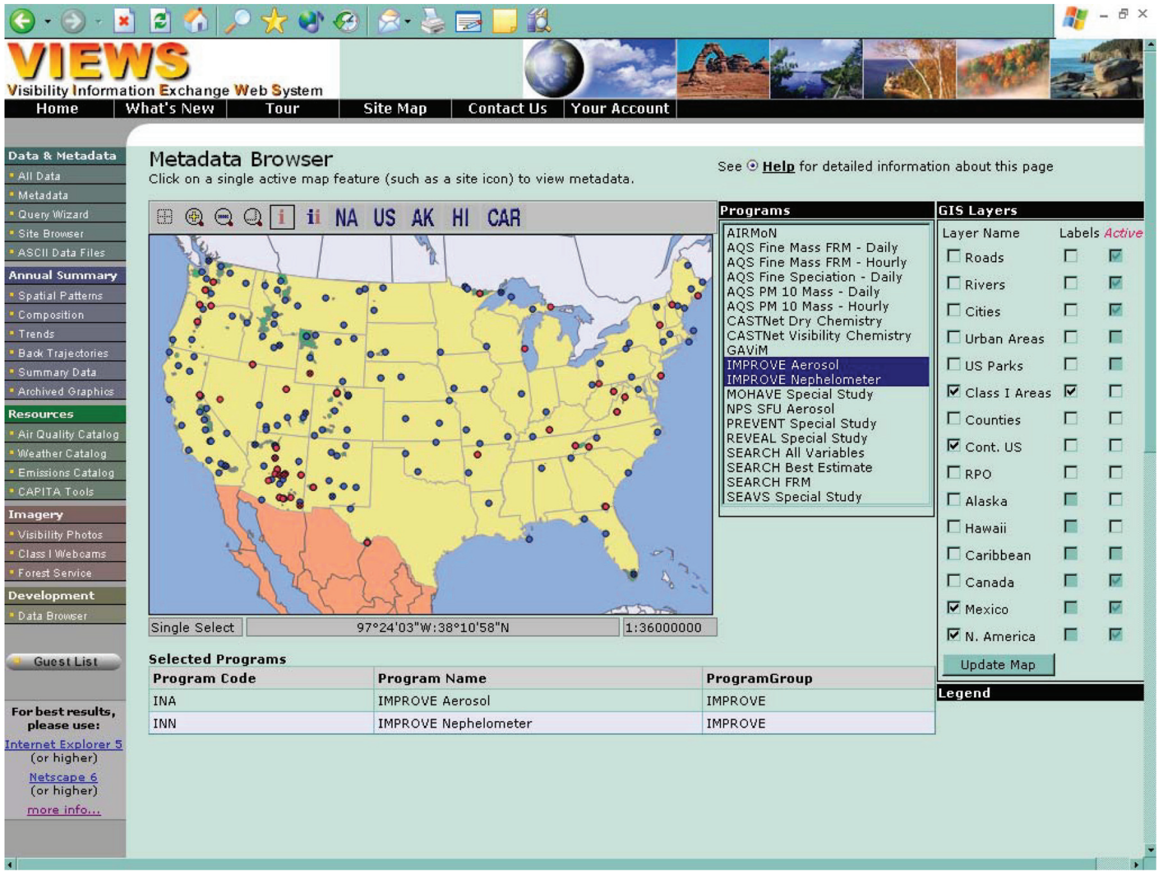

Figure 3. Class 1 areas and IMPROVE aerosol and visibility monitoring sites as presented in the VIEWS metadata browser.

Monitoring of Protected Visual Environment program, is a comprehensive monitoring program, supported by the EPA and federal land managers, to assess visibility and the chemical aerosols that degrade it at the 156 Clean Air Act Class 1 areas in the United States. Details about the IMPROVE program can be found on the VIEWS web site. The network includes 165 sites measuring fine particle aerosols and their chemical speciation every third day through out the year. Optical monitoring is also conducted at a subset of the aerosol sites facilitating the linkage between aerosol measurements and visibility. IMPROVE has been operating since 1988, but has only expanded to its current 165 sites since 2002. Figure 3 taken from the VIEWS metadata browser illustrates the current IMPROVE network along with the Class 1 areas in the continental US. The IMPROVE data include over 40 measured chemical components of the measured aerosol and some 17 calculated values based on the measurements. These data, all coming from rural locations selected to be representative of Parks and wilderness, represent a unique resource to provide information about the status of rural air quality in the US.

Without going into the details of how visibility is related to the concentration of aerosol chemical species, a simple view of visibility quickly indicates the Class 1 areas that are most likely impacted by air pollution. Figure 4 illustrates visibility from the latest year for which full data are available (2002). The current average, best (the best 20 percent of measured days) and worst (the worst 20 percent) standard visual ranges are mapped. The pattern of pollution displayed by these maps suggests that the worst rural air quality in the US is expected in the eastern central US and on the southwestern coast. The cleanest air is anticipated in the western interior regions of the country.

In addition to visibility, the conceptual impact model mentioned above addresses the deposition of sulfur and nitrogen. While IMPROVE does not measure deposition, it does measure concentrations that are related to dry deposition through often complex aerodynamic considerations. A simplified approach, that has been widely used, is to relate the concentration to dry deposition through a parameter called deposition velocity. While deposition velocity ranges from zero to quite high numbers on a diurnal basis, nevertheless dry deposition is at least expected to correlate with concentration. The IMPROVE network measures sulfur and nitrogen as their ammoniated aerosol components because it is as ammonia sulfate and

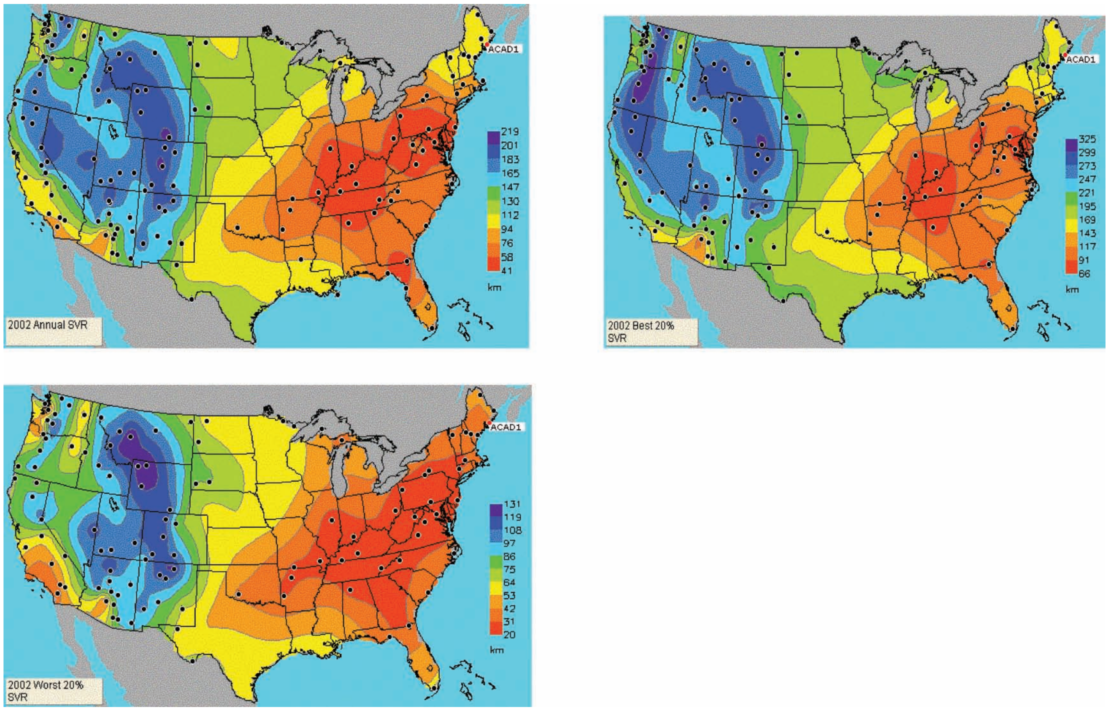

Figure 4. Visibility reported in kilometers of standard visual range (SVR) indicates how far one can see in each location. SVR has an inverse relationship with the extinction coefficient which is related to aerosol chemical concentrations and humidity.

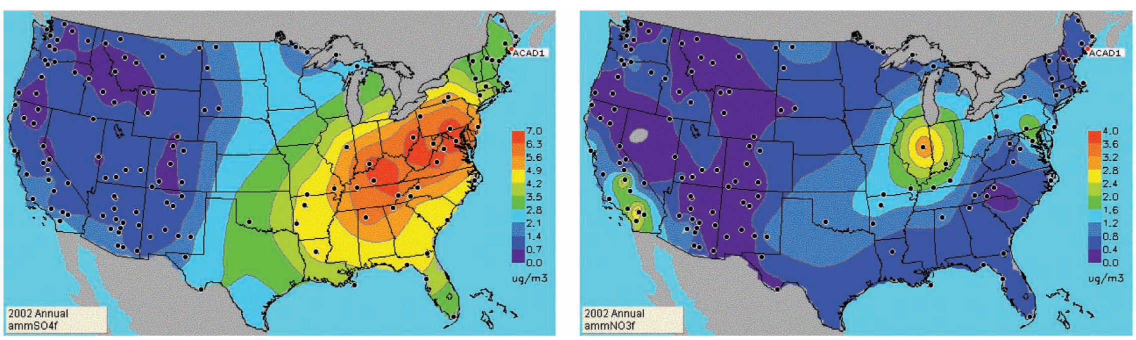

Figure 5. IMPROVE average measured ammonia sulfate and ammonia nitrate aerosol concentrations from 2002.

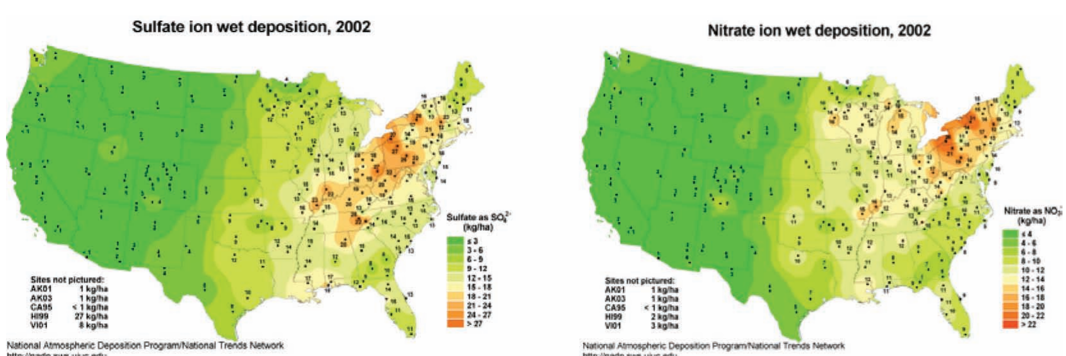

Figure 6. NADP measured sulfate and nitrate wet deposition in 2002.

ammonia nitrate that they generally are found in rural areas. Figure 5 shows the 2002 annual average concentrations of ammonium sulfate and ammonium nitrate.

A second component of deposition is so called wet deposition. Again while there are complex relationships with precipitation and wet deposition, it is reasonably approximated by measuring the chemistry of rain and snow collected in buckets. This is precisely what the National Atmospheric Deposition Program does at over 200 sites located around the US (http://nadp.sws.uiuc.edu/). Figure 6 presents wet deposition data from 2002 for sulfate and nitrate ion. There is also a network of dry deposition measurements, the Clean Air Status and Trends (CASTnet) network, that measures in rural areas, ambient aerosol, and gaseous concentrations, as well as relevant meteorological parameters to calculate dry deposition. CASTnet data are available for download from VIEWS. Figure 7 presents sulfur and nitrogen total deposition based on NADP and CASTnet data at National Park sites around the country for 2002 (http://www2.nature.nps.gov/air/Monitoring/drymon.htm).

Ozone is monitored by a large network of samplers in support of the EPA's National Ambient Air Quality Standard for that pollutant. There are over 4,000 State and Local Air Monitoring Stations(SLAMS) in this network; however, primarily monitors are sited to measure impacts on human health and are thus strongly biased toward urban areas. More characteristic of natural resources, the National Park Service monitors ozone in a number of National Parks (http://www2.nature.nps.gov/air/data/current/index.htm) and these results are displayed on the National Park Service web site in real time (fig. 8). A comprehensive picture of current and forecast air quality is available from EPA's AirNow web site (http://www.epa.gov/airnow/index.html). Figure 9 illustrates AirNow's presentation by showing the peak ozone concentrations that occurred on August 11, 2002.

Forest Service researchers have deployed networks of passive ozone samplers in forest areas, especially in California (Byterowicz and others 2003). These monitors have the capability of providing a more integral picture of ozone impacts on ecosystems.

Relevance to Critical Loads and Levels

The monitoring data that we have briefly outlined is needed before it will be possible to estimate critical loads. This is one, and only one component, of the critical steps in developing critical loads and levels. However, we hope we have illustrated that air quality monitoring data are available although not necessarily available in one location. The VIEWS web service has significant potential to display and allow manipulation of the data resources needed to project current air quality, the first of the three sets of knowledge displayed in figure 1 as being needed.

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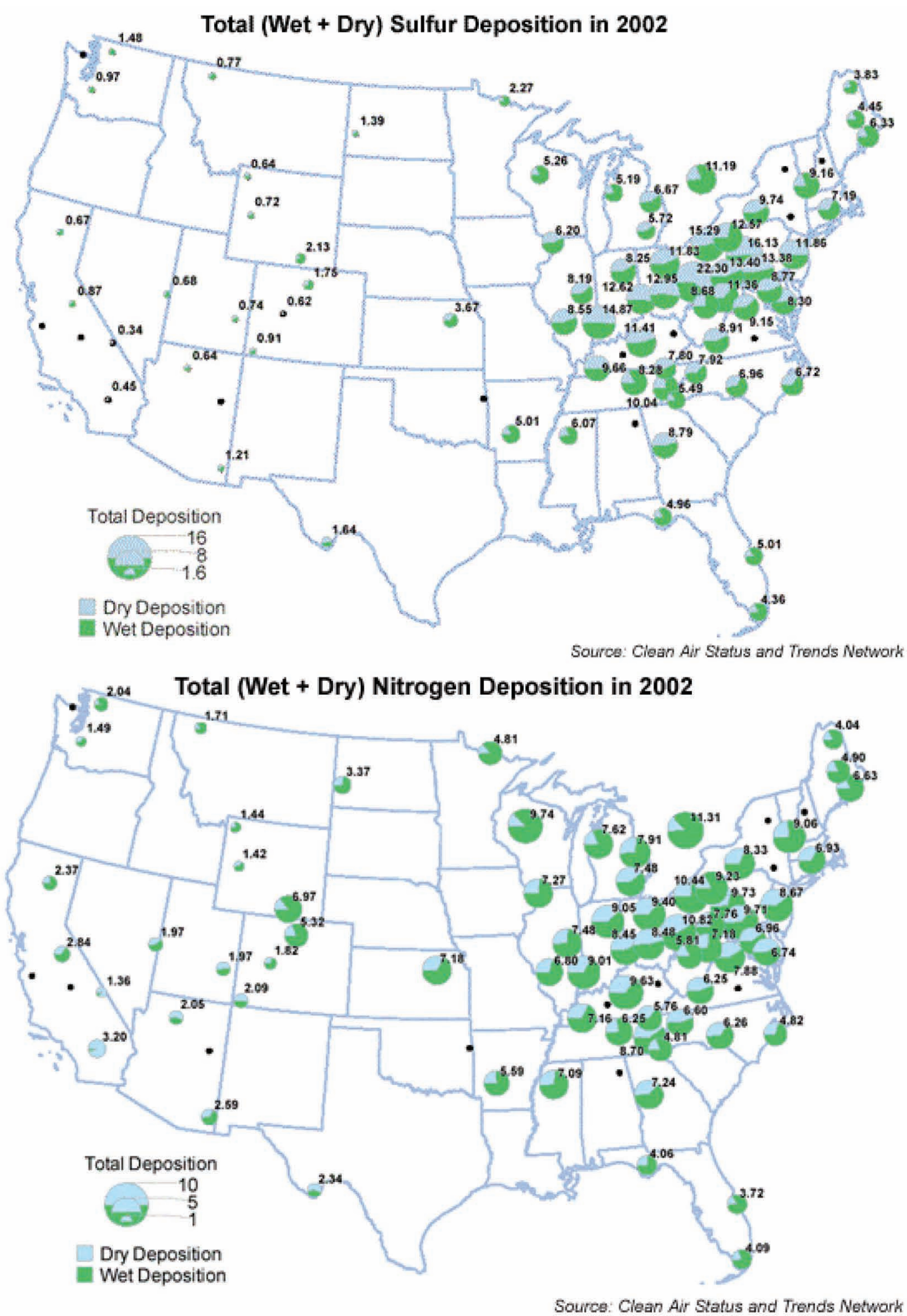
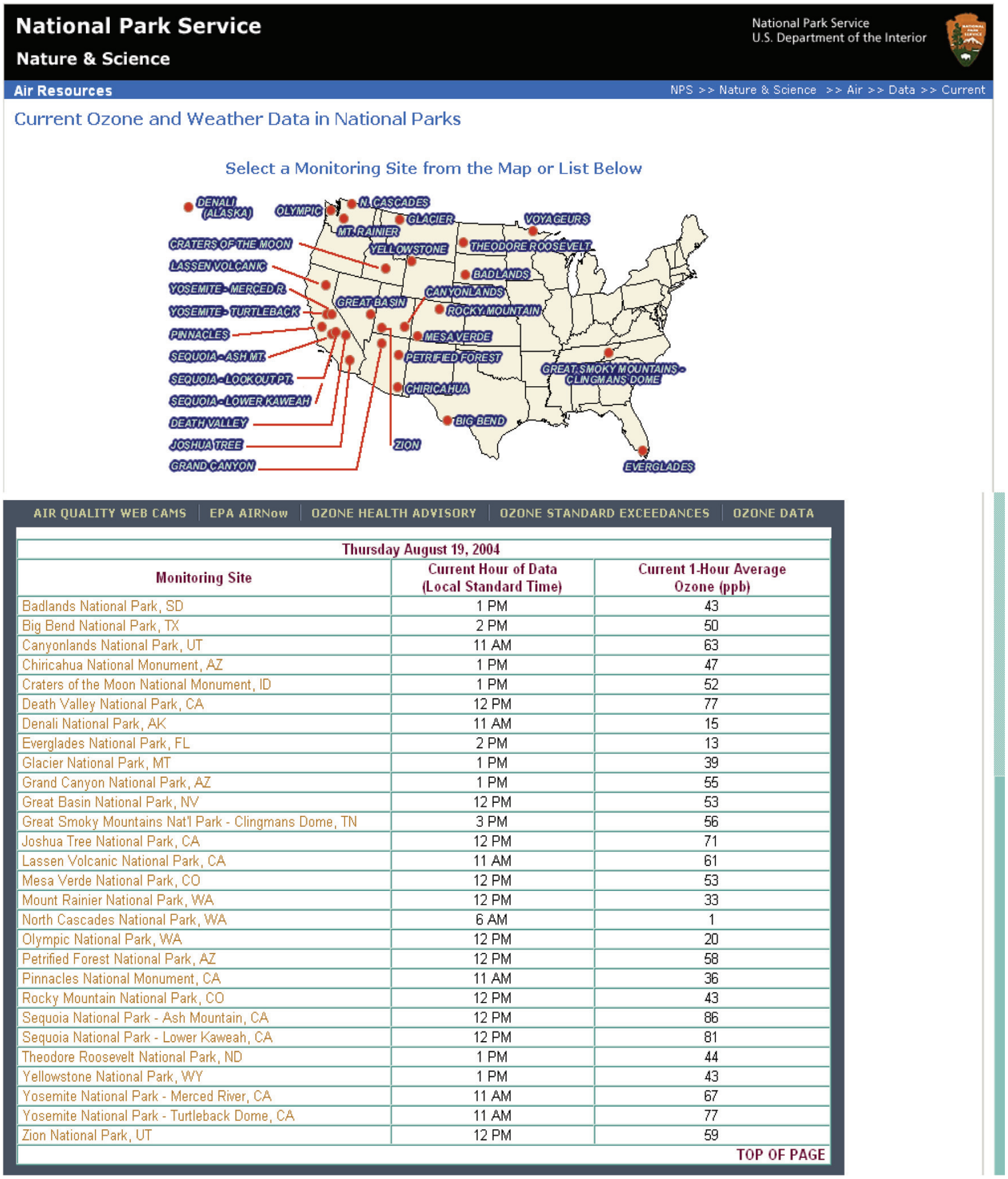


Figure 7. Total (wet-green and dry-blue) deposition at CASTnet sites in the US. Data are kilograms per hectare per year of sulfur and nitrogen deposition (from NPS web site http://www2.nature.nps.gov/air/Monitoring/drymon.htm).



Thursday August 19, 2004

Monitoring Site	Current Hour of Data (Local Standard Time)	Current 1-Hour Average Ozone (ppb)
Badlands National Park, SD	1 PM	43
Big Bend National Park, TX	2 PM	50
Canyonlands National Park, UT	11 AM	63
Chiricahua National Monument, AZ	1 PM	47
Craters of the Moon National Monument, ID	1 PM	52
Death Valley National Park, CA	12 PM	77
Denali National Park, AK	11 AM	15
Everglades National Park, FL	2 PM	13
Glacier National Park, MT	1 PM	39
Grand Canyon National Park, AZ	1 PM	55
Great Basin National Park, NV	12 PM	53
Great Smoky Mountains Nat'l Park - Clingmans Dome, TN	3 PM	56
Joshua Tree National Park, CA	12 PM	71
Lassen Volcanic National Park, CA	11 AM	61
Mesa Verde National Park, CO	12 PM	53
Mount Rainier National Park, WA	12 PM	33
North Cascades National Park, WA	6 AM	1
Olympic National Park, WA	12 PM	20
Petrified Forest National Park, AZ	12 PM	58
Pinnacles National Monument, CA	11 AM	36
Rocky Mountain National Park, CO	12 PM	43
Sequoia National Park - Ash Mountain, CA	12 PM	86
Sequoia National Park - Lower Kaweah, CA	12 PM	81
Theodore Roosevelt National Park, ND	1 PM	44
Yellowstone National Park, WY	1 PM	43
Yosemite National Park - Merced River, CA	11 AM	67
Yosemite National Park - Turtleback Dome, CA	11 AM	77
Zion National Park, UT	12 PM	59

Figure 8. The National Park Service ozone monitoring network presents the current status of ozone in the National Parks on their web page (http://www2.nature.nps.gov/air/data/current/index.htm).

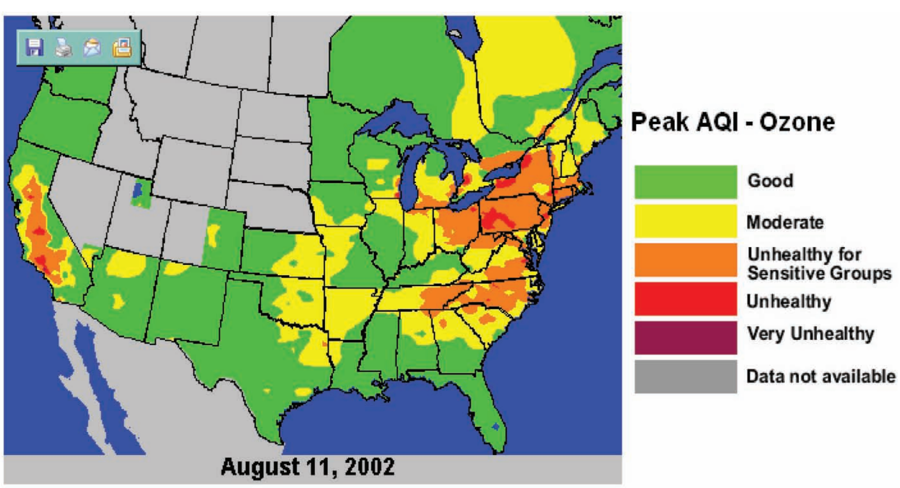


Figure 9. EPA's AirNow web site presents archived ozone data. Here a single day in August, 2002 is selected to show the peak Ozone concentrations that occurred on that day. Details are available at the web site (http://www.epa.gov/airnow/index.html).