United States Environmental Protection Agency

AMBIENT AIR MONITORING NETWORK ASSESSMENT GUIDANCE

Analytical Techniques for Technical Assessments of Ambient Air Monitoring Networks

EPA-454/D-07-001
February 2007

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Analytical Techniques for Technical Assessments of Ambient Air Monitoring Networks

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Contract No. EP-D-05-004
Work Assignment No. 2-12

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ACKNOWLEDGMENTS

The authors thank Kevin Cavender, the work assignment manager, for his assistance with this project. We also acknowledge those involved with the National Analysis (Schmidt, 2001) and the preliminary regional assessments, particularly those performed by U.S. Environmental Protection Agency Regions 3 and 5, upon which this document draws.

DISCLAIMER

This document provides guidance to EPA Regional, State, and Tribal air quality management authorities and the general public, on how EPA intends to exercise its discretion in implementing Clean Air Act provisions and EPA regulations, concerning ambient air monitoring. The guidance is designed to implement national policy on these issues. Section 110 of the Clean Air Act (42 U.S.C. § 7410) and implementing regulations at 40 CFR part 58 contain legally binding requirements. This document does not substitute for those provisions or regulations, nor is it a regulation itself. Thus, it does not impose binding, enforceable requirements on any party, nor does it assure that EPA may approve all instances of its application, and thus the guidance may not apply to a particular situation based upon the circumstances. EPA and State decision makers retain the discretion to adopt approaches on a case-by-case basis that differ from this guidance where appropriate. Any decisions by EPA regarding a particular State implementation plan (SIP) demonstration will only be made based on the statute and regulations, and will only be made following notice and opportunity for public review and comment. Therefore, interested parties are free to raise questions and objections about the appropriateness of the application of this guidance to a particular situation; EPA will, and States should, consider whether or not the recommendations in this guidance are appropriate in that situation. This guidance is a living document and may be revised periodically without public notice. EPA welcomes public comments on this document at any time and will consider those comments in any future revision of this guidance document.

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FOREWORD

This document represents guidance for the assessment of technical aspects of ambient air monitoring networks. It is designed to be flexible and expandable with additional types of analyses and examples as techniques are improved, enhanced, and more broadly applied. Its intended audience includes EPA Regional, state, local, and tribal air quality planning agencies. Depending on their unique situations, users of this guidance may select one or more analyses, or they may creatively modify one of the recommended analyses to facilitate a monitoring network assessment.

The contents of this document are summarized briefly in the following paragraphs:

- Section 1 summarizes the context of network assessments in general and this specific document, including background and key issues. Section 1 provides an overview of the requirements for network assessment contained in 40 CFR Part 58, and provides an overview of the network assessment process.
- Section 2 expands on the procedures for network assessments. It introduces consideration of the purposes of a monitoring network—i.e., a network's mission. The purposes provide a basis for performing a network assessment. They are the benchmarks against which the strengths and weaknesses of the network are measured. Section 2 continues with specific details for technical approaches to network assessments, including three general categories of analyses: site-by-site, bottom-up, and network optimization.
- Section 3 expands on the technical approaches introduced in Section 2. It includes a selection of two-page illustrations of analyses for network assessments.
- Section 4 provides information on the regulatory requirements for the discontinuation of a monitor used in National Ambient Air Quality Standards (NAAQS) compliance. The section also provides procedures that can be used to determine if a monitor meets the requirements.
- Section 5 concludes this guidance document with a summary and recommendations for further development of network assessment guidance with an emphasis on expected results and resource requirements. More detailed descriptions of the techniques, and more examples, could be added to future versions of this document as techniques are refined and more broadly applied.
- Section 6 lists the references cited in this guidance document.
- Appendix A discusses project-level example applications of the technical approaches discussed in Sections 2 and 3.

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1. INTRODUCTION

The U.S. Environmental Protection Agency (EPA) finalized an amendment to the ambient air monitoring regulations on October 17, 2006. As part of this amendment, the EPA added the following requirement for state, or where applicable local, monitoring agencies to conduct a network assessments once every five years [40 CFR 58.10(e)].

> *"(e) The State, or where applicable local, agency shall perform and submit to the EPA Regional Administrator an assessment of the air quality surveillance system every 5 years to determine, at a minimum, if the network meets the monitoring objectives defined in appendix D to this part, whether new sites are needed, whether existing sites are no longer needed and can be terminated, and whether new technologies are appropriate for incorporation into the ambient air monitoring network. The network assessment must consider the ability of existing and proposed sites to support air quality characterization for areas with relatively high populations of susceptible individuals (e.g., children with asthma), and, for any sites that are being proposed for discontinuance, the effect on data users other than the agency itself, such as nearby States and Tribes or health effects studies. For PM2.5, the assessment also must identify needed changes to population-oriented sites. The State, or where applicable local, agency must submit a copy of this 5-year assessment, along with a revised annual network plan, to the Regional Administrator. The first assessment is due July 1, 2010."*

This requirement is an outcome of implementing the National Ambient Air Monitoring Strategy (NAAMS, the most recent version is dated December 2005, U.S. Environmental Protection Agency, 2005). The purpose of the NAAMS is to optimize U.S. air monitoring networks to achieve, with limited resources, the best possible scientific value and protection of public and environmental health and welfare.

A network assessment includes (1) re-evaluation of the objectives and budget for air monitoring, (2) evaluation of a network's effectiveness and efficiency relative to its objectives and costs, and (3) development of recommendations for network reconfigurations and improvements. EPA expects that a multi-level network assessment will be conducted every five years (U.S. Environmental Protection Agency, 2005). Initial network assessments for the NAAMS were led by EPA and its 10 regional offices in 2001 through 2004 (U.S. Environmental Protection Agency, 2003b). This initial assessment, as well as peer-reviews of the NAAMS by subcommittees of the EPA Clean Air Scientific Advisory Committee (Hopke, 2003),(Henderson, 2005), produced the recommendation that guidance for regional-scale network assessments be established.

The NAAMS (U.S. Environmental Protection Agency, 2005), (U.S. Environmental Protection Agency, 2005), (Clean Air Scientific Advisory Committee and National Ambient Air Monitoring Strategy Subcommittee, 2003) and documentation of the initial national- and regional-scale network assessments provide a valuable context and a summary of the key technical issues for network assessment guidelines. This document builds on the lessons learned in the NAAMS and focuses on providing guidance on analytical techniques that can be used for regional-scale assessments.

1.1 BACKGROUND AND KEY ISSUES

Ambient air monitoring objectives have shifted over time—a situation which has induced air quality agencies to re-evaluate and reconfigure monitoring networks. A variety of factors contribute to these shifting monitoring objectives:

- Air quality has changed—for the better in most geographic areas—since the adoption of the federal Clean Air Act and National Ambient Air Quality Standards (NAAQS). For example, the problems of high ambient concentrations of lead and carbon monoxide have largely been solved.
- Populations and behaviors have changed. For example, the U.S. population has (on average) grown, aged, and shifted toward urban and suburban areas over the past four decades. In addition, rates of vehicle ownership and annual miles driven have grown.
- New air quality objectives have been established, including rules to reduce air toxics, fine particulate matter ($PM_{2.5}$),[1] and regional haze.
- The understanding of air quality issues and the capability to monitor air quality have both improved. Together, the enhanced understanding and capabilities can be used to design more effective air monitoring networks.

As a result of these changes, air monitoring networks may have unnecessary or redundant monitors or ineffective and inefficient monitoring locations for some pollutants, while other regions or pollutants suffer from a lack of monitors. Air monitoring agencies should, therefore, refocus monitoring resources on pollutants that are new or persistent challenges, such as $PM_{2.5}$, air toxics, and ground-level ozone and precursors, and should deemphasize pollutants that are steadily becoming less problematic and better understood, such as lead and carbon monoxide (CO). In addition, monitoring agencies need to adjust networks to protect today's population and environment, while maintaining the ability to understand long-term historical air quality trends. Moreover, monitoring networks can take advantage of the benefits of new air monitoring technologies and improved scientific understanding of air quality issues. Existing monitoring networks should be designed to address multiple, interrelated air quality issues and to better operate in conjunction with other types of air quality assessments (e.g., photochemical modeling, emission inventory assessments). Reconfiguring air monitoring networks can enhance their value to stakeholders, scientists, and the general public.

1.2 OVERVIEW OF MONITORING NETWORK TECHNICAL ASSESSMENTS

Analytical techniques to assess the technical aspects of monitoring networks fit within the overall framework of regional network assessments discussed in the most recent version of the NAAMS (U.S. Environmental Protection Agency, 2005). The NAAMS briefly describes the

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[1] Particulate matter of less than 2.5 microns aerodynamic diameter.

stepwise procedure for network assessments shown in **Table 1-1**. This document focuses on Steps 3 and 4: statistical analyses and objective situational analyses.

In some cases, network assessments can be handled simply by answering one or more straightforward questions. In others, detailed analytical techniques, such as those discussed in Section 2.2 and Section 3, are necessary. A thorough technical assessment will help inform decisions about reconfiguring a network. These decisions might include eliminating redundant monitors, reducing or expanding the monitoring season, moving monitors to better locations, switching a site to different technology (e.g., finer temporal resolution), adding monitors to the network, or switching a site to a different pollutant. In practice, a combination of several types of analyses might provide the most useful information. Network assessment can be performed at many levels (national, regional, local); however, the next level down may need to reassess the analyses to ensure the correct decision, given local conditions.

Table 1-1. Descriptions and examples of steps involved in performing network assessments.

Step	Description	Examples
1	Prepare or update a regional description, discussing important features that should be considered for network design	Topography, climate, population, demographic trends, major emissions sources, and current air quality conditions
2	Prepare or update a network history that explains the development of the air monitoring network over time and the motivations for network alterations, such as shifting needs or resources.	Historical network specifications (e.g., number and locations of monitors by pollutant and by year in graphical or tabular format); history of individual monitoring sites
3	Perform statistical analyses of available monitoring data. These analyses can be used to identify potential redundancies or to determine the adequacy of existing monitoring sites.	Site correlations, comparisons to the NAAQS, trend analysis, spatial analysis, and factor analysis
4	Perform situational analyses, which may be objective or subjective. These analyses consider the network and individual sites in more detail, taking into account research, policy, and resource needs.	Risk of future NAAQS exceedances, demographic shifts, requirements of existing state implementation plans (SIP) or maintenance plans, density or sparseness of existing networks, scientific research or public health needs, and other circumstances (such as political factors)
5	Suggest changes to the monitoring network on the basis of statistical and situational analyses and specifically targeted to the prioritized objectives and budget of the air monitoring program.	Reduction of number of sites for a selected pollutant, enhanced leveraging with other networks, and addition of new measurements at sites to enhance usefulness of data
6	Acquire the input of state and local agencies or stakeholders and revise recommendations as appropriate	

2. APPROACH TO MONITORING NETWORK TECHNICAL ASSESSMENTS

This section provides guidance to the user for identifying monitoring needs and introduces network assessment analyses.

2.1 IDENTIFY MONITORING NEEDS

Before beginning a network assessment, the purposes of the network must be reviewed and prioritized. Networks are likely to be used to meet a variety of purposes, such as monitoring compliance with the NAAQS, public reporting of the Air Quality Index (AQI), assessment of population exposure to pollutants, assessment of pollutant transport, monitoring of specific emissions sources, monitoring of background conditions, evaluating models, and possibly others. These purposes may be prioritized as primary or secondary and individual monitors within a network may serve different purposes. Each analytical technique selected to support a network assessment must be chosen in view of the purposes of the overall network and its individual monitoring sites. In addition, the resources invested in each analysis should be proportional to the priority of the purposes that are being evaluated. **Table 2-1** briefly lists some typical purposes for monitoring networks, although this list is neither comprehensive nor universally applicable to all pollutants.

Network assessments quantifiably measure the successes and shortcomings of monitoring networks' capabilities to meet their monitoring purposes. Therefore, clearly defined monitoring purposes are the basis for the technical assessment of a monitoring network. Once the purposes are defined, appropriate statistical or situational analyses may be considered and selected to evaluate each.

Table 2-1. Typical purposes for ambient air monitoring networks.

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Purpose	Examples	Comments
Establish regulatory compliance	Meet national requirements	Monitors may be sited to address NAAQS compliance or may be mandated by prior regulations or SIP provisions.
	Meet state and local regulations	States, or local air districts, may have air quality regulations that are more stringent than federal requirements.
Develop scientific understanding of air quality by supporting other types of assessments or analyses	Air quality model evaluation	Monitors near modeling domain boundaries are useful for defining boundary conditions. Monitors throughout a domain assist model application and evaluation.
	Emission reduction evaluation or emission inventory evaluation	Urban core and maximum emission area monitors can be helpful for evaluating inventories and tracking emissions.

Table 2-1. Typical purposes for ambient air monitoring networks.

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Purpose	Examples	Comments
Develop scientific understanding of air quality by supporting other types of assessments or analyses (continued)	Source apportionment	Monitors collecting data on many species (e.g., speciated $PM_{2.5}$) and at fairly high time resolution (1-in-3-day or better) are useful for source apportionment analyses.
	Temporal variability	Sub-daily (e.g., 1-hr, 3-hr) data can be used to track diurnal patterns.
Understand historical trends in air quality	Trend tracking	Monitors with long histories are valuable for understanding and tracking long-term trends.
	Historical consistency	Monitoring sites whose sampling methods have not been changed help maintain consistency for annual comparisons.
Characterize specific geographic locations or emissions sources	Monitor the air quality impacts of an emissions source	Monitors located close to specific source hot spots are useful for tracking emissions from a particular source and developing emission reduction strategies or tracking changes due to controls.
	Monitor the area of maximum precursor emissions	For secondary pollutants such as ozone, monitors located in areas of maximum precursor emissions are useful for modeling and control strategy design.
	Monitor the area of maximum pollutant concentration	Monitors located downwind of maximum emissions.
	Monitor the background concentration	Properly sited background monitors routinely measure the lowest expected values in the region. These monitors are used to asses regional vs. local contributions.
	Monitor surrogate pollutants	Some measurements are useful as surrogates for other pollutants that are not widely monitored. For example, CO monitors can be used as surrogates for wood smoke (Park et al., 2005).

Table 2-1. Typical purposes for ambient air monitoring networks.

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Purpose	Examples	Comments
Track the spatial distribution of air pollutants	Transport/border characterization	Sites located near political boundaries or between urban or industrial areas are useful for characterizing transport of pollutants between jurisdictions.
	Interpolation and understanding pollutant gradients	High monitor density improves interpolation maps such as those used in AIRNow (U.S. Environmental Protection Agency, 2003a). Monitors near the urban boundary are particularly useful for constraining the interpolation of high concentrations.
	Accountability/Performance measurement	Monitoring data is used to measure the effects of air pollution control programs and strategies. Monitors in impacted areas are most useful for assessing the effectiveness of controls.
	Forecasting assistance	Upwind monitors are useful for air quality forecasting. For forecasting ozone, NO_x measurements are helpful. For $PM_{2.5}$, continuous monitors are very valuable.
Evaluate population exposures to air pollutants	Environmental justice	Monitors located in areas that have large low income and/or minority populations may be of particular value for assessing environmental justice issues.
	Public reporting of the AQI	Monitors located where people live, work, and play are important for addressing exposure and protecting public health.

2.2 METHODS FOR TECHNICAL ASSESSMENT

2.2.1 Overview

In this document, techniques for assessing technical qualities of monitoring networks are grouped into three broad categories: site-by-site, bottom-up, and network optimization. Site-by-site comparisons rank individual monitors according to specific monitoring purposes; bottom-up analyses examine data other than ambient concentrations to assess optimal placement of monitors to meet monitoring purposes; and network optimization analyses evaluate proposed network design scenarios. Within these broad categories, specific techniques are rated by their complexity on the following scale.

*	Minimal special skills needed; quick
**	May require common tools, readily available data, and/or basic analysis skills; quick
***	Requires analysis skills; moderate investment of time
****	Significant analytical skills, specialized tools; time-intensive or iterative

2.2.2 Site-By-Site Analyses

Site-by-site analyses are those that assign a ranking to individual monitors based on a particular metric. These analyses are good for assessing which monitors might be candidates for modification or removal. Site-by-site analyses do not reveal the most optimized network or how good a network is as a whole. In general, the metrics at each monitor are independent of the other monitors in the network.

Several steps are involved in site-by-site analysis:

1. Determine which monitoring purposes are most important
2. Assess the history of the monitor (including original purposes)
3. Select a list of site-by-site analysis metrics based on purposes and available resources
4. Weight metrics based on importance of purpose
5. Score monitors for each metric
6. Sum scores and rank monitors
7. Examine lowest ranking monitors for possible resource reallocation

The low-ranking monitors should be examined carefully on a case-by-case basis. There may be regulatory or political reasons to retain a specific monitor. Also, the site could be made potentially more useful by monitoring a different pollutant or using a different technology. **Table 2-2** lists specific site-by-site analysis techniques, which are summarized in greater detail in Section 3.

Table 2-2. Site-by-site analysis techniques.

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Technique	Complexity (Section 2.1.1)	Objectives Assessed (See Table 2-1)	Summary Page
Number of other parameters monitored at the site	*	Overall site value Model evaluation Source apportionment	3-7
Trends impact	* to **	Trend tracking Historical consistency Emission reduction evaluation	3-9
Measured concentrations	**	Maximum concentration location Model evaluation Regulatory compliance	3-11

		Population exposure	
Deviation from NAAQS	**	Regulatory compliance Forecasting assistance	3-13
Area served	**	Spatial coverage Interpolation Background concentration	3-15

Table 2-2. Site-by-site analysis techniques.

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Technique	Complexity (Section 2.1.1)	Objectives Assessed (See Table 2-1)	Summary Page
Monitor-to-monitor correlation	** to ***	Model evaluation Spatial coverage Interpolation	3-17
Population served	***	Population exposure Environmental justice	3-23
Principal component analysis	***	Background concentration Forecasting assistance	3-25
Removal bias	***	Regulatory compliance Model evaluation Spatial coverage Background concentration Interpolation	3-27

2.2.3 Bottom-Up Analyses

Bottom-up methods examine the phenomena that are thought to cause high pollutant concentrations and/or population exposure, such as emissions, meteorology, and population density. For example, emission inventory data can be used to determine the areas of maximum expected concentrations of pollutants directly emitted (i.e., primary emissions). Emission inventory data are less useful to understand pollutants formed in the atmosphere (i.e., secondarily formed pollutants). Multiple data sets can be combined using spatial analysis techniques to determine optimum site locations for various objectives. Those optimum locations can then be compared to the current network. In general, bottom-up analyses indicate where monitors are best located based on specific objectives and expected pollutant behavior. However, bottom-up techniques rely on a thorough understanding of the phenomena that cause air quality problems. The most sophisticated bottom-up analysis techniques are complex and require significant resources (time, data, tools, and analytical skill). **Table 2-3** lists the specific bottom-up analysis techniques detailed in Section 3. Site-by-site and bottom-up analyses are best performed in combination. Site-by-site analyses typically identify network redundancies while bottom-up analyses identify network “holes” or deficiencies.

Table 2-3. Bottom-up analysis techniques.

Technique	Complexity (Section 2.1.1)	Objectives Assessed (Table 2-1)	Summary Page
Emission Inventory	** to ****	Emission reduction evaluation Maximum precursor location	3-19
Population density	**	Population exposure Environmental justice	Not included
Population change	***	Population exposure Environmental justice Maximum precursor location	3-21
Suitability modeling	****	Population exposure Environmental justice Source-oriented Model evaluation Maximum concentration location Background concentration Transport/border characterization	3-31
Photochemical modeling	****	Maximum concentration location Source-oriented Transport/border characterization Population exposure Background concentration	Not included

2.2.4 Network Optimization Analyses

Network optimization techniques are a holistic approach to examining an air monitoring network. These techniques typically assign scores to different network scenarios; alternative network designs can be compared with the current (base-case) design.

An example of a network optimization analysis is the EPA Region 3 ozone network reassessment (Cimorelli et al., 2003). Region 3 utilized an iterative 10-step process:

1. Select the set of scenarios (i.e., different hypothetical network designs) to be ranked
2. Define decision criteria for scoring each network design
3. Gather the data necessary to calculate scores for the decision criteria
4. Index decision criteria to a common scale
5. Weight the criteria based on relative importance
6. Produce initial results (ranking of scenarios)
7. Iterate – adjust scenarios, decision criteria, and criteria weighting as new information and understanding are developed
8. Obtain feedback from stakeholder deliberation
9. Finalize network optimization scenario results
10. Recommend changes

The formal analytical process used by Region 3 is called Multi-Criteria Integrated Resource Assessment (MIRA) (Cimorelli et al., 2003; Stahl et al., 2002) Forty metrics were used as decision criteria in the analysis. These metrics were arranged hierarchically with four top-level criteria: air quality, personnel impact, costs, and trends impact. For assessing the air quality criteria, Region 3 developed a base-case ozone concentration grid using photochemical modeling results.

Many of the metrics used by Region 3 in their assessment are similar to the analyses described as "site-by-site" analyses in this document. When different network scenarios are considered, the individual monitor scores for a particular analysis can be summed to provide a total score for the entire network. The total score can be compared to other network designs. **Table 2-4** lists some techniques for network optimization. Further details are provided in Section 3.

Table 2-4. Network optimization analysis techniques.

Technique	Complexity (Section 2.1.1)	Objectives Assessed (Table 2-1)	Summary Page
Monitor-to-monitor correlation	** to ***	Model evaluation Spatial coverage Interpolation	3-17
Principal Component Analysis	***	Background concentration Forecasting assistance	3-25
Removal bias	***	Regulatory compliance Model evaluation Spatial coverage Background concentration Interpolation	3-27
Positive matrix factorization	****	Source apportionment Emission inventory evaluation	3-29

3. METHOD SUMMARY SHEETS

The following pages represent summary sheets for individual analysis techniques. The summaries are designed to provide the vital statistics for the techniques at a glance and to help the analyst narrow down the list of possible analyses to perform based on their available resources and objectives. These summaries cover a range of analysis techniques that can be applied to network assessment; they can be expanded and other summary sheets can be prepared as examples become available. A brief introduction to each analysis technique that is covered in a summary sheet follows.

Number of Parameters Monitored

Sites are ranked by the number of parameters (or instruments) that are collected at a particular site. Air quality monitoring sites hosting monitors collocated with other measurement instruments are likely more valuable than sites at which fewer parameters are measured. In addition, the operating costs can be leveraged among several instruments at these sites. This analysis is performed by simply counting the number of other parameters that are measured at a physical site. Sites at which many parameters are measured are ranked highest.

Trend Impacts

Monitors that have a long historical record are valuable for tracking trends. In this analysis, monitors are ranked based on the duration of their continuous measurement records. The analysis can be as simple as ranking the available monitors based on the length of the continuous sampling record. The most important monitors are those with the longest continuous trend record.

Measured Concentrations

Individual monitors are ranked based on the concentration of pollutants they measure. Monitors that measure high concentrations or design values are ranked higher than monitors that measure low concentrations. Results can be used to determine which monitors are less useful in meeting the selected objective. The analysis is relatively straightforward, requiring only the site design values. The greater the design value, the higher the site rank. If more than one standard exists for a pollutant (e.g., annual and 24-hr average), monitors can be scored for each standard.

Deviation from NAAQS

Sites measuring concentrations (design values) that are very close to the NAAQS exceedance threshold are ranked highest in this analysis. These sites may be considered more valuable for NAAQS compliance evaluation. Sites measuring concentrations well above or below the threshold do not provide as much information in terms of NAAQS compliance. This technique contrasts the difference between the standard and actual measurements or design values. It is a simple way to assess a site's value for evaluating compliance. If a pollutant (e.g., annual and 24-hr average) has more than one standard, sites can be scored for each standard.

Area Served

Sites are ranked based on their area of coverage. Sites that are used to represent a large area score high in this analysis. Area of coverage (area served) for a monitor can be determined using the Thiessen polygons technique. Each polygon consists of the points closer to one particular site than any other site. This technique gives the most weight to rural sites and those sites on the edges of urban areas or other monitor clusters. Calculating Theissen polygons is one of the simplest quantitative methods for determining an area of representation around sites. However, it is not a true indication of which site is most representative of the pollutant concentration in a given area. Meteorology (including pollutant transport), topography, and proximity to population or emission sources are not considered, so some areas assigned to a particular monitor may actually be better represented by a different monitor.

Monitor-to-Monitor Correlation

Concentrations measured at one monitor are compared to concentrations measured at other monitors to determine if concentrations correlate temporally. Monitor pairs with correlation coefficient values near one are highly correlated and should be ranked lower than those with correlation coefficient values near zero. Monitors that do not correlate well with other monitors exhibit unique temporal concentration variation relative to other monitors and are likely to be important for assessing local emissions, transport, and spatial coverage. Monitors with concentrations that correlate well (e.g., $r^2 > 0.75$) with concentrations at another monitor may be redundant. This analysis should be performed for each pollutant.

Emission Inventory

Emission inventory data are used to find locations where emissions of pollutants of concern are concentrated. These locations can be compared to the current or proposed network. This analysis can be scaled to various levels of complexity, depending on available resources. At the simplest level, county-level emissions patterns, such as those in the National Emission Inventory, can be compared with monitor locations. For measuring maximum precursor or primary emissions, monitors should be placed in those counties with maximum emission density. More complex methods use gridded emissions and/or species-weighted emissions, depending on their importance producing secondary pollutants of concern.

Population Change

High rates of population increase are associated with potential increased emissions activity and exposure. Sites are ranked based on population increase in the area of representation. Area of representation can be determined using the Thiessen polygons technique. The total population change at the census-tract or block-group level that falls within the area of coverage of a monitor is assigned to that monitor. This technique gives most weight to sites in areas with high rates of population growth and large areas of representation. The population change method can also be applied to assess the importance of monitors from an environmental justice perspective. The technique is the same, except that population changes of specific groups (e.g., low income or minority) are calculated instead of total population.

Population Served

Large populations are associated with high emissions. Sites are ranked based on the number of people they represent. Area of representation can be determined using the Thiessen polygons technique. Populations at the census-tract or block-group level that fall within the area of representation of a monitor are assigned to that monitor. This technique gives the most weight to sites that are in areas of high population and have large areas of representation. This technique was one of five site-by-site criteria used in the national-scale network assessment.

Principal Component Analysis (PCA)

PCA can be applied to find monitoring sites that show a pattern of variability similar to other monitoring sites. PCA assigns each monitor to a group of monitors at which pollutant concentrations behave similarly to each other. This analysis can be useful for finding redundancy in the network. It is also useful in selecting sites for other analyses (e.g., source apportionment). PCA is commonly available in statistical software packages. Hourly or daily samples with high data completeness at each site are required to perform the analysis.

Removal Bias

Measured values are interpolated across a domain using the entire network. Sites are then systematically removed and the interpolation is repeated. The absolute difference between a concentration measured at a site and the concentration predicted by interpolation with the site removed is the site's removal bias. Greater bias or uncertainty indicates a more important site for developing interpolations to represent concentrations across a domain. Those sites with low bias may be providing redundant information. This analysis can also be performed on groupings of sites to test various site removal scenarios. Variations of this method were performed in the National Analysis, as well as in draft assessments for EPA Regions 3 and 4.

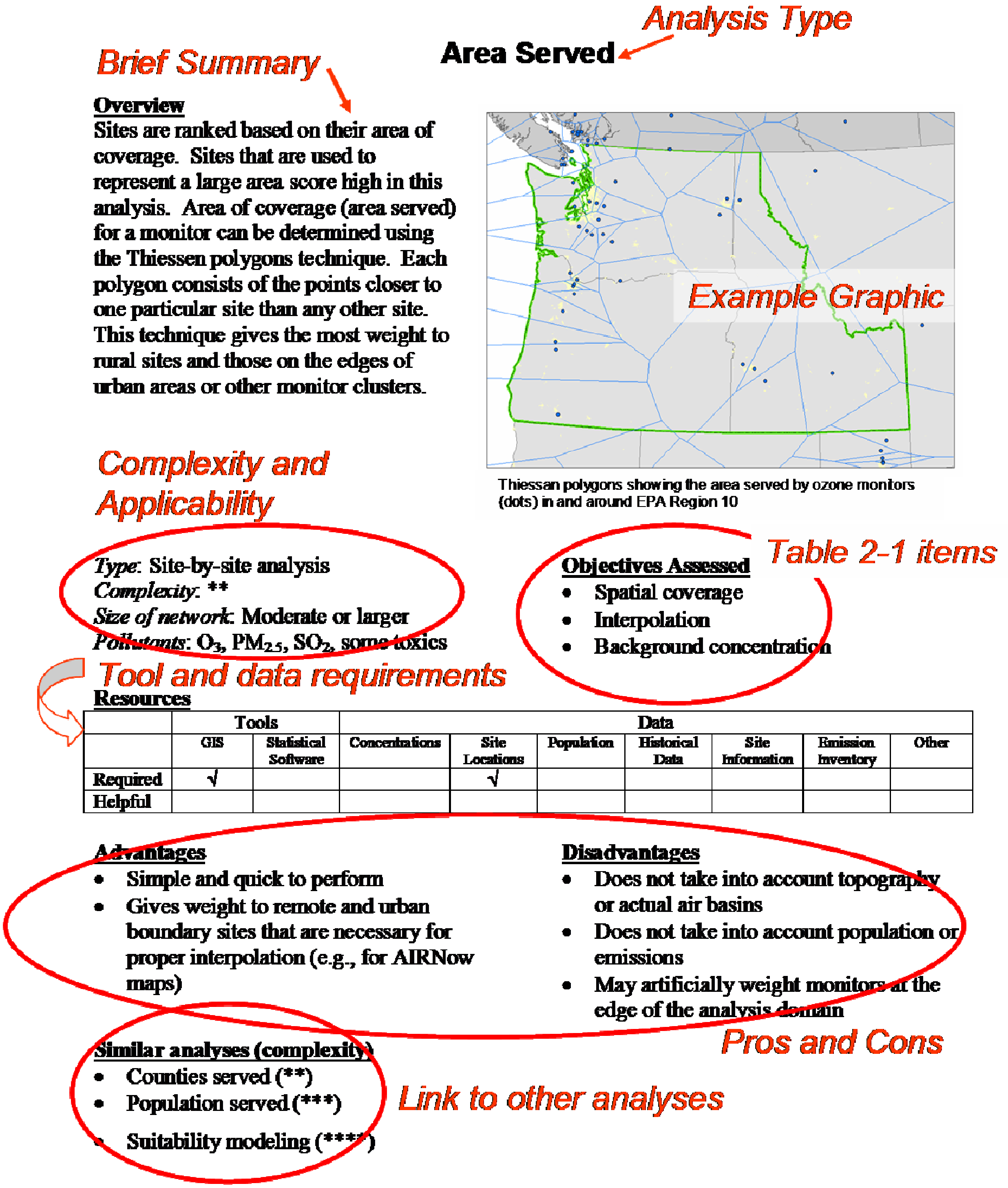
Positive Matrix Factorization (PMF)

Sites are assigned to a group according to similar variability in concentrations. Sites within the same group may be redundant. PMF also predicts concentrations. The predicted concentrations for each group can be compared to the actual concentrations at each site to determine specific monitors that are not contributing useful information and can be removed/relocated. PMF requires specialized software and large data records from many sites.

Suitability Modeling

Suitability modeling is a method for identifying suitable monitoring locations based on specific criteria. Geographic map layers representing important criteria, such as emissions source influence, proximity to populated places, urban or rural land use, and site accessibility, can be compiled and merged to develop a composite map representing the combination of important criteria in a defined area. Furthermore, each map layer input can be assigned a weighting factor based on the relative importance of each layer in the overall suitability model. The results identify the best locations to site monitors based on input criteria.

Figure 3-1 shows an example front page of an analysis technique summary sheet. This page contains basic information about the type of analysis, the objectives that can be assessed, and the complexity and resources required. Resources include desktop GIS (ArcGIS, MapInfo, etc.) and statistical (SAS, S-Plus, Systat, etc.) tools and data. The front page of the summary sheet also lists some advantages and disadvantages of the analysis and lists other analyses that can provide similar information but may be more or less complex. The back page provides more detail about the technique, including an example, interpretation, and references for more information.



Analysis Type

Area Served

Brief Summary

Overview

Sites are ranked based on their area of coverage. Sites that are used to represent a large area score high in this analysis. Area of coverage (area served) for a monitor can be determined using the Thiessen polygons technique. Each polygon consists of the points closer to one particular site than any other site. This technique gives the most weight to rural sites and those on the edges of urban areas or other monitor clusters.

Example Graphic

Thiessan polygons showing the area served by ozone monitors (dots) in and around EPA Region 10

Complexity and Applicability

Type: Site-by-site analysis
Complexity: **
Size of network: Moderate or larger
Pollutants: O_3, $PM_{2.5}$, SO_2, some toxics

Table 2-1 items

Objectives Assessed

- Spatial coverage
- Interpolation
- Background concentration

Tool and data requirements

Resources

	Tools		Data						
	GIS	Statistical Software	Concentrations	Site Locations	Population	Historical Data	Site Information	Emission Inventory	Other
Required	√			√					
Helpful									

Advantages

- Simple and quick to perform
- Gives weight to remote and urban boundary sites that are necessary for proper interpolation (e.g., for AIRNow maps)

Disadvantages

- Does not take into account topography or actual air basins
- Does not take into account population or emissions
- May artificially weight monitors at the edge of the analysis domain

Pros and Cons

Similar analyses (complexity)

- Counties served (**)
- Population served (***)
- Suitability modeling (****)

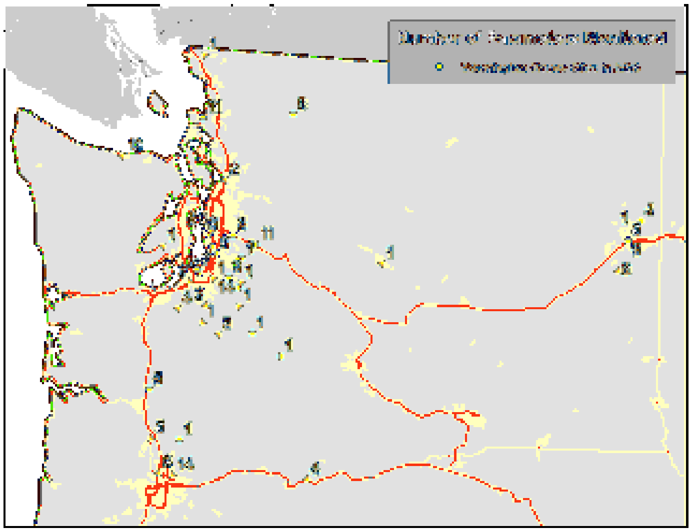
Link to other analyses

Figure 3-1. Summary sheet front page example.

Number of Other Parameters Monitored

Overview

Monitors that are collocated with other measurements at a particular air quality site are likely more valuable than sites that measure fewer parameters, particularly for source apportionment and other air quality studies. In addition, the operating costs can be leveraged among several instruments at these sites. Sites are ranked by the number of parameters (or instruments) that are collected at the particular site.



Count of additional parameters measured at Washington ozone sites within AQS

Type: Site-by-site analysis
Complexity: *
Size of network: any
Pollutants: any

Objectives Assessed

- Overall site value
- Model evaluation
- Source apportionment

Resources

	Tools		Data						
	GIS	Statistical Software	Concentrations	Site Locations	Population	Historical Data	Site Information	Emission Inventory	Other
Required				✓			✓		
Helpful									

Advantages

- Simple to perform (given data)
- Good first step in understanding monitor sites

Disadvantages

- Method does not “weight” the measurements (some pollutant measurements may be more useful than others)
- Up-to-date information on the pollutants measured at particular sites can be difficult to acquire

Similar Analyses (Complexity)

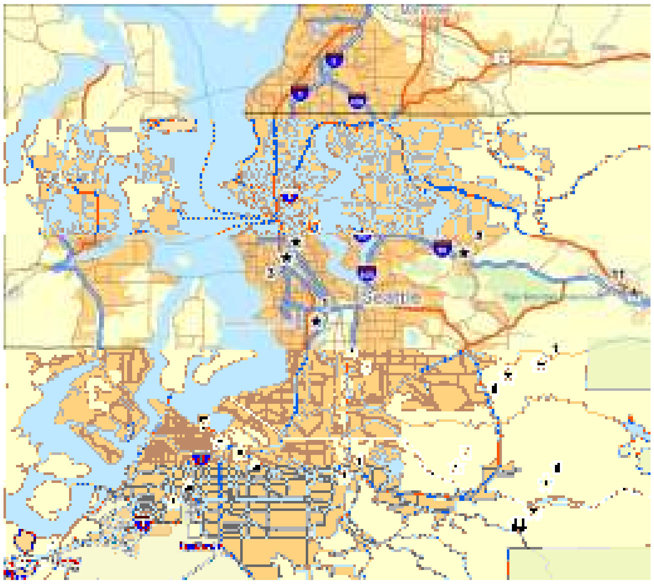
None

Number of Other Parameters Monitored

Analysis Goals

This analysis is performed by simply counting the number of other parameters that are measured at the physical site. Sites with many parameters measured are ranked highest. The metric addresses two aspects of monitor value. First, collocated measurements of several pollutants are valuable for many air quality analyses, such as source apportionment, model evaluation, and emission inventory reconciliation. Second, having a single site with multiple measurements is more cost-effective to operate than having monitors scattered at several sites. Other cost-based metrics were included in the Region 3 2003 network assessment.

Example



This example in and around the Seattle, Washington, area was created in ESRI ArcGIS 9.1, using the following steps:

1. Download monitor information from the Air Quality System (AQS) database.
2. Use the monitor coordinate information to determine which monitoring sites are within the study domain.
3. Sum the monitoring (measurements) parameters for each monitor location and determine the best locations to utilize in future air quality studies.

Interpretation

The table at right is an extract of the analysis example for Seattle. The monitor locations are ranked by the number of parameters measured. As shown in the table, three monitors are located within the project study domain and measure numerous parameters. The site measuring 98 parameters is the most valuable for scientific analyses, such as emission inventory reconciliation and source apportionment.

AIRS Code	Number of Parameters Measured	Study Domain
530330080	98	✓
530110011	14	
530330023	14	✓
530330017	11	✓
530570018	11	
530090012	10	
530630001	9	

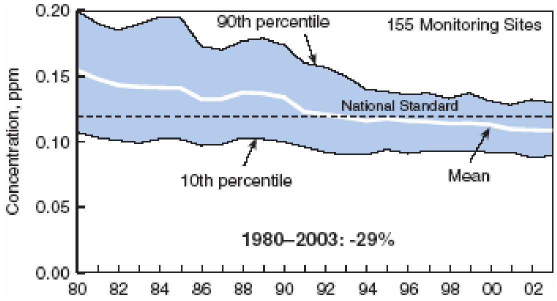
References

Cimorelli A.J., Chow A.H., Stahl C.H., Lohman D., Ammentorp E., Knapp R., and Erdman T. (2003) Region III ozone network reassessment. Presented at the *Air Monitoring & Quality Assurance Workshop, Atlanta, GA, September 9-11* by the U.S. Environmental Protection Agency, Region 3, Philadelphia, PA. Available on the Internet at http://www.epa.gov/ttn/amtic/files/ambient/pm25/workshop/atlanta/r3netas.pdf last accessed September 9, 2005.

Trends Impact

Overview

Monitors that have a long historical record are valuable for tracking trends. In this analysis, sites are ranked based on the duration of the continuous measurement record. The analysis can be as simple as ranking the available monitors based on the length of the continuous sampling record. This technique places the most importance on sites with the longest continuous trend record.



National ozone trends from EPA ozone trend report, 2003.

Type: Site-by-site analysis
Complexity: * to **
Size of network: any
Pollutants: any

Objectives Assessed

- Trend tracking
- Historical consistency
- Emission reduction evaluation

Resources

	Tools		Data						
	GIS	Statistical Software	Concentrations	Site Locations	Population	Historical Data	Site Information	Emission Inventory	Other
Required						✓			
Helpful			✓						

Advantages

- Simple analysis, requiring few statistical tools
- Useful for identifying long-term trend sites
- A good first look at monitor history

Disadvantages

- Length of continuous record does not ensure that data are of good quality throughout the time period
- Magnitude or direction of past trends are not necessarily good predictors of future trends
- Does not take into account changes in population, emissions, or meteorology
- Overemphasis on sites with long historical record can be misleading as land use changes and other factors may contribute to concentration changes at a site.

Similar Analyses (Complexity)

- Number of other parameters monitored (*)
- Measured concentrations (**)
- Deviation from NAAQS (**)

Trends Impact

Analysis Goals

Determining the trends impact of a monitor can be done simply. One approach is to rank sites based on their length of continuous sampling. Sites with the longest term of operation would score higher than those with shorter records, since they would be more useful for long-term trend analysis. Additional factors that could be used to adjust the simple ranking scale include (1) the magnitude and direction of trends observed to date at the site, (2) the suitability of a site's location for monitoring trends after a significant event (e.g., enactment of a specific control measure), or (3) proximity of another monitor that could be used to continue the trend record. A site may be weighted as less important if changes in sampling and analysis methodology lead to a discontinuous record. Weighing these factors would require consideration of the overall goals of the monitoring network and the importance of the historical record.

Example

This table shows the number of annual averages available for tetrachloroethylene at toxics trends sites from 1990 to 2003. For this analysis, sites with the longest record would be rated higher than those with shorter records.

City, State	AQS SiteID	Years
Stockton, CA	06-077-1002	13
Baltimore, MD	24-510-0040	12
Los Angeles, CA	06-037-1002	11
San Francisco, CA	06-001-1001	10
Fresno, CA	06-019-0008	10
Baltimore, MD	24-005-3001	10
Los Angeles, CA	06-037-1103	9
Los Angeles, CA	06-037-4002	9
San Diego, CA	06-073-0003	9
San Francisco, CA	06-075-0005	9
San Jose, CA	06-085-0004	9
Baltimore, MD	24-510-0006	9
Sacramento, CA	06-061-0006	8
San Diego, CA	06-073-0001	8
Oxnard, CA	06-111-2002	8
Chicago, IL-IN-WI	18-089-2008	8
Baltimore, MD	24-510-0035	8

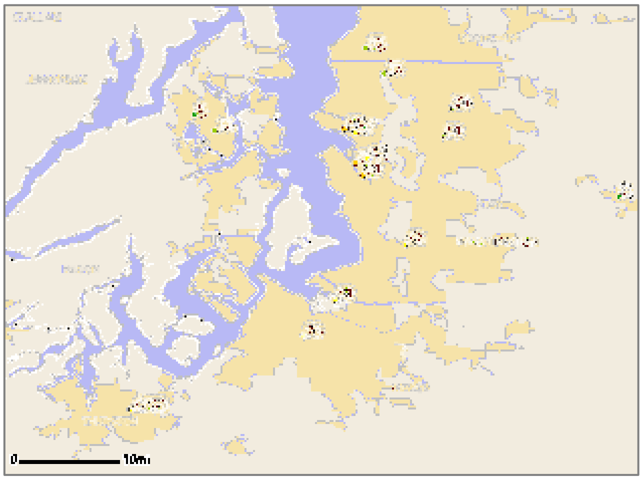
References

Cimorelli A.J., Chow A.H., Stahl C.H., Lohman D., Ammentorp E., Knapp R., and Erdman T. (2003) Region III ozone network reassessment. Presented at the *Air Monitoring & Quality Assurance Workshop, Atlanta, GA, September 9-11* by the U.S. Environmental Protection Agency, Region 3, Philadelphia, PA. Available on the Internet at http://www.epa.gov/ttn/amtic/files/ambient/pm25/workshop/atlanta/r3netas.pdf last accessed September 9, 2005.

Measured Concentrations

Overview

Individual sites are ranked based on the concentration of pollutants they measure. Monitors that measure high concentrations or design values are ranked higher than monitors that measure low concentrations. Results can be used to determine which monitors are less useful in meeting the selected objective.



1-hour $PM_{2.5}$ concentrations in the Seattle area (ug/m^3)

Type: Site-by-site analysis
Complexity: **
Size of network: any
Pollutants: any above detection limits

Objectives Assessed

- Maximum concentration location
- Model evaluation
- Regulatory compliance
- Population exposure

Resources

	Tools		Data						
	GIS	Statistical Software	Concentrations	Site Locations	Population	Historical Data	Site Information	Emission Inventory	Other
Required			✓						
Helpful		✓					✓		

Advantages

- Identifies key sites from a regulatory perspective based on maximum concentrations.

Disadvantages

- Does not account for monitor-siting problems; monitors may not be measuring maximum concentrations if not properly placed.
- Only focuses on high concentrations; low-concentration monitors may be useful for representing rural locations or background concentrations.

Similar Analyses (Complexity)

Deviation from NAAQS (**)
Emission inventory (** to ****)

Measured concentrations

Analysis Goals

Sites that measure high concentrations are important for assessing NAAQS compliance and population exposure (AQI) and for performing model evaluations. The analysis is relatively straightforward, requiring only the site design values. The greater the design value, the higher the site rank. If more than one standard exists for a pollutant (e.g., annual and 24-hr average), monitors can be scored for each standard.

Example

This metric was one of five used in the 2000 National Analysis. The map shows the results for CO monitors. Sites in red record the highest CO concentrations and are the most valuable based on this metric. Sites in blue record the lowest values and are candidates for removal or repurposing.


8-Hour CO 2nd Max: Red=Large Value, Blue=Small Value

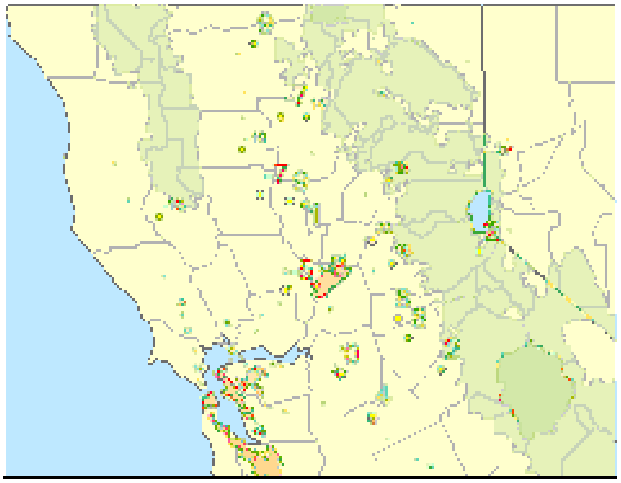
References

Schmidt M. (2001) Monitoring strategy: national analysis. Presented at the *Monitoring Strategy Workshop, Research Triangle Park, NC, October* by the U.S. Environmental Protection Agency. Available on the Internet at http://www.epa.gov/ttn/amtic/netamap.html.

Deviation from NAAQS

Overview

Sites that measure concentrations (design values) that are very close to the NAAQS exceedance threshold are ranked highest in this analysis. These sites may be considered more valuable for NAAQS compliance evaluation. Sites well above or below the threshold do not not provide as much information in terms of NAAQS compliance.



Ozone monitors in California and their deviation (ppb) from the maximum 8-hr NAAQS for a single day.

Type: Site-by-site analysis
Complexity: **
Size of network: any
Pollutants: Any with NAAQS or other standards

Objectives Assessed

- Regulatory compliance
- Forecasting assistance

Resources

	Tools		Data						
	GIS	Statistical Software	Concentrations	Site Locations	Population	Historical Data	Site Information	Emission Inventory	Other
Required			✓						
Helpful	✓			✓		✓			

Advantages

- Assesses monitor importance for determining NAAQS compliance

Disadvantages

- If design values vary from year to year, historical data should be included in the analysis
- Care is needed in interpreting absolute differences

Similar Analyses (Complexity)

Measured concentrations (**)
Removal bias (***)

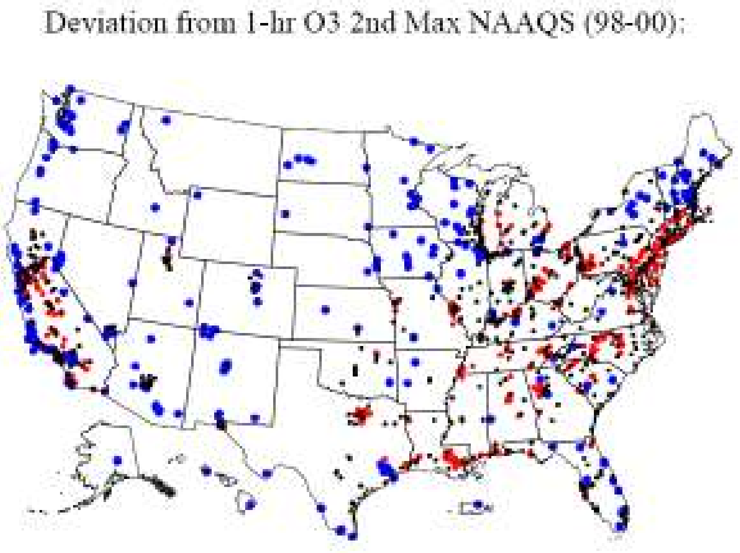
Deviation from NAAQS

Analysis Goals

This technique contrasts the difference between the standard and actual measurements or design values. It is a simple way to assess a monitor's value for evaluating compliance. The design values for each pollutant should be calculated as they impact regulatory compliance. If a pollutant (e.g., annual and 24-hr average) has more than one standard, monitors can be scored for each standard. The absolute value of the difference between the measured design value and the standard can be used to score each monitor. Monitors with the smallest absolute difference will rank as most important. However, monitors that have higher design values than the standard (i.e., those in violation of the standard) may be considered more valuable from the standpoint of compliance and public health than those with design values lower than the standard, but with a similar absolute difference. Thus, absolute values of the difference can be ranked by peak concentration. It may be desirable to use more than one year of design values to look for consistency from year to year.

Example

Deviation from the NAAQS was one of five metrics used in the 2000 National Analysis. The analysis used one design value (1998–2000) and considered monitors above and below the standard equally. The map shows the results. Red circles denote sites that are nearest the standard, blue circles are those well above or below the standard, and black circles are in between.


Deviation from 1-hr O3 2nd Max NAAQS (98-00):

Interpretation

The red sites are ranked highest in this analysis. Depending on the network assessment objectives, the number of red-site monitors might be adjusted. Blue sites are candidates for removal or repurposing.

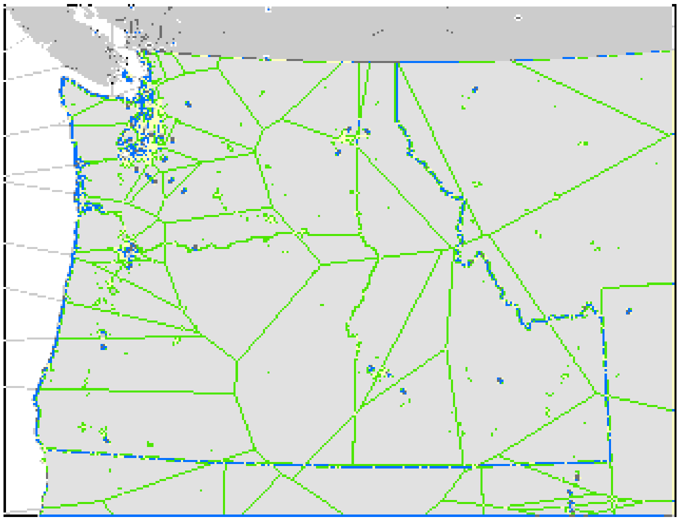
References

Schmidt M. (2001) Monitoring strategy: national analysis. Presented at the *Monitoring Strategy Workshop, Research Triangle Park, NC, October* by the U.S. Environmental Protection Agency. Available on the Internet at http://www.epa.gov/ttn/amtic/netamap.html.

Area Served

Overview

Sites are ranked based on their area of coverage. Sites that are used to represent a large area score high in this analysis. Area of coverage (area served) for a monitor can be determined using the Thiessen polygons technique. Each polygon consists of the points closer to one particular site than any other site. This technique gives the most weight to rural sites and those on the edges of urban areas or other monitor clusters.



Thiessan polygons showing the area served by ozone monitors (dots) in and around EPA Region 10.

Type: Site-by-site analysis
Complexity: **
Size of network: Moderate or larger
Pollutants: O_3, $PM_{2.5}$, SO_2, some toxics

Objectives Assessed

- Spatial coverage
- Interpolation
- Background concentration

Resources

	Tools		Data						
	GIS	Statistical Software	Concentrations	Site Locations	Population	Historical Data	Site Information	Emission Inventory	Other
Required	✓			✓					
Helpful									

Advantages

- Simple and quick to perform
- Gives weight to remote and urban boundary sites that are necessary for proper interpolation (e.g., for AIRNow maps)

Disadvantages

- Does not take into account topography or actual air basins
- Does not take into account population or emissions
- May artificially weight monitors at the edge of the analysis domain

Similar Analyses (Complexity)

- Population served (***)
- Suitability modeling (****)

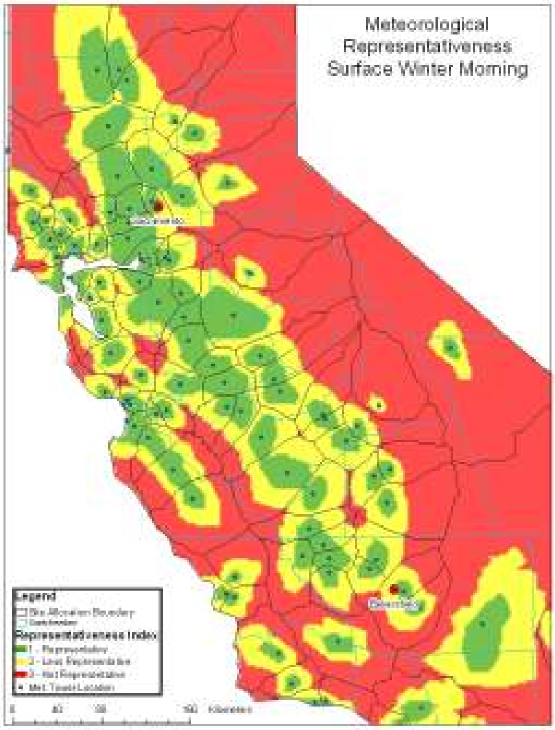
Area Served

Analysis Goals

Area served was one of five site-by-site criteria used in the national-scale network assessment. In the National Assessment, the "area served" metric was used as a proxy for the spatial coverage of each monitor. Theissen polygons (also called Voronoi diagrams) are applied as a standard technique in geography to assign a zone of influence or representativeness to the area around a given point. These polygons can be determined using a GIS package. Calculating Theissen polygons is one of the simplest quantitative methods for determining an area of representation around sites. However, it is not a true indication of which site is most representative in concentration to a given area. Meteorology (including pollutant transport), topography, and proximity to population or emission sources are not considered, so some areas assigned to a particular monitor may actually be better represented by a different monitor. More accurate determinations of representative monitors require a more sophisticated spatial analysis technique, such as suitability modeling, photochemical modeling, or parameter weighted distance.

Example

The map shows results of a study to determine zones of representativeness for meteorology towers in central California using a parameter-weighted distance technique. The method takes into account several factors to determine the "nearest" site: elevation, slope, time of day, season, height above ground, average wind speed, predominant wind direction, and geographic distance. The result is a zone of influence around each site that is more realistic than simple Theissan polygons, which only consider distance. In this map, the green areas are those that are best represented by the allocated tower for surface meteorological conditions during winter morning hours while red areas are not well represented by any of the existing measurements.



Interpretation

Regardless of the method for determining the boundaries of influence, the interpretation is the same. Sites with a greater area served are ranked higher than sites that only cover a small area. Sites that rank highly with this metric are valuable for interpolation, background concentration, and spatial coverage.

References

Knoderer C.A. and Raffuse S.M. (2004) CRPAQS surface and aloft meteorological representativeness (California Regional PM_{10}/$PM_{2.5}$ Air Quality Study Data Analysis Task 1.3). Web page prepared for the California Air Resources Board, Sacramento, CA, by Sonoma Technology, Inc., Petaluma, CA. Available on the Internet at http://www.sonomatechdata.com/crpaqsmetrep/ (STI-902324-2786).

O'Sullivan D. and Unwin D.J. (2003) *Geographic Information Analysis*, John Wiley & Sons, Inc., Hoboken, New Jersey.

U.S. Environmental Protection Agency (2001) National assessment of the existing criteria pollutant monitoring networks O_3, CO, NO_2, SO_2, Pb, PM_{10}, $PM_{2.5}$ - Part 1. Outputs from the National Network Assessment Introduction and Explanation, July 21. Available on the Internet at http://www.epa.gov/ttn/amtic/netamap.html.

Monitor-to-Monitor Correlation

Overview

Measured concentrations at one monitor are compared to concentrations at other monitors to determine if concentrations correlate temporally. Monitors with concentrations that correlate well (e.g., $r^2 > 0.75$) with concentrations at another monitor may be redundant. Conversely, a monitor with concentrations that do not correlate with other nearby monitored concentrations may be unique and have more value for spatial monitoring objectives. This analysis should be performed for each pollutant.

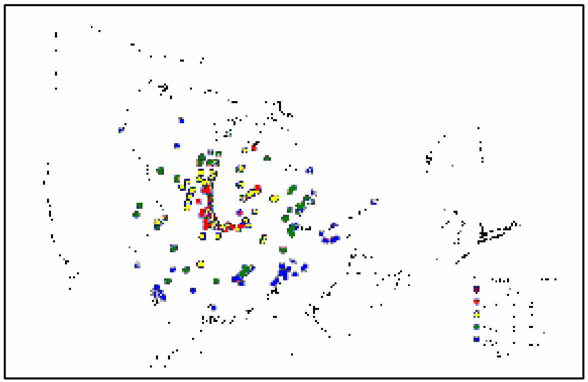


Figure from EPA Region 5 network assessment showing monitor-to-monitor correlation in and around the Chicago area.

Type: Site-by-site; Network optimization
Complexity: ** to ***
Size of network: large
Pollutants: O_3, $PM_{2.5}$, some toxics

Objectives Assessed

- Model evaluation
- Spatial coverage
- Interpolation

Resources

	Tools		Data						
	GIS	Statistical Software	Concentrations	Site Locations	Population	Historical Data	Site Information	Emission Inventory	Other
Required		✓	✓	✓					
Helpful	✓					✓	✓		

Advantages

- Gives measure of site's uniqueness and representativeness
- Useful for identifying redundant sites

Disadvantages

- Large data requirements
- Requires high data completeness
- Correlations are probably pollutant specific

Similar Analyses (Complexity)

- Measured concentrations (**)
- Principal Component Analysis (***)
- Removal Bias (***)

Monitor-to-Monitor Correlation

Analysis Goals

Determining the monitor-to-monitor correlation in a network requires at least two steps: (1) determining the temporal correlation between monitors through a regression analysis of concentrations; and (2) ranking the monitor's uniqueness. Step one can be accomplished most simply by calculating Pearson correlation coefficients (r^2) between each monitoring pair. Simple linear regressions can introduce error in the correlation coefficients, since they assume the ordinal axis has no error. Alternative methods include calculating Deming Regression or other types of correlation coefficients. In addition, choice of monitoring metrics may influence results (i.e., 1-hr peak ozone, every hour, 8-hr peak ozone, 24-hr average). Site pairs that have correlation coefficients with values near one are highly correlated and should be ranked lower than those with correlation coefficient values near zero. Sites that do not correlate well with other sites have unique temporal concentration variation relative to other sites and are likely to be important for assessing local emissions, transport, and spatial coverage. Conversely, those monitors that correlate with many other monitors may be redundant.

Example

This example shows a correlogram for ozone monitors located in the Chicago metropolitan area. Distance between monitors in kilometers is on the x-axis, and monitor-to-monitor correlation coefficients (r^2) are on the y-axis. The correlogram shows that ozone concentrations are highly correlated at most sites in Chicago with values above 0.8, and only decrease weakly as a function of distance.

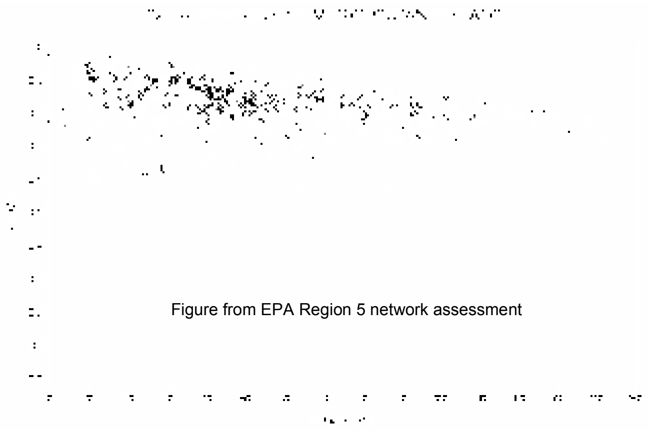


Figure from EPA Region 5 network assessment

This plot was created by calculating correlation coefficients and distance between sites.

Interpretation

This plot could be used to justify removing redundant sites, since concentrations correlate so well between most sites. Those monitor pairs with the lowest correlations (values around 0.6) would be rated as most important to retain. Note that high correlation may exist in ranges of concentrations; it is important to evaluate correlation above certain levels, as these days may be driving NAAQS decisions.

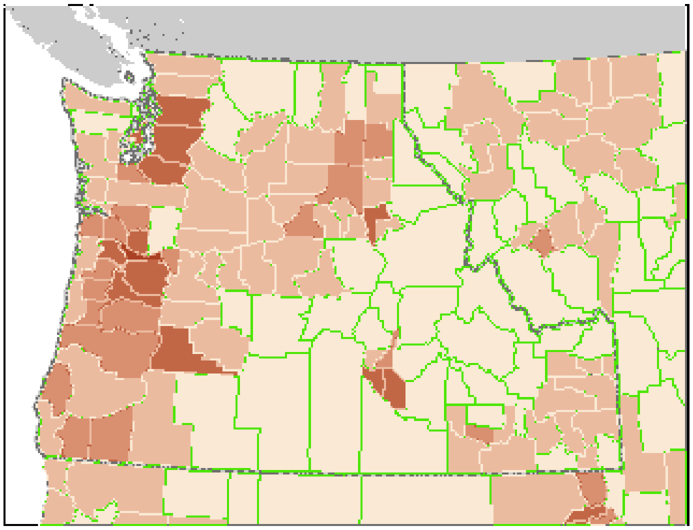
References

U.S. Environmental Protection Agency (2003) Region 5 network assessment. Presented at the *Air Monitoring & Quality Assurance Workshop, Atlanta, CA, September 9-11* by the U.S. Environmental Protection Agency, Region 5. Available on the Internet at <http://www.epa.gov/ttn/amtic/files/ambient/pm25/workshop/atlanta/r5netas.pdf> last accessed September 9, 2005.

Ito K., De Leon S., Thurston G.D., Nadas A., and Lippman M. (2005) Monitor-to-monitor temporal correlation of air pollution in the contiguous U.S. *J. Exposure Analy. Environ. Epidem.* **15**, 172-184.

Emission Inventory

Overview



Emission inventory data are used to find locations where emissions of pollutants of concern are concentrated. These locations can be compared to the current or proposed network. Does the network capture the areas of maximum emissions? This analysis can be scaled to various levels of complexity, depending on resources. The simplest version looks at county-level emissions of a single pollutant. More complex methods use gridded emissions and/or species-weighted emissions, depending on their importance in producing the secondary pollutant(s) of concern.

Type: Bottom-up analysis
Complexity: ** to ****
Size of network: any
Pollutants: primary pollutants and secondary precursors

Objectives Assessed

- Emission reduction evaluation
- Maximum precursor location

Resources

	Tools		Data						
	GIS	Statistical Software	Concentrations	Site Locations	Population	Historical Data	Site Information	Emission Inventory	Other
Required								✓	
Helpful	✓			✓				Gridded and/or speciated	

Advantages

- Scaleable in complexity and spatial resolution
- Can find areas where primary pollutant concentrations will be high

Disadvantages

- Emission inventory data are not always current or may be incomplete or inaccurate
- Emission inventory quality varies by pollutant and source type
- More useful high resolution emission inventory data are not readily available and difficult to produce
- Does not consider transport

Similar Analyses (Complexity)

Site suitability modeling (****)

Emission Inventory

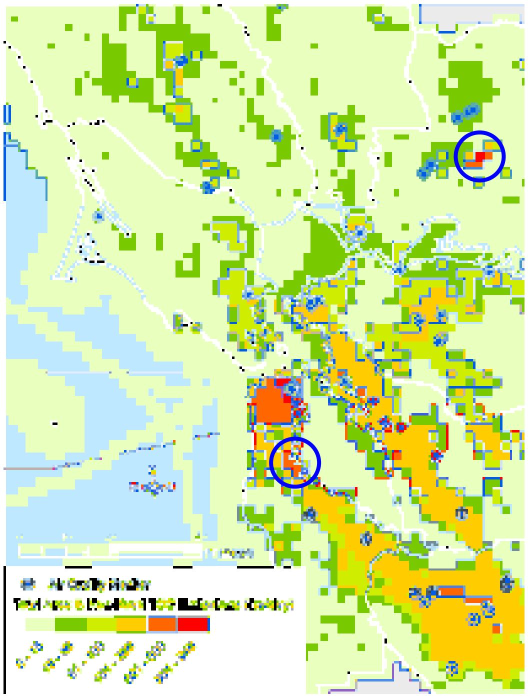
Analysis Goals

Emission inventory information is useful for determining locations of maximum emissions. At the simplest level, county-level emission data, such as the National Emission Inventory, can be compared with monitor locations. For measuring maximum precursor or primary emissions, monitors should be placed in those counties with maximum emission density (tons per year per square mile). More refined site placement decisions can be considered with more refined emission inventory data or wind data to indicate the up- and downwind directions. State and local air quality agencies can supply gridded emission inventories, which will depict more focused areas for measuring maximum precursor or primary emissions. Speciated emissions inventory data can also be used. The process of disaggregating inventory pollutants into individual chemical species components or groups of species will help determine placement of monitors that have pollutant-specific monitoring objectives.

Example

This example in and around the San Francisco Bay Area was created in ESRI ArcGIS 9.1 using the following steps:

1. Acquire a gridded emission inventory for the greater San Francisco Bay Area
2. Overlay an existing monitor network on the gridded inventory
3. Determine the estimated emissions amount at each monitor location based on the grid cell it falls within
4. For areas with high estimated emissions values, calculate the distance to the closest monitor location

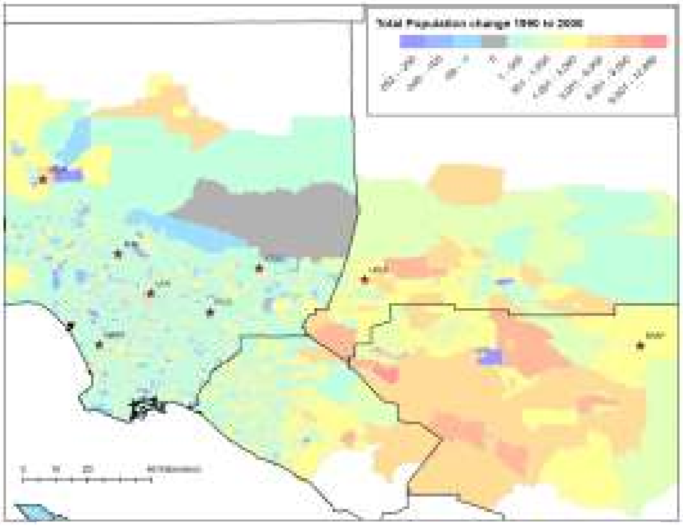


Interpretation

The table at right is an extract of the analysis example for the San Francisco Bay Area. The high emission estimates listed by grid cell coincide with a distance value to the closest monitor location. A zero distance means a monitor is located within that grid cell. The table shows that the grid cell containing the largest amount of estimated emissions has a monitor over 10 kilometers away. The two blue circles on the map show areas of high emission density with no current monitors. These areas may be good candidates for future monitoring sites.

Cell ID ; emissions (lbs/day)	Distance to closest monitor (kilometers)
4850 ; 936	10.7
1099 ; 788	0
1323 ; 777	1.4
3395 ; 664	2.1
745 ; 655	11.5
4021 ; 627	3.1
5223 ; 585	2.7
788 ; 565	8.5

Population Change



Overview

High rates of population increase are associated with increased potential emissions activity and exposure. Sites are ranked based on population increase in the area of representation. Area of representation can be determined using the Thiessen polygons technique or a more sophisticated method (see Area Served). The total population change at the census-tract or block-group level that falls within the area of coverage of a monitor is assigned to that monitor. This technique gives most weight to sites in areas with high rates of population growth and large areas of representation.

Type: Site-by-site analysis; bottom up
Complexity: ***
Size of network: any
Pollutants: O_3, $PM_{2.5}$, SO_2, some toxics

Objectives Assessed

- Population exposure
- Environmental justice
- Maximum precursor location

Resources

	Tools		Data						
	GIS	Statistical Software	Concentrations	Site Locations	Population	Historical Data	Site Information	Emission Inventory	Other
Required	✓			✓	✓	✓			
Helpful									Demographics

Advantages

- Assesses site importance for population exposure, an important regulatory goal
- Flexible (a few possible methods)
- Helpful for determining where monitoring may be required in the future
- Helps identify monitors near which emissions may have substantially changed

Disadvantages

- Does not take into account topography or actual air basins (using basic method)
- Highly resolved population data may be difficult to work with
- Changing census boundaries make it difficult to compare populated areas over time

Similar Analyses (Complexity)

- Area served (**)
- Population served (***)
- Suitability modeling (****)

Population Change

Analysis Goals

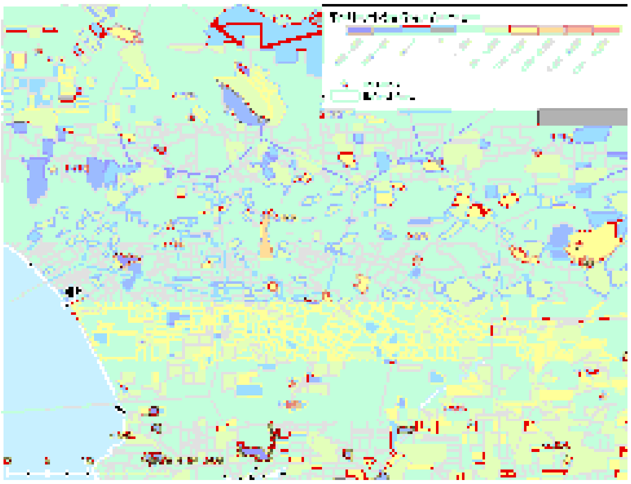
Determining the population change near a particular monitor requires two steps: (1) identify the area of responsibility for each monitor; and (2) determine the percent change in population within each area of responsibility. Step 1 can be done most simply using the Theissen polygons technique; however, a more sophisticated method that takes into account distance, meteorology, topography, etc. can also be applied (see Area Served). Step 2 can be performed using U.S. Census population data at a variety of geographic levels (i.e., census block group, census tract). However, because census boundaries change over time, it is difficult and time-intensive to link localized census boundary data. The link between census boundary files is necessary to join the comparison population values and find an accurate percent change in population. One way to accomplish this is by gridding both data sets to a common grid scale.

Sites that score high with this metric are important for assessing population exposure and tracking future emissions growth. The population change method can also be applied to assess the importance of monitors from an environmental justice perspective. The technique is the same, except population changes of specific groups (e.g., low income or minority) are calculated instead of total population. Population change can also be applied as a bottom-up technique. Using the census data, areas of rapid growth can be located and considered as potential locations for new monitors.

Example

This example in and around the Los Angeles, California, area was created in ESRI ArcGIS 9.1 using the following steps:

1. Create Theissen polygon coverage of monitoring sites
2. Link the 1990 and 2000 census tract polygons by tract ID in order to get total change in population by census tract
3. Convert census tract polygons to centroid points
4. Calculate the percent change in population for each monitoring area by spatially joining Theissen polygons to census tract centroids



Interpretation

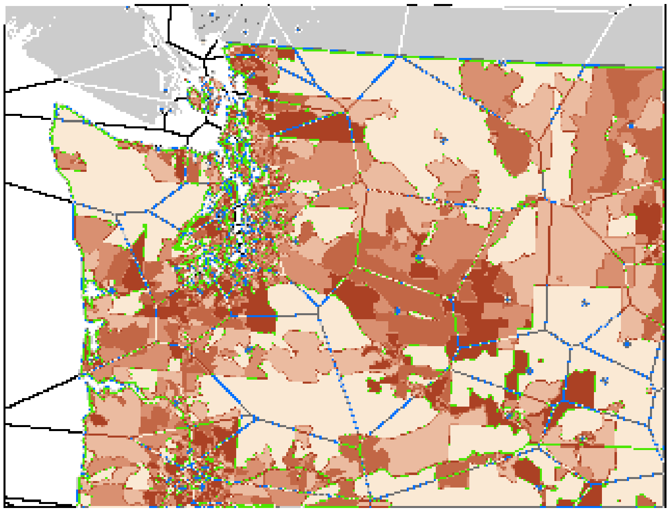
The table at right is an extract of the analysis example for Los Angeles. The area around site location 4 has seen a 13% increase in population and has, therefore, grown in importance for monitoring population exposure.

Site Location	% Population Change 1990 to 2000
1	5%
2	12%
3	10%
4	13%
5	5%
6	6%
7	5%
8	5%

References

U.S. Census Bureau, Census 2000; 1990 Census, Population and Housing Unit Counts, United States. Available at <http://www.census.gov/>

Population Served



Overview

Large populations are associated with high emissions. Sites are ranked based on the number of people they represent. Area of representation can be determined using the Thiessen polygons technique or a more sophisticated method (see Area Served). Populations at the census-tract or block-group level that fall within the area of representation of a monitor are assigned to that monitor. This technique gives the most weight to sites that are in areas of high population and have large areas of representation.

Type: Site-by-site analysis
Complexity: ***
Size of network: Moderate or larger
Pollutants: O_3, $PM_{2.5}$, SO_2, some toxics

Objectives Assessed

- Population exposure
- Environmental justice

Resources

	Tools		Data						
	GIS	Statistical Software	Concentrations	Site Locations	Population	Historical Data	Site Information	Emission Inventory	Other
Required	✓			✓	✓				
Helpful									Demographics

Advantages

- Assesses site importance for population exposure, an important regulatory goal
- Flexible (a few possible methods)

Disadvantages

- Does not take into account topography or actual air basins (using basic method)
- Highly resolved population data may be difficult to work with

Similar Analyses (Complexity)

- Area served (**)
- Counties served (**)
- Population change (***)
- Suitability modeling (****)

Population Served

Analysis Goals

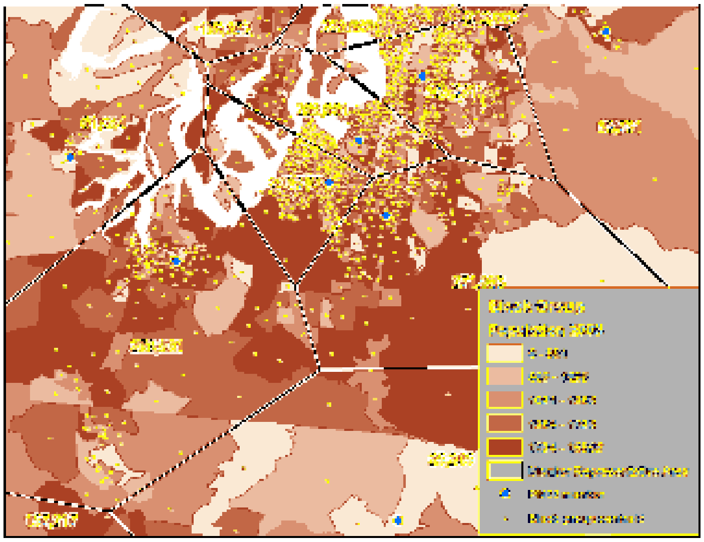
Calculating the population served by a particular monitor requires two steps: (1) determine the area of representation for each monitor; and (2) determine the population within each area of representation. Step 1 can be performed most simply using the Theissen polygons technique; however, a more sophisticated method that takes into account distance, meteorology, topography, etc. could also be applied (see Area Served). Sites that score high with this metric are important for assessing population exposure. This technique was one of five site-by-site criteria used in the national-scale network assessment. Theissen polygons (also called Voronoi diagrams) are applied as a standard technique in geography to assign a zone of influence or representativeness to the area around a given point.

The “population served” method can also be applied to assess the importance of monitors from an environmental justice perspective. The technique is the same, except populations of specific groups (e.g., low income or disadvantaged) are used instead of total population.

Example

This example in and around the Seattle, Washington, area was created in ESRI ArcGIS 9.1 using the following steps:

1. Create Theissen polygon coverage of $PM_{2.5}$ monitoring sites
2. Convert census block group polygons (available on ESRI data CDs) to centroid points
3. Sum population in each monitoring area by spatially joining Theissen polygons to block group centroids



Interpretation

The table at right is an extract of the analysis example for Washington State. Note that the population served varies by two orders of magnitude. The actual population values could be used to weight the sites, or they could simply be ranked. If the population values are used, the highly populated monitor sites will be given much greater weight than the sparsely populated monitor sites. This method could also be used within a network optimization assessment. For each network scenario, an average population served can be calculated. Scenarios with a lower average population served cover fewer persons per monitor, which may be less desirable.

530630016	423,089
530332004	383,571
530110013	379,893
530610005	349,160
530750003	32,633
530210002	28,538
530330037	25,245
530750006	12,363
530130001	9,092
530010003	8,961
530750005	2,392

References

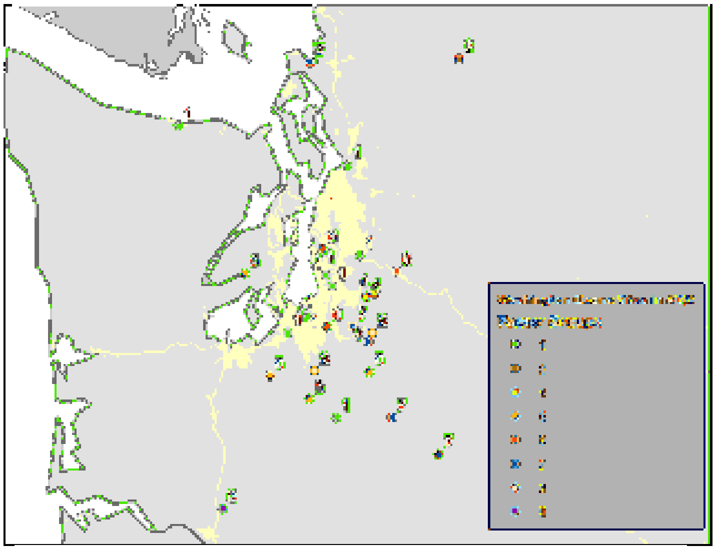
U.S. Environmental Protection Agency (2001) National assessment of the existing criteria pollutant monitoring networks O_3, CO, NO_2, SO_2, Pb, PM_{10}, $PM_{2.5}$ - Part 1. Outputs from the National Network Assessment Introduction and Explanation, July 21. Available on the Internet at http://www.epa.gov/ttn/amtic/netamap.html.

O'Sullivan D. and Unwin D.J. (2003) *Geographic Information Analysis*, John Wiley & Sons, Inc., Hoboken, New Jersey.

Principal Component Analysis

Overview

Principal component analysis (PCA) can be applied to find monitoring sites that have a pattern of variability similar to other monitoring sites. PCA assigns each monitor to a group of monitors at which pollutant concentrations behave similarly to each other. This analysis can be useful for finding redundancy in the network. It is also useful in selecting sites for other analyses (e.g., source apportionment).



Type: Network Optimization
Complexity: ***
Size of network: large
Pollutants: O_3, $PM_{2.5}$, SO_2, toxics

Objectives Assessed

- Background concentration
- Forecasting assistance

Resources

	Tools		Data						
	GIS	Statistical Software	Concentrations	Site Locations	Population	Historical Data	Site Information	Emission Inventory	Other
Required		✓	✓	✓					
Helpful	✓					✓	✓		

Advantages

- Can identify potentially redundant monitors
- Highlights spatial trends in data that help identify hot spots and large sources
- Useful for site selection for other investigatory analyses
- Identifies areas in similar air basins

Disadvantages

- Requires analyst skill to avoid over-interpretation
- Groups monitors by variability, not by concentration
- Some monitors may appear in multiple groups
- Requires high data completeness and lots of data

Similar Analyses (Complexity)

Monitor-to-monitor correlation (** to ***)
Removal bias (***)

Principal Component Analysis (PCA)

Analysis Goals

PCA is a useful tool for examining possible monitor redundancies. PCA identifies recurring and independent signals within large and noisy data sets such as ambient data (Eder et al., 1993). The results can be used to identify groups of sites with similar variance in measured concentrations. PCA is commonly available in statistical software packages. Hourly or daily samples (the more the better) with high data completeness at each site are required to perform the analysis.

Example

The example comes from an analysis of visibility measurements at Class I areas in the Central Regional Air Planning Association (CENRAP). Each color represents an identified cluster of sites that have similar variance patterns in visibility. Similar techniques have been applied to ozone in rural sites in the eastern United States (Eder et al., 1993; Lehman et al., 2004).

For its 2002 network assessment, EPA Region 5 performed positive matrix factorization (PMF) on ozone monitors. PMF is a more complex analysis that achieves similar goals.

Interpretation

The direct outputs from PCA or other factor analysis tools are not site groupings. Rather, they are principal components that describe a percentage of the concentration variance at a particular site. Sometimes, a given site may be in multiple principal components (factors), which can indicate a site that is in a transition zone between factors. Therefore, the results require interpretation to assign a specific monitor to a particular group or to understand the "transition zones" in the network. The groupings are useful to select sites for additional analyses, assess zones of influence for a given pollutant, and identify possible redundant sites.

References

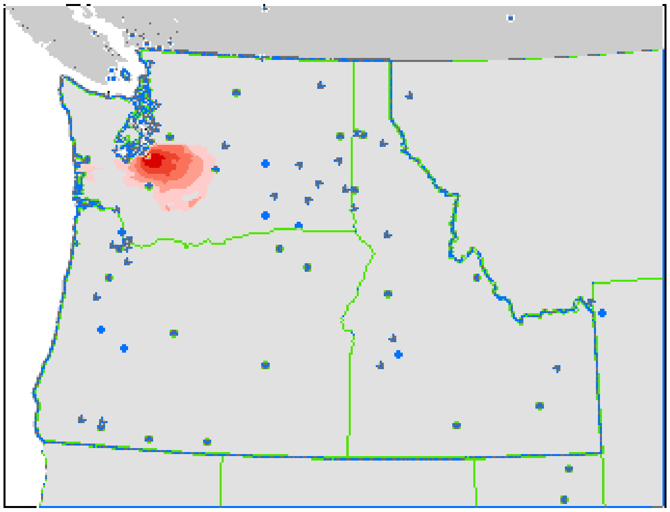
Eder B.K., Davis J.M., and Bloomfield P. (1993) A characterization of the spatiotemporal variability of non-urban ozone concentrations over the eastern United States. *Atmos. Environ.* **27A**, 2645-2668.

Lehman J., Swinton K., Bortnick S., Hamilton C., Baldridge E., Eder B., and Cox B. (2004) Spatio-temporal characterization of tropospheric ozone across the eastern United States. *Atmos. Environ.* **38**, 4357-4369.

Sullivan D.C., Hafner H.R., Brown S.G., MacDonald C.P., Raffuse S.M., Penfold B.M., and Roberts P.T. (2005) Analyses of the causes of haze for the Central States (phase II) summary of findings. Executive summary prepared for the Central States Regional Air Planning Association by Sonoma Technology, Inc., Petaluma, CA, STI-904780.08-2754-ES, August.

U.S. Environmental Protection Agency (2003) Region 5 network assessment. Presented at the *Air Monitoring & Quality Assurance Workshop, Atlanta, CA, September 9-11* by the U.S. Environmental Protection Agency, Region 5. Available on the Internet at http://www.epa.gov/ttn/amtic/files/ambient/pm25/workshop/atlanta/r5netas.pdf last accessed September 9, 2005.

Removal Bias



Overview

Measured values are interpolated across the domain using the entire network. Sites are then systematically removed and the interpolation is repeated. The absolute difference between the concentration measured at a site and the concentration predicted by interpolation with the site removed is the site's removal bias. The greater the bias, the more important the site is for interpolation. This analysis can also be performed on groupings of sites to test various site removal scenarios.

Type: Site-by-site; Network optimization
Complexity: ***
Size of network: large
Pollutants: O_3, $PM_{2.5}$, SO_2, some toxics

Objectives Assessed

- Interpolation
- Spatial coverage
- NAAQS compliance
- Background concentration
- Model evaluation

Resources

	Tools		Data						
	GIS	Statistical Software	Concentrations	Site Locations	Population	Historical Data	Site Information	Emission Inventory	Other
Required	✓		✓	✓					
Helpful		✓							

Advantages

- Gives measure of site's importance for several objectives
- Useful for site-by-site ranking and network optimization

Disadvantages

- Requires geostatistical tools
- Does not account for geographic features
- Most useful for pollutants with large networks

Similar Analyses (Complexity)

- Monitor-to-monitor correlation (**)
- Principal Component Analysis (***)

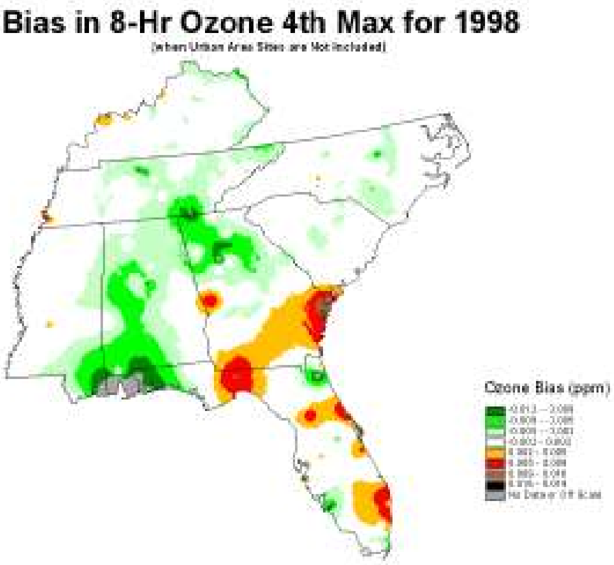
Removal Bias

Analysis Goals

Removal bias is a sensitivity analysis to determine how important a particular monitor (or set of monitors) is for interpolating concentrations across the domain. Variations of this method were performed in the National Analysis, as well as the draft assessments for EPA Regions 3 and 4. The basic method is to compare interpolations with and without data from specific monitors to determine either the bias or uncertainty that results from the removal of those monitors. Greater bias or uncertainty indicates a more important site for developing interpolations to represent concentrations across the domain. Those sites with low bias may be providing information that is redundant. With a base concentration field across the entire domain (developed through photochemical modeling), hypothetical monitors can also be tested.

Example

For the National Analysis, a site-by-site approach was used. That is, each site was removed individually and the resulting uncertainty at the site was calculated. Region 4 applied a network optimization technique, removing certain classes of sites (e.g., rural, urban core) and calculating interpolation bias. The image at right is from the Region 4 assessment. It shows the bias in 8-hr ozone when all urban sites are removed: positive bias is shown in red and negative bias in green.



Interpretation

It is perhaps counterintuitive that removing all urban sites would produce a positive bias in concentrations of ozone. This is likely because 8-hr ozone concentrations are often at maximum downwind from the areas of maximum precursor emissions (urban areas).

When looking at individual contributions to bias or uncertainty, as in the National Analysis, it is important to avoid over-interpretation. For example, clustered sites may all have low individual biases because of their redundancy and may all be candidates for removal. However, removing all of those sites would potentially create a large bias in the area. If a suite of monitors are targeted for removal, it would be useful to perform a bias analysis on the resulting network to ensure that the combined effects of removal are acceptable.

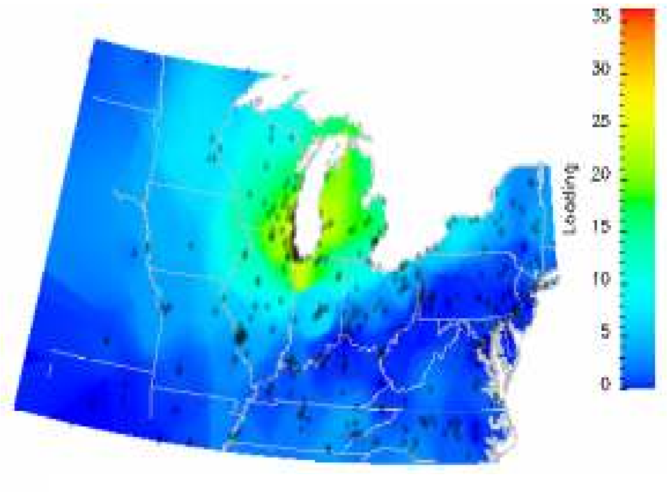
References

Cimorelli A.J., Chow A.H., Stahl C.H., Lohman D., Ammentorp E., Knapp R., and Erdman T. (2003) Region III ozone network reassessment. Presented at the *Air Monitoring & Quality Assurance Workshop, Atlanta, GA, September 9-11* by the U.S. Environmental Protection Agency, Region 3, Philadelphia, PA. Available on the Internet at http://www.epa.gov/ttn/amtic/files/ambient/pm25/workshop/atlanta/r3netas.pdf last accessed September 9, 2005.

Schmidt M. (2001) Monitoring strategy: national analysis. Presented at the *Monitoring Strategy Workshop, Research Triangle Park, NC, October* by the U.S. Environmental Protection Agency. Available on the Internet at http://www.epa.gov/ttn/amtic/netamap.html.

U.S. Environmental Protection Agency (2002) Assessment of the ambient air monitoring networks. Draft report prepared for the U.S. Environmental Protection Agency, Research Triangle Park, NC, by the U.S. Environmental Protection Agency, Region 4, October. Available on the Internet at http://www.epa.gov/ttn/amtic/files/ambient/pm25/workshop/atlanta/r4netas.pdf last accessed September 9, 2005.

Positive Matrix Factorization (PMF)



Overview

Positive matrix factorization (PMF) can be applied to a network of monitoring sites to look for areas with similar concentrations and variability. With PMF, monitors are grouped with other monitors that behave similarly. PMF also predicts concentrations at each site. These predictions can help determine which sites within a particular group are providing useful (i.e. not redundant) information.

Type: Network Optimization
Complexity: ****
Size of network: large
Pollutants: O_3, $PM_{2.5}$, SO_2, toxics

Objectives Assessed

- Background concentration
- Forecasting assistance
- Transport/border characterization
- Interpolation and understanding pollutant gradients

Resources

	Tools		Data						
	GIS	Statistical Software	Concentrations	Site Locations	Population	Historical Data	Site Information	Emission Inventory	Other
Required			✓	✓					PMF software, uncertainty estimates
Helpful	✓	✓				✓	✓		

Advantages

- Can identify potentially redundant monitors
- Highlights spatial trends in data that help identify hot spots and large sources
- Identifies areas in similar air basins
- Provides predicted concentrations and time series of factors

Similar Analyses (Complexity)

- Monitor-to-monitor correlation (** to ***)
- Principal component analysis (***)
- Removal bias (***)

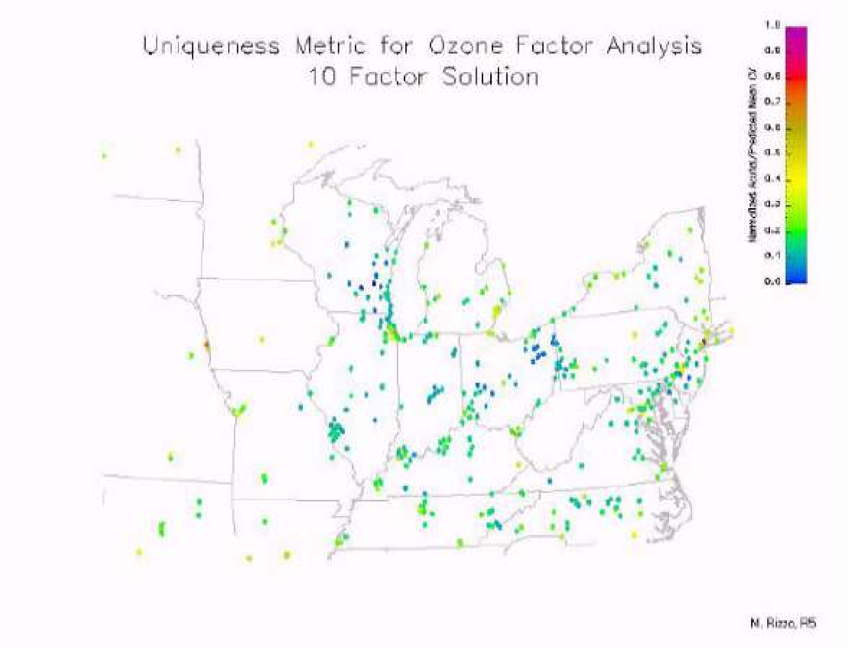
Disadvantages

- Requires analyst skill to avoid over-interpretation
- Groups monitors by variability, not by concentration
- May assign some monitors to multiple groups
- Requires high data completeness (all sites must have values for every day included in the model) and lots of data
- Requires specialized software

Positive Matrix Factorization

Analysis Goals

PMF is traditionally used as a source apportionment tool in which data from many different parameters measured at the same site are used to determine common sources of the parameters. PMF does this by separating the data into “factors” that can be interpreted as source profiles. If multiple sites measuring the same parameter are input into PMF, the factors constructed by PMF are interpreted as groups of similar sites. In addition to the factors, PMF also predicts concentrations for each factor. The factors can be used to determine redundant monitors in a network, and the ratios of actual-to-predicted concentrations for each site can indicate which sites are providing useful information. PMF also produces time series of each factor that can be used to assess transport. Specialized software, available from EPA, is necessary to perform PMF, and only days with measurements at all sites can be used in analysis. (Interpolation can be used to increase data completeness.)



Example

PMF was used in an assessment of the ozone monitoring network in EPA Region 5. This example shows the normalized coefficient of variation of the ratio of actual-to-predicted ozone concentrations for each day modeled (Rizzo and Scheff, 2004). A value close to 0 implies that a site could potentially be removed without significant loss of information about ozone concentrations in that area.

Interpretation

PMF outputs “factors,” which are groups of sites with similar concentrations. The output of PMF tells the contribution each factor makes to a specific site’s concentrations. One site can be included in multiple factors, each with a unique contribution. The results need to be evaluated to determine which group each monitor should be assigned to. These groupings, similar to PCA results, can be used to examine zones of influence for a pollutant and identify areas with redundant sites. PMF also provides predicted concentrations which can be compared to actual concentrations to determine individual sites that can be removed or relocated.

References

Rizzo, M.J. and Scheff, P.A. (2004) Assessing Ozone Networks Using Positive Matrix Factorization. *Environ. Progress.* **23** (2), 110-119.

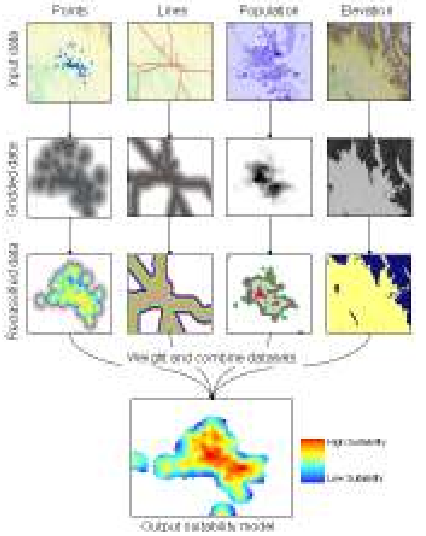
Paatero P., Hopke P.K., Hoppenstock J., and Eberly S.I. (2003) Advanced factor analysis of spatial distributions of $PM_{2.5}$ in the eastern United States. *Environ. Sci. Technol.* **37** (11), 2460-2476.

U.S. Environmental Protection Agency (2003) Region 5 network assessment. Presented at the *Air Monitoring & Quality Assurance Workshop, Atlanta, CA, September 9-11* by the U.S. Environmental Protection Agency, Region 5. Available on the Internet at http://www.epa.gov/ttn/amtic/files/ambient/pm25/workshop/atlanta/r5netas.pdf last accessed September 9, 2005.

Suitability Modeling

Overview

Suitability modeling is a method for identifying suitable monitoring locations based on specific criteria. Geographic map layers representing important criteria, such as emissions source influence, proximity to populated places, urban or rural land use, and site accessibility can be compiled and merged to develop a composite map representing the combination of important criteria for a defined area. Furthermore, each map layer input can be assigned a weighting factor based on the relative importance of each layer in the overall suitability model. The results provide the best locations to site monitors based on the input criteria.



Suitability model conceptual diagram. Input feature data are converted to gridded surfaces, classified to a common scale, weighted, and combined to form the output model.

Type: Bottom-up analysis
Complexity: ****
Size of network: any
Pollutants: any

Objectives Assessed

- Population exposure
- Environmental justice
- Source-oriented monitoring
- Model evaluation
- Maximum concentration location
- Background concentration
- Transport/border characterization

Resources

	Tools		Data						
	GIS	Statistical Software	Concentrations	Site Locations	Population	Historical Data	Site Information	Emission Inventory	Other
Required	✓			✓	✓		✓	✓	Demographics
Helpful			✓						Meteorology

Advantages

- Assesses site importance for population exposure—an important regulatory goal
- Flexible (able to run several model scenarios)
- Does not require ambient data
- Graphic results are useful to a broad audience

Disadvantages

- Time-intensive
- Weighting scheme is subjective; analysis is iterative
- Requires skilled GIS analyst
- GIS data layers can be difficult and costly to acquire

Similar Analyses (Complexity)

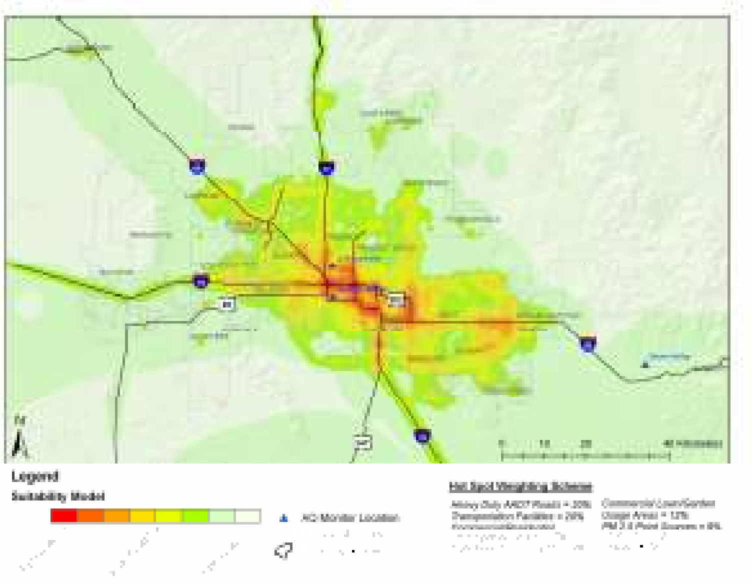
Area served (**)
County served (**)
Population served (***)
Population change (***)

Suitability Modeling

Analysis Goals

Suitability modeling can be used to determine ideal locations for potential monitoring or to assess existing monitors. The first step of a suitability analysis involves selecting criteria that can address monitoring objectives. The second step of the analysis is to acquire and process the spatial data for the suitability model within a GIS. The third and last step is to develop and run a suitability model for different model scenarios (see analysis approach figure below).

Example



In this example, suitability modeling was used to determine candidate sites for monitoring diesel particulate matter (DPM) in and around Phoenix, Arizona. Because we are interested in identifying locations where emissions for a particular pollutant are likely to be high, we must be able to spatially characterize the distribution of emissions for each major pollutant source category.

The example was created using ESRI ArcGIS 9.1 (Spatial Analysis extension) using the following steps:

1. Assess an emission inventory to determine the predominant sources of DPM in the region and determine the best available data to represent the spatial pattern of the identified emissions sources in the Phoenix region.
2. Acquire and process the spatial data (map layers) required for the analysis. For example, a map of roadways and associated traffic volumes for heavy- and light-duty vehicles were used to characterize the spatial distribution of emissions from on-road mobile sources.
3. Develop and run the suitability model for different model scenarios. Three model scenarios were defined to examine the spatial distribution of DPM emissions: (1) development of a composite map to represent the spatial distribution and density of DPM emissions based on the locations of DPM sources (hot spots), (2) proximity of total population to DPM sources, and (3) proximity of sensitive population groups to DPM sources (see the figure above).

Interpretation

Existing monitor locations, not originally located to investigate DPM, were suitable. Other locations in this fast-growing area were identified that would be suitable for assessment of DPM impacts on the population.

References

Hafner H.R., Penfold B.M., and Brown S.G. (2005) Using spatial analysis techniques to select monitoring locations. Presentation at the *U.S. Environmental Protection Agency's 2005 National Air Quality Conference: Quality of Air Means Quality of Life, San Francisco, CA, February 12-13* (STI-2645).

4. REMOVING A NAAQS COMPLIANCE MONITOR

In addition to the requirement for state or local monitoring agencies to conduct a network assessment every 5 years, the October 17, 2006 amendments to the national monitoring regulations added a requirement that a state or local agency seek the Regional Administrator's approval prior to shutting down a State or Local Air Monitoring Site (SLAMS) Federal Reference Method (FRM), Federal Equivalent Method (FEM), or Approved Regional Method (ARM) monitor. While the Regional Administrator may approve any monitor shutdown on a case-by-case basis, the monitoring regulations specify several situations where the state or local agency can be confident the request for monitor shutdown will be approved [40 CFR 58.14(c)]. The following paragraphs describe these situations.

4.1 ATTAINMENT REACHED AND EXPECTED TO BE MAINTAINED

A monitor can be removed (after Regional Administrator approval) if it is currently in attainment with the applicable NAAQS standard and if the following four tests can be met:

1. The $PM_{2.5}$, ozone, carbon monoxide (CO), PM_{10}, sulfate dioxide (SO_2), lead, or nitrogen dioxide (NO_2) monitor showed attainment during the previous five years.
2. The probability is less than 10% that the monitor will exceed 80% of the applicable NAAQS during the next three years based on the concentrations, trends, and variability observed in the past.
3. The monitor is not specifically required by an attainment plan or maintenance plan.
4. The monitor is not the last monitor in a nonattainment area or maintenance area that contains a contingency measure triggered by an air quality concentration in the latest attainment or maintenance plan adopted by the state and approved by EPA.

Tests 1, 3 and 4 are straightforward and do not require additional guidance. However, Test 2 is more complicated. While other methods may be approved by the Regional Administrator, one approach to conservatively demonstrate the second test is to use Equation 1.

$$\overline{X} + \frac{t*s}{\sqrt{n}} < 0.8*NAAQS \qquad \textbf{(1)}$$

Where $\overline{X}$ is the average design value for the last 5 yeas (or more), *t* is the student's t value for n-1 degrees of freedom at the 90% confidence level, *s* is the standard deviation of the design values, *n* is the number of records (i.e., number of design values), and NAAQS is the standard of interest.

Values for 0.8*NAAQS are provided in **Table 4-1**. Values for n, n-1, and student's t value are provided in **Table 4-2**. A minimum of five years of data for pollutants with annual NAAQS (CO, NO_2, SO_2, PM_{10}, lead) and five design values for O_3 and $PM_{2.5}$ are required for this demonstration.

Table 4-1. National Ambient Air Quality Standards[a]

Criteria Pollutant	Form of the NAAQS	NAAQS	0.8* NAAQS
CO	8-hr[b]	9 ppm	7.2 ppm
	1-hr[b]	35 ppm	28 ppm
Lead	Quarterly average	1.5 µg/m^3	1.2 µg/m^3
NO_2	Annual arithmetic mean	0.053 ppm	0.042 ppm
PM_{10}	24-hr[b]	150 µg/m^3	120 µg/m^3
$PM_{2.5}$	Annual[d] arithmetic mean	15.0 µg/m^3	12.0 µg/m^3
	24-hr[e]	35 µg/m^3	28 µg/m^3
Ozone	8-hr[f]	0.08 ppm	0.06 ppm
	1-hr[g]	0.12 ppm	0.10 ppm
SO_2	Annual arithmetic mean	0.03 ppm	0.02 ppm
	24-hr[b]	0.14 ppm	0.11 ppm

[a] As of Febrary 22, 2007. Current NAAQS can be found at http://www.epa.gov/air/criteria.html

[b] Not to be exceeded more than once per year

[c] To attain this standard, the three-yr average of the weighted annual mean PM_{10} concentration at each monitor within an area must not exceed 50 µg/m^3.

[d] To attain this standard, the three-yr average of the weighted annual mean $PM_{2.5}$ concentrations from single or multiple community-oriented monitors must not exceed 15.0 µg/m^3.

[e] To attain this standard, the three-year average of the 98th percentile of 24-hr concentrations at each population-oriented monitor within an area must not exceed 65 µg/m^3.

[f] To attain this standard, the three-year average of the fourth highest daily maximum 8-h4 average ozone concentrations measured at each monitor within an area over each year must not exceed 0.08 ppm.

[g] The standard is attained when the expected number of days per calendar year with maximum hourly average concentrations above 0.12 ppm is < 1, as determined by 40CFR, appendix H. As of June 15, 2005, EPA revoked the 1-hr ozone standard in all areas except the 14 8-hr ozone nonattainment Early Action Compact (EAC) Areas.

Table 4-2. Values for n, n-1, and student's t value.

Number of Data Values (n)	Degrees of Freedom (n-1)	Student's t value (90% confidence)
5	4	2.13
6	5	2.02
7	6	1.94
8	7	1.89
9	8	1.86
10	9	1.83
11	10	1.81
12	11	1.80
13	12	1.78
14	13	1.77
15	14	1.76
16	15	1.75
17	16	1.75
18	17	1.74
19	18	1.73
20	19	1.73

Note that the use of Equation 1 is just one approach that can be used to determine if Test 2 is met. Other approaches can be approved by the Regional Administrator. In particular, approaches that are sensitive to trends over the 5 years and/or that utilize the daily or hourly data rather than the design values may also be appropriate.

As an example, consider the following CO measurements at several sites that have been operating for five years (Table 4-3). In this example, none of the sites are in a designated nonattainment or maintenance area.

Table 4-3. Example computations for four CO monitoring sites.

Site		2001	2002	2003	2004	2005	Average $\overline{X}$	Standard Deviation s	t	N	90% Upper CI
1	8-hour	6.8	7.2	**9.6**	6.3	6.4	7.26	1.35	2.13	5	**8.6**
	1-hour	25	26	22	22	19	22.8	2.77	2.13	5	25
2	8-hour	4.9	6.3	6.5	4.4	2.0	4.82	1.81	2.13	5	6.5
	1-hour	34	15	18	22	28	23.4	7.67	2.13	5	**31**
3	8-hour	5.1	4.9	4.8	5.2	5.0	5.00	0.16	2.13	5	5.2
	1-hour	24	26	25	23	22	24.0	1.58	2.13	5	26
4	8-hour	7.4	6.8	6.4	6.4	6.3	6.66	0.46	2.13	5	7.1
	1-hour	28	27	22	25	23	25.0	2.55	2.13	5	27

CI = confidence interval

Site 1 fails Test 1 because the design value for year 2003 exceeds the NAAQS, and fails Test 2 because the 90% upper confidence interval (8.6 ppm) is greater than 80% of the applicable 8-hour NAAQS. Therefore, site 1 should not be removed. Site 2 fails Test 2 because the 90% upper confidence interval (31 ppm) is greater than 80% of the applicable 1-hour NAAQS, and therefore this site should not be removed. The remaining sites pass all four tests, and could be shut down after Regional Administrator approval.

4.2 CONSISTENTLY LOW CONCENTRATIONS RELATIVE TO OTHER MONITORS

Four tests must be passed in order to be sure a monitor can be removed on the basis that it is redundant because it has measured consistently low concentrations relative to other monitors:

1. The CO, PM_{10}, SO_2, lead, or NO_2 monitor has consistently measured lower concentrations of the same pollutant than another monitor in the same county (or portion of a county with a distinct attainment area or maintenance area, as applicable) during the previous five years.
2. Control measures scheduled to be implemented or discontinued during the next five years do not apply to the areas around both monitors.
3. Control measure changes will have similar effects on measured concentrations such that the retained monitor would remain the higher reading of the two monitors being compared.
4. The monitor is not specifically required by an attainment plan or maintenance plan.

4.3 MONITORS NOT MEASURING VIOLATIONS OF NAAQS

Two tests must be passed in order to be sure a monitor can be removed that has not measured violations of the NAAQS:

1. Any monitor for any pollutant in a county (or portion of a county within a distinct attainment, nonattainment, or maintenance area) that has not measured violations of the applicable NAAQS in the previous five years may be eligible for removal.
2. The approved State Implementation Plan (SIP) provides for a specific, reproducible approach to representing the air quality of the affected county in the absence of actual monitoring data.

4.4 MONITORS WITH SITING ISSUES

A monitor that has been determined by EPA not to be comparable to the relevant NAAQS because of monitor siting (see FR Section 58.30) may be recommended for removal.

4.5 UPWIND MONITORS

For a monitor that is designed to measure concentrations upwind of an urban area to characterize transport into the area, the following two criteria should be met for removal:

1. The monitor has not recorded violations of the relevant NAAQS in the previous five years.
2. The monitor discontinuation is tied to start-up of another station also characterizing transport.

4.6 LOGISTICAL PROBLEMS BEYOND AGENCY CONTROL

A SLAMS monitor not eligible for removal under any of the above criteria may be moved to a nearby location with the same scale of representation if logistical problems beyond the State’s control make it impossible to continue operation at its current site.

5. RECOMMENDATIONS

Network assessment facilitates developing an optimal balance between scientific quality, protection of public and environmental health and welfare, and available resources. It is a tool for identifying opportunities to

- redistribute resources to valued programs from low-priority or low-benefit ones;
- create additional resources for programs previously thought to be unaffordable;
- extract more value from existing networks; and
- fully leverage the value of EPA's or other agencies' existing networks.

Before beginning a network assessment, the purposes of the monitoring network—i.e., the network's mission (e.g., establish regulatory compliance, further scientific understanding)—should be established or carefully revisited and prioritized. With the network's purposes and priorities in mind, users of this guidance document may perform the analyses described singly or in combination to design a technical network assessment suitable for their circumstances. Site-by-site comparisons help identify monitoring sites within an existing network that are most or least valuable relative to the purposes of the network. Bottom-up analyses yield appraisals of existing monitoring sites' value relative to their optimal placement. Network optimization analyses are particularly useful when considering alternative scenarios for network design.

This guidance document addresses specific technical elements of the overall framework for network assessments that is discussed in the most recent draft of the NAAMS (U.S. Environmental Protection Agency, 2005)—specifically, statistical and objective situation analyses. However, the NAAMS recognizes other key elements of network assessment, such as *subjective* situational analyses, cost considerations, sensitive populations, preparation of regional descriptions or network histories, and solicitation of input from state and local agencies or stakeholders. Further, the NAAMS acknowledges the importance of considering non-technical factors, such as political or justice-related issues. Therefore, this guidance document represents a starting point for the development of further guidance for network assessments. It is designed to be flexible and expandable with additional types of technical analyses and examples as techniques are improved, enhanced, and more broadly applied. In addition, the development of additional guidance covering other key elements of network assessments and non-technical considerations are areas for further work.

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APPENDIX A

EXAMPLE APPLICATIONS

Several network assessments and other projects related to network assessment have already been executed for air quality monitoring networks. Here we present a few examples, covering a range of scales, objectives, and available resources.

A.1 NATIONAL ASSESSMENT

A national assessment was performed in 2000 on the criteria pollutant monitoring network. Its goal was to provide broad directional recommendations on a national level and act as a guide for more focused regional (and local) assessments. The National Assessment (U.S. Environmental Protection Agency, 2001) utilized five site-by-site analysis metrics and several weighting schemes to rank individual monitors. Each pollutant was considered separately. The five metrics used were (in the terms of this document) area served, population served, measured concentrations, deviation from NAAQS, and uncertainty on removal. Divestment opportunities were highlighted using the ranked monitors. The National Assessment is available at http://www.epa.gov/ttn/amtic/netamap.html.

A.2 REGIONAL ASSESSMENTS

In fiscal year 2003, each of the ten EPA regions began their own network assessments, building from the 2000 National Assessment. These assessments varied greatly in their methods and depth, partly motivating this document. The approaches taken by three of the regions are highlighted below.

A.2.1 Region 3 Ozone Network Assessment

EPA Region 3 employed a network optimization technique for its network assessment. The technique was based on an iterative analytical decision making processed called Multi-Criteria Integrated Resource Assessment (MIRA) (Cimorelli et al., 2003),(Stahl et al., 2002). In brief, the technique started with several possible network configurations and ranked them using 40 decision criteria organized hierarchically; the four primary level criteria are trends impact, costs, air quality, and personnel impact. The "air quality" criterion was the ability of the network to capture and properly interpolate concentrations from a base-case scenario developed with photochemical modeling. MIRA incorporates stakeholder feedback and participation throughout the process, and network configurations, design criteria, and weighting schemes were modified as learning proceeded.

A.2.2 Region 4 Network Assessment

EPA Region 4 utilized EPA monitoring re-engineering guidance (U.S. Environmental Protection Agency, 1998) for all criteria monitors except ozone and $PM_{2.5}$. The re-engineering guidance suggests monitors that do not exceed 60% of the NAAQS are candidates for termination. From this baseline, Region 4 worked with state and local agencies to determine which candidate monitors were of low value or redundant and which monitors provided useful research information or satisfied regulatory requirements.

Because none of the ozone monitors and only one of the $PM_{2.5}$ monitors in Region 4 were below the 60% threshold, additional geospatial analyses were performed using the National Assessment (U.S. Environmental Protection Agency, 2001) as a guide. Region 4 used the removal bias technique to determine the effects of removing certain classes of monitors (e.g., urban core, downwind, upwind).

A.2.3 Region 5 $PM_{2.5}$ Network Assessment

The EPA Region 5 $PM_{2.5}$ network assessment process was organized by the Lake Michigan Air Directors Consortium (LADCO) ((U.S. Environmental Protection Agency, 2003c). It is a site-by-site analysis, similar to the National Assessment, and considered four metrics: measured concentrations, monitor-to-monitor correlation, population change, and monitor density. Rather than weighting each metric and developing a combined score, the metrics were considered in a stepwise fashion. Sites were first ranked only on the most important metric (monitor density), the highest scoring monitors (i.e., those farthest from other monitors) were then eliminated from consideration for removal. The remaining monitors were ranked based on the next most important metric and so on. The monitors in the final list were then considered individually for possible elimination.

A.3 PHOTOCHEMICAL ASSESSMENT MONITORING STATIONS (PAMS) NETWORK ASSESSMENT

In 2001, a portion of the PAMS network (the northeast and mid-Atlantic) was assessed with the goal of balancing and redirecting resources to meet evolving program objectives (Main and Roberts, 2001). Starting with the existing network, the analysis identified the minimum type and number of observations required to satisfy PAMS goals, determined what monitors met the those goals, developed recommendations for eliminating monitors that were not required, and identified ways to further enhance the PAMS program in the long-term with the resources saved. To determine monitors that could be eliminated, the study looked at site pairs in close proximity and performed several statistical data analysis techniques to determine similarity, including medians, interquartile ranges, confidence intervals, and p-values. They also found that some sites were designated as types (upwind, maximum ozone, etc.) that did not match the data.

A.4 PHOENIX DIESEL PARTICULATE MATTER SITE SUITABILITY MODELING

Diesel particulate matter (DPM) is an issue of increasing concern for protecting public health. The Arizona Department of Environmental Quality (ADEQ) sponsored a study to determine possible locations for placing monitors to measure DPM ((Hafner et al., 2005). Suitability modeling was used to predict areas of high DPM emissions within Phoenix, Arizona. Maps of emission sources, emissions activity data, and meteorology were combined within a GIS model to produce a composite map identifying regions where DPM emissions are likely to be high.

United States
Environmental Protection
Agency

Office of Air Quality Planning and Standards
Air Quality Assessment Division
Research Triangle Park, NC

Publication No. EPA-454/D-07-001
February 2007