

# **Guidance on Air Quality and Air Quality Related Values Vital Signs Monitoring in National Parks**

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## **Introduction**

Air pollution damages resources and values that national parks have been set aside to protect. The National Park Service (NPS) has responsibility to remedy and prevent damage to air quality and related values. Comprehensive scientific information is essential to understand and document air quality conditions and effects of air pollution on park resources. More than ten years of monitoring in several parks shows that air pollution is degrading visibility, injuring vegetation, changing water and soil chemistry, contaminating fish and wildlife, and endangering visitor and employee health. Information generated through the existing NPS air quality monitoring network and related research programs has been used by NPS managers to secure substantial pollution reductions at specific industrial facilities, to persuade States to limit emissions from new pollution sources, and to bolster the U.S. Environmental Protection Agency's (EPA) promulgation of more stringent air pollution regulations.

## **Servicewide Air Quality Strategy**

Long-term protection of air quality in the National Park System requires a sustained effort to monitor air quality and related values and to enhance scientific understanding of how air pollution affects resources. To that end, the NPS developed an Air Quality Action Plan (The Plan) as part of the Natural Resource Initiative. Among other things, the Plan proposes to expand and enhance the current air quality monitoring network to ensure adequate representation of ecoregions, with emphasis on units most threatened by air pollution or most vulnerable to degradation. Other aspects of the Plan include funding for enhanced ambient monitoring and for short-term (up to 3-year) ecological effects projects. The Plan's budget includes an additional \$3 million over 5 years to support expanded ambient air quality and effects monitoring. Also, the Plan requests 35 additional field-based FTEs to support: 1) 0.5 FTE at all parks conducting air quality monitoring, and 2) ten full-time air quality specialists which will be strategically located in parks or field offices to provide expertise in the analysis and use of air quality information collected.

As part of the implementation of the Plan, the Air Resources Division (ARD), in consultation with field staff and others, will identify critical gaps in the Servicewide monitoring network and develop a strategic plan for additional monitoring, taking into account scientific needs and air quality improvement goals. To aid this effort, the ARD has contracted with the University of Denver (DU) to develop a GIS-based map that uses data from all federal, state, and locally operated air quality monitors throughout the United States to interpolate (estimate) air quality data for each NPS unit in a Vital Signs Network. DU will also evaluate the level of confidence in each of the interpolated values. The DU project should be completed in the fall of 2001. The ARD anticipates that the 32 Vital Signs technical committees will identify ambient air quality and effects monitoring needs in each Vital Signs Network. When possible, the Network-specific needs will be incorporated into the Servicewide air quality monitoring strategy. If identified local needs do not fit into Servicewide needs, ARD will help the Networks seek funding from other sources.

## **Ambient Air Quality Monitoring**

The Servicewide air quality monitoring strategy will help ensure NPS compliance with the Clean

Air Act and associated regulations, the NPS Organic Act, and the Government Performance and Results Act (GPRA) as well as develop the comprehensive scientific information that is essential to understand and document air quality conditions in parks. To that end, the ARD has identified the following list of core ambient air quality parameters that should be monitored in each Network.

- Wind speed and direction (adjacent to pollutant monitor(s))
- Relative humidity (adjacent to pollutant monitor(s))
- Ozone (O<sub>3</sub>)
- Wet deposition (including pH, sulfate, nitrate, and other ions)
- Atmospheric particulates (including sulfate, nitrate, ammonium, and elemental and organic carbon)

ARD also recommends that sulfur dioxide (SO<sub>2</sub>) monitoring be conducted, using continuous analyzers or weekly filter-pack measurements, in parks located near large cities or other significant sources of SO<sub>2</sub> emissions.

Chemical transformation, topography and elevation can influence air pollutant concentrations. For example, concentrations of SO<sub>2</sub> are high close to a source, while downwind of the source, SO<sub>2</sub> is converted to sulfate and sulfuric acid, which contribute to acid deposition and visibility impairment. Wet deposition of nitrate and sulfate is usually greater at high elevations than low elevations due to increased snowfall. Ozone concentrations are frequently higher on ridgetops and in major river drainages with steep topography. Therefore, pollutant concentrations can differ significantly within a Network and even within a large, topographically complex park. The Network technical committee should ensure that existing and proposed monitoring adequately represent the range of pollutant concentrations in the Network (ARD can assist with this evaluation).

In addition to the NPS, the U.S. Fish and Wildlife Service, the U.S.D.A. Forest Service, states, and EPA conduct ambient air quality monitoring. Network technical committees should identify all ambient monitoring sites that occur in or near the area that encompasses the Network. These sites should then be evaluated to determine how well they represent the Network (Again, ARD can help Networks acquire this information). In many cases, sites are part of a national ambient air quality monitoring network. For example, ozone, SO<sub>2</sub> and particulate matter data that are collected using EPA protocols, and that meet EPA data quality criteria, are entered into EPA's Aerometric Information Retrieval System (AIRS), which provides summary data via the Internet (protocols for gaseous pollutant and meteorology monitoring, and related information, available at <http://www2.nature.nps.gov/ard/gas/network.htm#ops>). Similarly, wet deposition data that are collected as part of the National Atmospheric Deposition Program/National Trends Network (NADP/NTN) are available on the Internet (protocols for NADP/NTN data collection available at <http://nadp.sws.uiuc.edu/lib>).

Estimated capital and operating costs of monitoring the core, and other common, air quality parameters are provided in the table below. Note that these are very rough estimates since factors such as remoteness of the site, existence of line power, *etc.* may greatly influence costs.

TYPE OF MONITOR	CAPITAL COST	ANNUAL COST
<b>Visibility:</b>		
Camera	\$8,000	\$5,000
Nephelometer	\$29,000	\$25,000
Transmissometer	\$46,000	\$25,000
Particulates	\$15,000	\$30,000
<b>Criteria or Gaseous Pollutants:</b>		
Equipment shelter, facilities, site preparation	\$30,000-\$40,000	\$500
Utilities – power, phone, access	\$6,000-\$20,000	\$2,000
Ozone	\$25,000	\$28,000
Filter-pack sulfate, nitrate, nitric acid, and SO <sub>2</sub>	\$15,500	\$12,000-\$15,000
Continuous SO <sub>2</sub>	\$25,000	\$26,000
<b>Meteorology</b> (wind speed, wind direction, temperature, relative humidity, solar radiation, and precipitation)	\$15,000	\$10,000
<b>Wet Deposition (NADP/NTN)</b>	\$12,000-\$15,000	\$7,000
<b>Station Operator</b>	---	\$8,000-\$20,000

For some Networks, additional ambient air quality-related concerns may be identified. For example, other parameters that could be monitored include dry deposition, snow chemistry, fog chemistry, pesticides, dioxins, hazardous air pollutants, mercury, and other trace metals. For parks in urban areas, carbon monoxide, volatile organic compound, or nitrogen dioxide monitoring may be warranted. In some situations, it may be desirable to perform tracer studies to identify the primary sources of pollution affecting the parks.

Monitoring protocols already exist for many of the ambient air quality parameters. The ARD will coordinate development of additional protocols (with outside experts, if necessary) if a Servicewide need is identified.

### **Monitoring Air Pollution Effects on Resources**

Air pollution-sensitive resources are typically called air quality related values, or AQRVs. Resources differ significantly in their sensitivity to air pollutants, so air pollution effects will be a greater concern for some Networks, and some parks, than others. For example, fumigation studies have identified a handful of species, *e.g.*, Ponderosa pine, black cherry, and others, that are sensitive to ozone. While the level of sensitivity differs based on genotype and local environmental conditions, these species still represent the best candidates for ozone injury surveys. If known ozone-sensitive species do not occur in the Network, an intensive and expensive effort would be required to identify the most appropriate species to monitor. High elevation alpine lakes and low order streams on granitic bedrock (resistant to weathering) are most susceptible to acidification. Watersheds on easily weathered bedrock are not likely to be sensitive to acid deposition. Therefore, it is important to consider the potential sensitivity of resources in the Network and evaluate the ambient air quality data to determine if there is a need to monitor AQRVs.

Each Vital Signs Network technical committee should compile and evaluate existing information on park resources that are potentially sensitive to air pollution. This information should include lists of air pollution sensitive plant species in each park (the lists can be compiled by comparing park plant lists to master lists of air pollution sensitive species), data on surface water chemistry, and reports of any air pollution effects monitoring (*e.g.*, foliar injury surveys, invertebrate or fish studies, soil monitoring) that would be relevant to the Network. Note that such monitoring may have been conducted by another agency in the area or by a park in another Network.

Resource monitoring for air pollution effects can often be incorporated into programs developed to monitor for other stressors. For example, if a Network chooses to initiate a lake or stream monitoring program, including water quality parameters such as pH, acid neutralizing capacity, conductivity, and others will provide information regarding sensitivity to atmospheric deposition. Concurrent aquatic biota surveys (*e.g.*, phytoplankton, macroinvertebrates, fish) could indicate if atmospheric pollutants are affecting sensitive species. Ozone injury surveys could be incorporated into a general vegetation monitoring program. Technical committees should explore opportunities for integrating air pollution effects monitoring with other resource monitoring programs in the Network. The ARD can provide monitoring protocols for surface water chemistry and ozone injury monitoring, among others (see appendices for examples). The ARD can also provide guidance on the suitability of developed protocols for Networks and parks and will coordinate development of additional protocols (with outside experts, if necessary) if a Servicewide need is identified.

### **Link to Water Resources Division-Funded Water Quality Monitoring**

The Network scoping process for water monitoring should consider the potential effects of air pollutants on surface waters. Aquatic systems can be good indicators of air quality. Deposition of sulfate and nitrate can acidify surface waters with low buffering capacity, while nitrate and ammonia deposition can eutrophy nitrogen-limited systems. Network technical committees should evaluate the physical and chemical characteristics of their aquatic systems, as well as examine representative deposition data (*e.g.*, NADP/NTN) to determine the need to monitor aquatic systems for air pollution effects. It is important to determine if any aquatic systems in the Network are already impaired by air pollution, as well as to identify and monitor air pollution-sensitive systems to ensure they remain in pristine condition.

The physical characteristics of waters that are sensitive to acid deposition include those at moderate to high elevation, in areas of high relief, with flashy hydrology and minimal contact between drainage waters and soils or geologic material that may contribute weathering products to solution. Sensitive streams are generally low order. Sensitive lakes are generally either small drainage systems or small seepage systems that derive much of the hydrologic input as direct precipitation to the lake surface. Streams sensitive to acid deposition have been identified in parks in the Southern Appalachian Mountains, while sensitive lakes have been identified in parks in the Sierra Nevada, Cascade, and Rocky Mountains. Sensitive waters generally have specific conductance below 25  $\mu\text{S}/\text{cm}$ , acid neutralizing capacity (ANC) below 100  $\mu\text{eq}/\text{l}$  for episodic acidification (50  $\mu\text{eq}/\text{l}$  for chronic acidification), total base cation (calcium, magnesium, sodium, and potassium) concentration below 100  $\mu\text{eq}/\text{l}$ , and pH below 6.0.

It may be necessary to inventory systems that are potentially sensitive to acid deposition before finalizing a water monitoring plan. Parameters that should be measured as part of an inventory include specific conductance, ANC, base cations, ammonium, sulfate, nitrate, chloride, pH, and water temperature. In eastern U.S. parks, dissolved organic carbon should also be measured.

Water samples should ideally be taken at the time of greatest sensitivity, *e.g.*, immediately following snowmelt, and should follow appropriate sample collection, analysis, and QA/QC procedures for acid deposition. If air pollution-sensitive or air pollution-impaired waters are identified and incorporated into a water monitoring program, in addition to the parameters listed above, it may be appropriate to include some of the following chemical constituents: dissolved organic carbon (for western U.S. parks), dissolved inorganic carbon, dissolved oxygen content, total and dissolved phosphorus, total and dissolved nitrogen, aluminum or other metals. It would also be useful to collect some baseline soil chemistry data including cation exchange capacity, base saturation, pH, and bulk density. Specific sample collection protocols should be developed and documented.

In general, freshwater systems are phosphorus limited, while coastal systems are nitrogen limited. Therefore, eutrophication will primarily be a consideration for Networks with coastal parks. If eutrophication is a concern, the parameters that should be monitored include chlorophyll a, organic and inorganic nitrogen, total phosphorus, and turbidity.

Because sensitive surface waters generally have low concentrations of many significant ions, it is critical that Networks use water quality laboratories that are experienced in evaluating low ionic strength samples. It is also important that ARD be able to compare results between labs so that data can be “rolled up” to address national issues and needs. To that end, selected laboratories should participate in specific laboratory performance blind audit programs. For example, the Canadian National Laboratory for Environmental Testing, National Water Research Institute, Environment Canada sends out ten blind samples to participating laboratories every six months and performs inter-laboratory comparisons of the reported results.

Network staff should contact the ARD for assistance in evaluating deposition and water quality data, identifying air pollution-sensitive aquatic systems, and implementing air pollution-related water monitoring protocols. This coordination will enable individual Networks to meet their monitoring objectives, while at the same time ensuring the ARD can use data collected by all Networks to promote Systemwide air quality protection.

### **Example of the Process**

In the spring of 2000, the ARD compiled air quality information to assist in the monitoring scoping workshop for the Coastal and Barrier parks Network which includes Assateague Island National Seashore (NS), Cape Cod NS, Colonial National Historical Park (NHP), Fire Island NS, Gateway National Recreation Area (NRA), George Washington Birthplace National Monument (NM), Sagamore Hill National Historic Site (NHS), and Thomas Stone NHS. Given the geographic extent of the Network, and the proximity of a number of the parks to large cities, ARD staff surmised that air quality parameters should be monitored in a number of locations throughout the Network. Staff determined the location of the nearest ozone, SO<sub>2</sub>, particulate matter, wet deposition, dry deposition, and visibility monitors for each unit in the Coastal and Barrier parks Network, and determined whether the parks were located in or near a non-attainment area, *i.e.*, an area which is not in compliance with a human health-based National Ambient Air Quality Standard. The ARD concluded that most parks in this Network had adequate coverage of all air quality parameters. Note that this assessment was based solely on distances between monitors and parks, the DU products mentioned above will improve the ability to assess how well off-site data represent conditions in a park. From an ambient monitoring standpoint, ARD recommended only that the Coastal and Barrier parks Network install an ozone monitor at Assateague Island NS.

ARD staff also evaluated available resource data, including water quality inventory reports prepared by the Water Resources Division. Ozone sensitive plant species lists were developed for the six parks in the Network that had plant lists in NPFLORA. All six parks have good candidates for foliar injury monitoring, *i.e.*, black cherry (*Prunus serotina*), trembling aspen (*Populus tremuloides*), and/or common milkweed (*Asclepias syriaca*). Such monitoring should be considered if ambient data indicate high ozone concentrations exist near a park. Fire Island NS, Gateway NRA, George Washington Birthplace NM, Sagamore Hill NHS, and Thomas Stone NHS are all located in or near ozone nonattainment areas, so ozone injury surveys are warranted. Given the potential acid-sensitivity of some of the ponds at Cape Cod NS, ARD recommended water quality monitoring. During the scoping workshop, eutrophication from nitrogen deposition was identified as a potential concern at a number of parks in the Network.

### **Data Management**

As discussed above, many of the ambient air quality monitoring data are managed as part of national databases. These databases, as well as statistical analyses and data summaries, are available to NPS staff via the Internet. ARD will assume responsibility for ensuring that ambient data collected under the Air Quality Action Plan undergo quality assurance and are included in the appropriate national databases. The Natural Resources Information Division is developing a natural resource information management system called Synthesis. The Inventory and Monitoring Program is encouraging Networks to use Synthesis to manage data collected as part of the Vital Signs program, and ARD assumes Synthesis would be a logical platform for managing air pollution effects monitoring data. When Networks develop or populate databases for the Vital Signs monitoring data, ARD can help identify appropriate data fields for ambient air quality and AQRV information.

### **Other Funding Sources**

Because it is likely that technical committees will identify far more monitoring needs than can be funded by either the Vital Signs Program or the monitoring component of the Servicewide air quality strategy, it is important for Networks to explore other sources of funding. Other possible internal sources of funding include park fee demo programs, and park construction and maintenance funds which can be used to cover capital costs such as purchase of air monitoring equipment and monitoring shelters. The EPA, states, or local communities may be interested in installing an ambient monitor in a park to collect representative rural data. The EPA or other land management agencies may be willing to collaborate on AQRV monitoring. The ARD can help Networks prepare proposals for these and other potential sources of funding.

### **Air Quality Data Websites**

NADP/NTN - <http://nadp.sws.uiuc.edu/>

Dry deposition - <http://www.epa.gov/castnet/>

IMPROVE - <http://vista.cira.colostate.edu/improve/>

Pollution sources and air quality data - <http://www.epa.gov/air/data/>

Pollution sources and air quality data - <http://www.epa.gov/ttn/rto/areas/>

Pollution sources and air quality data - <http://www.epa.gov/agweb/>

Air toxics monitoring - <http://www.epa.gov/glnpo/air/>

Dioxin monitoring - <http://www.epa.gov/ncea/1page.htm#air>

Persistent Organic Pollutants (POPs) - <http://www.chem.unep.ch/pops/default.html>

### **Appendices**

(Note: The following protocols are provided for information purposes only. It is important that Networks work with ARD or other experts in air pollution effects monitoring to identify the most up-to-date monitoring protocols and tailor them to Network needs.)

- A. Protocol for Snowpit Chemistry Sampling
- B. Protocol for High Elevation Lake Chemistry Sampling
- C. Protocol for Identifying Ozone Injury on Eastern Forest Plants
- D. Protocol for Identifying Ozone Injury on Western Pines

## APPENDIX A

### Protocol for Snowpit Chemistry Sampling

U.S. Geological Survey  
Water Resources Division  
Denver, Colorado

#### PROCEDURE

##### **1) Locate Site**

Be aware of avalanche danger along the route. If current storm conditions indicate dangerous loading, choose an optional site in the vicinity along a safer route. Use provided site maps, GPS, and altimeter to locate sampling sites as close to designated locations as possible.

Sites should be chosen away from open roadways and in reasonably level and sheltered clearings protected by trees where snow has not been drifted or wind-scoured. The depth probes can be used to find a site of uniform depth. Avoid onsite disturbances, such as excessive tree litter and animal activity. It is imperative to choose site locations where mid-winter melt is minimal. Avoid sunny, south-facing slopes. Check the following:

- a) soil conditions beneath the snowpack should be relatively dry or frozen.
- b) the snowpack should appear dry, there should be no visible “free-water.”
- c) 30 to 40 cm above the soil, snow temperatures should be  $< 0$  C.

If these conditions do not exist at the designated elevation, document your observations and move to another location.

##### **2) Dig Snow Pit**

Once spot is selected for digging the pit, scribe a line perpendicular to the sun to delineate the face of the pit wall, dig the pit so the wall faces away from the sun, and avoid walking on or shoveling snow on the snow surface for at least 1 m on the other side of the line (where the pit wall will be sampled). For deep snowpits, the width of the column should be narrow enough to cut steps in the sides so that the top layers can be reached easily. Metal shovels can be used to dig the pit, but the final vertical surface (approx. 50 cm wide) of the pit-wall should be cut into with the clean plastic shovel for at least 10-20 cm. The sample shovel and ice scoop are stored in a protective bag and should be “snow-rinsed” before each site. Bisect pit wall with a 2 m fiberglass ruler vertically with 0 cm at the soil-snow interface; do sampling on one side, and temperature and density measurements on the other side to avoid contamination of sample-face.

##### **3) Collect Samples**

###### A) Duplicate snow columns:

Avoid contamination of very dilute snow samples from soil, forest litter, sweat, etc. Discard the top 2 cm of snow at snow-air interface. With all workers doing sampling wearing plastic gloves and liners provided, one person holds zip lock bag open being careful not to touch inside of bag, while another person scoops out a vertically representative column of snow using the plastic shovel and ice scoop provided. This process can be tedious in a deep and/or very consolidated snowpack. One method that works well is to cut into the face with the ice scoop about 1-2 cm and remove a column of these dimensions by 10-15 cm increments starting at the top and working downward. With shovel cutting horizontally into the column to be removed, vertically scoop out sample down to shovel with the ice scoop and dump this increment into the zip lock bag. Repeat at 10-15 cm intervals downward until within about 5 cm of soil. If soil gets on blade or scoop, plunge into snow away from sample-face several times to clean. Fill bags to no more than

2/3 full to allow for closure of the bags. Shape bags in roughly rectangular shapes before the snow sets up--basketball shaped samples do not store efficiently. Label bag with Site ID, Sample number (1 of 2, 2 of 2, etc.), date and time. Repeat.

#### B) Field Blank

Each sampling team will do one field blank at a chosen site. Label zip lock bag “Field Blank” and include Site ID, date and time of sample. Pour field blank water over the shovel into the scoop. Also rinse the scoop with the water and carefully pour into zip lock bag. Deflate the bag as much as possible and seal.

### 4) Complete Data Sheet

A) Fill in location, time, and conditions data, please be thorough but concise.

B) scale and label snowpack by 10 cm increments in “Depth” column on datasheet. Clearly mark the air-snow and snow-soil interfaces. Make physical measurements of:

1) **thermometer precision:** place all thermometers in same layer of snow and note precision before and after measurement of temperature profile. If a single thermometer is out of calibration with the others, set aside.

2) **temperature profile:** at 10 cm intervals for pits < 2 m deep, 20 cm intervals after that

3) **density profile:** tare the balance with the density cutter, use density cutter (1-liter) and lid to remove block of snow every 10 cm, staggering every other sample.

4) **hardness:** note the hardness of the snowpack (fist, 4 fingers, 1 finger, pencil or knife). Note ice lenses, discolored layers, unusual snow, etc. in comments adjacent to layer.

5) Sign the datasheet.

### 5) Refrigerate Samples

In the field, extra care should be taken to keep all samples frozen, by keeping buried in snow...be sure to use flagging, so the samples are not lost.

Upon return to the truck, place samples in coolers blue-ice blocks. To avoid contamination of sample, do not use H<sub>2</sub>O-ice. Maintain temperature below -5 degrees C.

### 6) Ship Samples

It is very important that samples do not arrive at the lab over the weekend. Ship Monday through Wednesday only, overnight via Federal Express.

For additional information, contact Don Campbell at [dhcampbe@usgs.gov](mailto:dhcampbe@usgs.gov) or (303) 236-4882 x298.

## APPENDIX B

### Protocol for High Elevation Lake Chemistry Sampling<sup>(1)</sup>

#### BASIC HYDROLOGY OF THE STREAM/LAKE CONTINUUM

To effectively design or conduct a surface-water sampling program some knowledge of basic hydrology is needed. The chemistry of lakes and streams is largely a function of what surfaces and substances the inflowing water has contacted and for how long, and of some basic physics driven by sunlight and wind. Thus, selection of lakes and streams as monitoring sites needs to consider the hydrology of the system so that the chemistry can be interpreted in the proper context. If the site is to monitor the effects of acid rain or other atmospheric inputs on surface water, then the hydrology should minimize the possibility of processes that neutralize the atmospheric inputs.

Lakes and streams with factors that minimize the contribution of weathering products (and thus maximize the influence of atmospheric precipitation) have at least one of the following characteristics, perhaps several:

- 1) Large surface area of lake or stream to watershed area ratio.
- 2) Subject to periods of great inflow discharge from snowmelt, rain on snowmelt, intense thunderstorms, or hurricanes.
- 3) Little exposed soil in the watershed or, at least, near the lake or stream. Soil zones that do exist should be shallow.
- 4) Topographically perched relative to the local ground water, e.g., in topographic saddles, near places of rapid topographic drop-off or cliffs. This requires that an effective "seal" of clay or organic matter keep the lake from draining faster than it can be recharged by inflow. In such systems, the local groundwater table is lower than the lake surface or the groundwater level is about the same elevation as that of the lake surface, thus providing little or no pressure difference to cause ground water to flow into the lake. Instead, the lake normally drains to ground water or there is insignificant contribution by ground water to the lake.

The discussion above centers around weathering products, which are important in determining sensitivity of lakes and streams to atmospheric deposition and some other sources of acid. Some types of bedrock, e.g. limestone and other sedimentary rocks with significant amounts of carbonate, weather readily and provide great protection against acid deposition. Other types of bedrock, e.g., granite and quartzite, weather slowly and often underlie areas that contain sensitive lakes and streams. Such systems also may be very sensitive to other inputs, such as nutrients from atmospheric deposition or land use disturbance.

#### PROTOCOL REQUIREMENTS

##### Bottles

The bottles required for samples vary with the constituents to be sampled and the laboratory doing the analysis. Sometimes, several bottles will be required for each sample, with differing processing of each bottle required in the field or at the laboratory. The bottles used need to be non-reactive with the constituents measured from that bottle. Most constituents are collected in polyethylene bottles, but organic constituents such as pesticides typically are collected in glass bottles. The sample must be large enough for the laboratory to do any needed processing and analysis and have sufficient excess if a rerun of the archived sample is needed. Each bottle must have a waterproof label and all the information required by the laboratory must be written with waterproof ink. Because the needs of the laboratory must be considered it is advisable to obtain all bottles from the laboratory doing the analyses. The laboratory also may be able to supply appropriate labels

with pre-printed data fields showing what information is required.

To minimize contamination of the sample by impurities in the bottle itself polyethylene bottles should be rinsed three times with deionized water, filled with deionized water, and allowed to stand for at least 48 hours. This service may be provided by the laboratory supplying the bottles. Bottles should be carried to the sampling site filled with deionized water from the laboratory. The deionized water then is emptied, in a manner so as not to mix the deionized water with the water to be sampled, immediately prior to sampling and the bottle and cap rinsed three times with sample. Then the sample is collected and the bottle capped. At all stages of sampling care should be taken not to contaminate the inside of the bottle or cap with fingerprints or soil and other impurities. Powder-free gloves should be worn to minimize contamination by the sampler's arm as the sample is collected. It requires only very small amounts of solids such as soil to overwhelm the chemistry of the water sample itself. For the analysis of trace metals acid cleaning of the polyethylene bottles is required; the laboratory providing the bottles should do this. These bottles and their caps are rinsed three times with sample before collecting the sample.

Glass bottles used for organic analyses often are cleaned by heating in a furnace to burn off all traces of organic materials. These glass bottles do not need to contain deionized water nor do they require rinsing with sample before sample collection.

To assure that the bottles used are not contaminating the sample it is necessary to analyze samples of "blank" water that have been stored in the bottles for time periods comparable to the amount of time sample remains in the bottle before analysis. This is most conveniently done on each batch of bottles obtained from the manufacturer. Thus, it is most efficient if the laboratory supplying the bottles perform this quality assurance test. It is necessary to know the composition of the deionized water prior to being stored in the bottles and then analyze samples after storage in the bottles. The stored water should show constituents below the detection limit. If significant concentrations are found the batch may need to be rejected or the bottles may need additional cleaning.

Bottles need to be protected from contamination during transport to and from the sampling site. It is most convenient to keep the complete set of pre-labeled bottles for each site together in a sealed plastic bag. This minimizes the chance for dust to accumulate on the bottle and potentially contaminate the sample, as well as making all the required bottles readily available. If one or more bottles have some remaining acid from cleaning, such bottles should be packed separately to minimize the potential for cross contamination, e.g., of nutrient samples by nitric acid washed bottles.

Bottles need to be protected from excessive heat to minimize degradation of the sample. Excessive cold can freeze samples, which may rupture bottles or irreversibly precipitate out some constituents. Sunlight not only can heat the sample, but also encourage the growth of phytoplankton. The bottles filled with sample should be stored in the dark and just a few degrees above freezing. Thus, packing them with ice, cold packs, or snow if it is handy, in an insulated cooler is best. Dry ice should not be used because it could freeze the sample. If an extended period without cooling is the only feasible option, filtration of the samples at the site of collection and addition of preservatives such as nitric acid to some aliquots should be used to protect the integrity of the sample.

### **Filters**

Many samples require filtration either in the field or the laboratory. This filtration separates

constituents dissolved in the water from detritus and other solids that may alter the chemistry of the sample before it can be analyzed. Filtration in the field adds the possibility of sample contamination if not done carefully. Program needs and the nature of the water being sampled determine whether the greater risk is from field filtration or from sample degradation before filtration at the laboratory. Samples containing large amounts of suspended solids or organic matter and samples analyzed for trace constituents (such as dissolved iron) are the most susceptible to degradation before filtration at the laboratory. If samples are filtered in the field, it is possible to check for contamination by processing (filtering) deionized water of known composition at the same time to determine whether field filtration is associated with contamination.

As with bottles, each batch of filters must be checked to assure that they do not contaminate the samples. For the same reasons discussed for bottles, it is most efficient if the laboratory supply and quality assure any filters that are used for field filtration. As with bottles, care should be taken to avoid contamination of the filter and filter apparatus from fingerprints and soil. The filter and apparatus need to be rinsed well with either deionized water or sample prior to filling the sample bottles. Because filtering apparatus varies greatly in size, it is impossible to give universal guidelines on the amount of rinse needed. Thus, it is most efficient if the laboratory specifies or provides any filtering apparatus and determines an appropriate rinse protocol for that apparatus. Filters commonly used are made of polycarbonate or are cellulose-based, e.g., cellulose acetate. The pore size of the filter is critical in determining what actually is analyzed in filtered samples. A pore size of 0.45 microns is commonly used for many constituents, .1 microns is used for many metals such as aluminum; however, smaller pore sizes may be needed for the analysis of some trace metals if colloidal material is present in significant amounts. This is best determined by comparing a series of aliquots collected with filters of differing pore sizes, for example, 0.4 and 0.1 micron filters. This needs to be done only in studies that need the best estimates of dissolved trace metal concentrations.

### **Standard Surface Water Constituents**

Constituents to be determined are best considered as packages or analytical suites. The most basic suite includes all those constituents that have the greatest concentrations and that together exert many chemical controls on the nature of the water. This core group is called the major ions and common field measurements and includes:

1) Major cations -  $H^+$  (from pH),  $Ca^{+2}$ ,  $Mg^{+2}$ ,  $K^+$ ,  $Na^+$ ,  $NH_4^+$ .  $H^+$  and pH are important because of direct toxicity to aquatic organisms and they affect the solubility of toxic metals. The ions  $Ca^{+2}$ ,  $Mg^{+2}$ ,  $K^+$ ,  $Na^+$  are important indicators of how the rock and soil in the watershed react with water.

2) Major anions – Acid neutralizing capacity (ANC),  $SO_4^{-2}$ ,  $NO_3^-$ ,  $Cl^-$ . ANC is an important measure of the lake or stream's ability to neutralize acid; if its concentration is near zero then additional acid can easily affect pH and produce toxic conditions. The ions  $SO_4^{-2}$  and  $NO_3^-$  are common indicators of acid from manmade or natural sources.  $Cl^-$  is very useful in estimating the amount of evapo-transpiration in some watersheds.

3) Common field measurements -  
 Water temperature, pH, and specific conductance  
 Dissolved oxygen  
 Secchi disk depth (if sampling from a boat) in a lake

Water level and, if applicable, discharge

### **Additional Surface Water Constituents**

Depending on the stated program objectives, many additional constituents can be added to the major ion/common field measurement suite. Common additions are:

- 1) Additional nutrients - total P, soluble reactive P, total N. Nutrients are important in studies involved with the productivity of fisheries and with oxygen depletion. Point sources of nutrients, such as sewage outfalls, and non-point sources, such as intensive grazing near waterways, can greatly affect water chemistry, algal productivity, and the viability of aquatic organisms.
- 2) Additional inorganic chemistry - dissolved Al, large suites of other dissolved trace metals. Increased solubility of trace metals at low pH can cause toxic concentrations. Low pH commonly is a result of acid precipitation in watersheds of unreactive geology or of acid mine drainage.
- 3) Organic chemistry - Total organic carbon (TOC), dissolved organic carbon (DOC), various suites of pesticides and other organic toxins. TOC and DOC affect the toxicity of some trace metals, such as Al. Pesticides and organic toxins may be deposited by atmospheric deposition or runoff from treated lands.
- 4) Basic aquatic biology - phytoplankton, zooplankton, macroinvertebrates, fishery. Each type of organism interacts with water chemistry and may be an indicator of adverse chemistry not initially detected by sampling only chemistry. These organisms frequently are considered AQRVs or to have economic importance, such as fisheries.
- 5) Bacteria - total and fecal coliform, fecal strep. These organisms are used as indicators of contamination from sewage, grazing, or general soil contamination.

### **Selection of Sampling Site**

The sampling site needs to be safe, accessible, easily located by others using field descriptions, and representative of that part of the lake or stream of interest. In both lakes and streams the site should have good hydrologic connection with the main mass of water, i.e., circulation should not be impeded by excessive vegetation, shallow water depth, or be in a restricted embayment. The presence of tributaries needs to be considered so that adequate mixing is assured if sampling downstream of a tributary. Some measurement of specific conductance across a stream or in the vicinity of a lake inflow can determine whether mixing is complete.

If possible, lakes should be sampled away from shore by boat. If otherwise suitable, the deepest part of the lake is preferable. After determining the sampling location it should be marked with a permanent buoy, coordinates determined by GPS, or triangulated from easily recognized landmarks and these should be noted in any instructions to future sampling teams. If sampling by boat is not feasible then a shore location such as a rocky point located on the main body of the lake may be suitable. Lake outflows also may be suitable for sampling if the lake normally has significant discharge; otherwise, the outflow may not have good circulation with the lake.

Sampling locations in streams, including inflows and outflows of lakes, should be in areas of significant flow and little possible effect from tributaries, stagnant flow areas, or point sources and structures that may introduce their own chemistry. If safe, the sampler should wade to mid-stream in a well-mixed section of small streams. If available, a bridge or a boat can provide access to

mid-stream areas of larger streams. If it is unsafe or not practical to sample at mid-stream then an area of unrestricted flow that can be sampled from shore should be used.

### **Observations**

In addition to field measurements, described below, the person sampling should note a variety of things that can be observed. For example, are insects, fish or amphibians observed? If so, information on approximate numbers, size, and type might be valuable later in determining whether changes have occurred in the biotic community. Certainly, any observation of dead biota should be noted, as this may indicate recent harmful changes in chemistry or physical conditions such as lack of oxygen, toxic agents, etc. Indications of recent high stage flow should be indicated. Land use and disturbances such as camps, livestock, and evidence of recent timber harvest or mining need to be recorded. Photographs of the sampling site, lake, and watershed provide valuable information in understanding the system.

### **Weather**

Weather can affect surface water chemistry. Wind and the amount of solar radiation are very important to the stratification of water and chemistry in lakes. Rain and snowmelt are important to the chemistry of streams. Air temperature and atmospheric pressure can indicate whether conditions are stable or a storm has recently occurred or is about to develop. It takes only a few minutes to record basic conditions, i.e., Percent cloud cover, approximate wind speed and direction, whether storms are or have recently occurred, the status of snowmelt (if applicable), air temperature, and atmospheric pressure.

### **Dissolved Oxygen Measurement**

Dissolved oxygen (D.O.) can only be measured in the field. It is an important measurement because there are minimum D.O. requirements for aquatic vertebrates such as fish and amphibians, and the presence or absence of D.O. is a major influence on the solubility of constituents such as trace metals. Dissolved oxygen can be added to the water from the atmosphere or from photosynthesis by phytoplankton, macrophytes, and periphyton. Dissolved oxygen can be removed from the water to the atmosphere or by respiration and by decay processes in the water or the sediments. The ability of the water to contain D.O. is determined by its temperature, salinity, and the atmospheric pressure, with the solubility of D.O. decreasing with increasing temperature, increasing salinity, and with decreasing atmospheric pressure. Tables of solubility as a function of these variables are available (Wilde and others, 1998-1999). In lakes, the D.O. normally differs from the surface to the bottom and profiles of D.O. are done if samples are collected from a boat.

### **Water Temperature Measurement**

Water temperature can only be measured in the field. Water temperature is important as a measure of habitat conditions for organisms and is an excellent index to compare samples among different years. Because of annual differences in weather, the water temperature often is a better indicator of the annual hydrologic cycle than is the calendar date. Water temperature should be measured at all sites when collecting water samples. Either thermometers or thermistors may be used; either must be calibrated at two temperatures.

### **pH**

The pH of water, especially in very dilute systems, can be difficult to determine accurately unless sampling personnel are carefully trained. Thus, pH of samples collected during initial inventories may be better measured in the laboratory. Because the pH can change between collection and analysis in the laboratory it is useful to have trained personnel make at least some field

measurements for comparison to verify that the laboratory measurements differ little from field values. Both measurements are useful and at least one of the two is necessary. The pH is an important control on solubility of many trace elements and also may have biological effects itself. The meter must be digital and capable of reading to the nearest 0.01 pH unit. Other types of pH monitors are not acceptable because there is a high likelihood of erroneous measurement. The electrode typically is a combination (reference and pH indicating electrodes together) and should be suitable for measuring even low ionic-strength water. Calibration requires the use of two buffers that bracket the expected pH, commonly 4.00 and 7.00 buffers. Some electrodes that calibrate well with buffers, which are very concentrated solutions, fail to accurately measure pH in dilute water. The dilute acid standard used for National Acid Deposition Program (NADP) calibration can be used to verify the proper function of the electrode.

### **Specific Conductance**

The specific conductance can be measured at the laboratory but at least some field measurements should be taken for comparison (particularly for inventory sampling) to verify that the laboratory measurements differ little from field values. Specific conductance is critical in quality assuring most major ion analyses. Specific conductance often is so highly correlated with each major ion's concentration that it can be used cost effectively to approximate those concentrations in between actual analyses. Because of these uses and because of the simplicity of the measurement it should be measured on all samples.

### **Secchi Disk Depth**

The Secchi Disk depth measurement is performed from a boat in water deep enough to exceed the visibility limitations of the water. The disks come in differing sizes and may be black and white, all white, or mirror finish. Measurements are subject to individual eyesight problems, glare on the water, waves, etc. so notes on who is measuring and how are important. For consistency, it is best to measure on the shady side of the boat to minimize glare and to not wear sunglasses. A calibrated chain is attached to the disk and the disk lowered until it disappears, and the depth recorded. The disk is slowly raised until it reappears and that depth recorded. The average of the two depths is the single value normally entered as the Secchi Disk depth. If the disk can be lowered to the bottom and still be visible this should be noted, e.g., "Secchi Disk depth greater than maximum depth."

### **Water Level and Discharge**

Surface water chemistry can change in response to changes in the inflow of water, on timescales from less than a day to over an entire season. In lakes the water level can be a convenient measure of whether the sample is being collected during a period of generally normal, dry or wet conditions. The water level can be measured and continuously recorded by instruments that monitor a float assembly or pressure transducer, or just when samples are collected. It is important that a constant reference elevation is available so that all measurements are relative to the same reference; this could be a permanently mounted staff gage (a weatherproof "yardstick" used especially for this purpose) or a spike or other convenient point from which a metal tape can be dropped to the water surface.

### **SAMPLE HANDLING**

Sample collection removes the sample from an environment operating at approximately steady state. The counteracting physical and biological influences that maintain surfacewater chemistry fairly constant from day-to-day no longer are in balance within the sample bottle. There are rapid changes in temperature and, perhaps, dissolved oxygen concentration. Without sunlight, algae

cease to grow whereas zooplankton continue to eat algae and to excrete. Bacteria may thrive on dead algae and the zooplankton excretions. Thus, nutrient concentrations may rapidly change. Trace metals may move from the dissolved state to being adsorbed to bottle walls or being taken up by bacteria. Regarding how rapidly the chemistry may change the sample can be thought of as a dilute soup; the same changes that can cause such a soup to spoil happen to water samples and at comparable rates. The sampler should arrange to have samples analyzed before this "spoilage" can occur.

Immediate analysis is impractical in most field situations except for the common field measurements, such as water temperature, pH, specific conductance, and dissolved oxygen. Chilling immediately after collection to a few degrees above freezing and rapid shipment to the laboratory are the most effective approach if field processing, such as filtering and the addition of preservatives, is impractical. The samples must not freeze because this can break the bottle or cause irreversible precipitation of some constituents, such as dissolved orthophosphate. Holding times before analysis vary among constituents. Morrison (1991) lists holding times between 48 hours (color) and 6 months (major cations and Al). For constituents needed by many programs, 7 days is a practical limit (nitrate and laboratory pH) as long as the samples are kept chilled until analysis is conducted.

## **DATA QUALITY ASSURANCE**

### **Long Term Monitoring Samples**

Quality assurance of data is greatly facilitated if a site has been sampled many times before. At a site, fairly stable relationships among constituents and with variables such as discharge and season exist and can be used to decide whether new data are suspect. At each site, some relationships will be more reliable than others and the quality assurance should be tailored to what works at that site. Suspect data require that the sample be rerun analytically and/or the data flagged in the database.

### **Synoptic (Inventory) Samples**

Although synoptic samples may have few or no historic samples to use for quality assurance, it may be possible to do similar stepwise quality assurance of each analysis. Samples from lakes or streams draining terrain similar in geology, elevation, vegetation, etc. may be combined in the plots described above and one or more clusters of relationships may be apparent. These can be used to determine which constituent likely is in error; although, the apparent outliers are more subject to real differences among the sites.

### **Cross Comparison and Sample Archive**

In any sampling program, historical data will sometimes be questioned for accuracy. Changes in methodology for sampling and analysis can cause systematic differences in the data that complicate detection of trends. Before any change in methodology is adopted, it is important to collect and analyze duplicate samples by the old and new methods. A sufficient number of comparisons to cover the normal range of values and to provide a valid statistical comparison are needed.

Even when care is used in adopting changes in methodology, questions can develop as to the validity of older data or it may be desired to analyze for constituents not originally determined. Archived samples often can determine whether the older data are valid or to expand the constituents determined as new project needs develop. Archives representing the range of values for chemistry can be collected as duplicate samples to be used only for archive purposes or remaining portions of routine samples can be used. Although archive samples necessarily violate

holding time requirements for routine samples many constituents may be effectively preserved for an indefinite period. Changes can be minimized by techniques including:

- 1) Filtering the sample.
- 2) Minimizing headspace in the bottle.
- 3) Keeping the samples chilled and in the dark.

Because archived samples require a commitment of time, space, and attention it is desirable and efficient to have a centralized sample archive. A more limited local archive also can be maintained.

### **Responsibility for QA**

Basic quality assurance of data, as discussed above, can be done locally by the office collecting the samples and/or centrally; also, it can be done internally or contracted. Depending upon the expertise and time available it can be done well, poorly, or not at all in any of these choices. The most important decision to make in planning for quality assurance is to assure that someone qualified does it and does it soon after samples have been analyzed. It is almost useless to determine that data are suspect only after the laboratory has discarded the samples; at best, the data only can be deleted or flagged in the data base. To assure that the quality assurance plan is adequate there should be a formal report submitted of what has been done to quality assure data and what is planned for future data. It is critical that whoever reviews and approves the quality assurance report have the proper background and commitment to provide a critical review. Because data may be used for interpretation or in litigation, either immediately or much later after all project personnel have changed, the reports should be archived. Preferably, the reports should be available for review from the same data administrators who provide the data for public or internal use. Occasional review of the quality assurance process by qualified professionals from outside the agency can help assure that generally accepted approaches are used.

<sup>(1)</sup>Excerpted from Turk, J.T. 2001. *Field Guide for Surface Water Sample and Data Collection*. Report prepared for the Air Program, U.S.D.A. Forest Service. 67p.  
(for complete publication or additional information, contact Tamara Blett at (303) 969-2011 or [Tamara\\_Blett@nps.gov](mailto:Tamara_Blett@nps.gov))

## APPENDIX C

### Protocol for Identifying Ozone Injury on Eastern Forest Plants<sup>(1)</sup>

#### Steps for Diagnosing Ozone Injury on Selected Eastern Forest Bioindicator Plants

1. Look for ozone injury during the mid to late summer. In the East, the best time to observe injury is between mid-July and mid-September. At higher elevations, however, ozone injury may be masked by early fall coloration.
2. Find an opening with full sunlight exposure. Good places to look for ozone injury on bioindicator plants are openings away from major paved roads and power lines. Examples of openings include clearings for wildlife, old meadows, and recently harvested areas. The bioindicator plants to look for include blackberry (second-year canes), black cherry, common milkweed, green ash, yellow-poplar, and white ash.
3. Select areas with no obvious conditions that would cause mimicking symptoms of ozone injury. Examples include herbicide applications and mechanical or physical damage. Determine the presence of herbicide or other damaging agent if many plant species in the area (in addition to bioindicator plants) show the same symptoms. These types of areas should be avoided during surveys.
4. Look for symptoms on mature leaves that are in full sunlight. The leaves must be exposed to the sun to reveal injury. Symptoms should appear over most of the plant that is in full sunlight, rather than on just one or two branches or leaves. It is easiest to examine plants for which at least 25 percent of the foliage is within your reach.

The typical symptom of ozone is an upper leaf surface interveinal stipple. Stipple is the discoloration of small groups of cells between the veins, appearing as uniformly sized red to brown spots.

The ozone injury pattern normally does not go through to the underside of the leaf. If the injury pattern carries through to the underside, then the injury on the upper surface is probably caused by something other than ozone, such as insects, disease, or weather-related factors.

Older leaves show injury. Look for injury on the more mature foliage. There should be an increase in severity of injury from the youngest to the oldest leaves. Sometimes, young leaves look sunburned and have an overall red appearance. This is not due to ozone.

Shaded portions of overlapped leaves do not show visible ozone injury. If you move a leaf with ozone injury that is overlapping another leaf with injury, you should see no injury on the lower leaf where the top leaf covered it.

Leaves may show signs of premature aging. Some plants respond to ozone by dropping their injured leaves. Check on the ground beneath the plant to confirm if there is ozone injury on the fallen leaves.

5. Does the bioindicator plant you are evaluating fit these criteria? Have you considered site

factors and other agents that can cause mimicking symptoms? If so, you may feel confident that you are observing ozone injury!

### **List of selected eastern forest bioindicator plants and most common visible symptoms of ozone injury:**

Blackberry, secondary canes (*Rubus spp.*): Red to purple stipple.

Black cherry (*Prunus serotina*): Red to purple stipple, may drop the injured leaves early.

Common milkweed (*Asclepias syriaca*): Purple to black stipple, leaves may be chlorotic (yellow).

Yellow-poplar (*Liriodendron tulipifera*): Brown stipple, may drop the injured leaves early.

White ash (*Fraxinus americana*): Red to brown stipple. Similar injury is also found on green ash.

### **Quantifying Ozone Injury on Plants**

There are a number of ways to assess ozone injury on bioindicator plants. One method is to document the presence or absence on a predetermined number of plants in a given area. Another method is to quantify the amount and severity of injury that is present on leaves or plants. Amount and severity of injury are generally evaluated on a percent scale to obtain precise estimates of ozone injury. Changes in the ratio of injured to uninjured plants or in the amount and severity of injury can provide an indication of changes in air quality and injury conditions for a given area.

### **Reference**

Skelly, John M.; Davis, D.D.; Merrill, W.; Cameron E.A.; Brown, H.D.; Drummond, D.B.; Dochinger, L.S.; eds. 1987. *Diagnosing injury to eastern forest trees: a manual for identifying damage caused by air pollution, pathogens, insects, and abiotic stresses*. National Acid Precipitation Assessment Program, Forest Response Program, Vegetation Survey Research Cooperative. University Park, PA: Agricultural Information Services, College of Agriculture, Department of Plant Pathology, Pennsylvania State University. 122 p.

<sup>(1)</sup> excerpted from Brantley, E.A., R.L. Anderson, and G. Smith. *How to Identify Ozone Injury on Eastern Forest Bioindicator Plants*. U.S.D.A. Forest Service. Southern Region. Forest Health Program. Asheville, NC.

(for complete publication, see <http://fhpr8.srs.fs.fed.us/pubs/ozone/r8-pr25/ozoneh2.htm>)

## APPENDIX D

### Protocol for Identifying Ozone Injury on Western Pines<sup>(1)</sup>

Tree-level data should be collected by evaluating the crown and bole condition of each tree including whole crown, branch variables, and whorl variables. These evaluations are performed by visual estimates and by using simple instruments, both on the whole tree and on branch samples extracted from the lower crown. The approved methods for measuring DBH, selecting the category of slope position, and category of microrelief should become familiar to the field crew (Zedaker and Nicholas 1990).

Whole tree and crown evaluations may be recorded on a data sheet. Instructions are provided for judging the crown position, measuring tree height, and rating the severity of dwarf mistletoe infection. A visual estimate should be used to record further tree injury observations using these classes: 0=none; 1=present; 2=severe for the following: conks (identify species if possible); bark beetles (identify species if possible); witches brooms (with or without presence of dwarf mistletoe plants); fire scars (the rating refers to the percent of the circumference affected); mechanical injury (specify type); and lightning scars.

However, factors that may confound the evaluation of chlorotic mottle and needle retention that occur on specific branches should be avoided if they are not present on the majority of all branches in the lower crown. Branches with dead terminal buds, severe needle cast fungi, severe scale infestations, or that have obviously been severely chewed by insects or squirrels should therefore be rejected. Branches with cones or those which bifurcate (split) within the foliated length should be accepted, although their evaluation may be more time-consuming. "Branchlets" (the smallest side branch with a full complement of needle whorls) should be cut from near the crown edge without pruning the branch leader of major branches; the middle of the lower crown should be sampled on all sides of the tree. The very lowest branch on mature trees should be avoided because it may soon die as the tree self-prunes with age; its overall vigor is probably less than the rest of the lower crown. Small trees should not be over-pruned.

Five branchlet measurements are required for adequate within-tree replication:

- Foliated length-The length of the woody stem should be measured from the base node of the oldest whorl with green foliage (even if younger whorls are missing) to the base of the terminal bud. This is a general measure of overall vigor of the tree and potential growth rate.
- Number of whorls-The whorls of needles retained should be counted. This is a measure of the age of the oldest foliage retained on the branch in years minus one. If a whorl is missing between older and younger foliage, it is tallied on the data sheet as a "0". Whorls with short needles must also be included.

- Chlorotic mottle-The severity of chlorotic mottle resulting from ozone injury should be estimated as a visual estimate of the surface area of each whorl covered with mottle using the following classes:

0 = no mottle observed  
 1 = 1-6 pct  
 2 = 7-25 pct  
 3 = 26-50 pct  
 4 = 51-75 pct  
 5=>75pct.

- Fascicle retention in whorls-The portion of the full complement of needle fascicles that remain, should be estimated by using the following classes:

1 = 1-33 pct  
 2 = 34-66 pct  
 3 = 67-100 pct

To estimate fascicle retention, abscission scars (small pits in the scaly branch surface) should be noted between the whorl nodes. Most often on younger needle whorls none will be present, and the retention class will be 3 (100 pct). It is not necessary to actually count all abscission scars and retained fascicles; a visual estimate is sufficient.

- Common needle length-The common needle length in each whorl should be measured with a ruler to the nearest centimeter in the center portion of the whorl. The needle tips should not be chewed off at the same point by insects, but if they have been, a "missing" data value should be recorded or another branch selected.

<sup>(1)</sup> excerpted from Miller, P.R., K.W. Stolte, D.M. Duriscoe, and J. Pronos, technical coordinators. 1996. *Evaluating Ozone Air Pollution Effects on Pines in the Western United States*. General Technical Report PSW-GTR-155. Pacific Southwest Research Station. Forest Service. U.S. Department of Agriculture. Albany, CA. 79p.