Visibility and Air Quality Measurement Methods Used by the National Park Service

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Visibility Measurements

The National Park Service measures the background visibility with optical, view, and particle monitoring. Optical monitoring measures the optical condition of the atmosphere; view monitoring documents the appearance of the scene; and particle monitoring determines the nature of the air pollutants responsible for visual impairment.

Optical Monitoring

Before discussing optical monitoring, it is necessary to define several key terms used in visibility science: scattering, absorption, extinction, contrast, and standard visual range.

The passage of light through the atmosphere is affected by the constituents of the atmosphere. The atmosphere contains gases such as oxygen and nitrogen and suspended bits of matter (particles) of natural and manmade origin. The gases and particles influence light by scattering or absorbing it. Scattering is the process by which a particle takes energy from an incoming beam of light and reradiates that light into all directions. Looking through a dirty car windshield toward the sun when it is low in the sky illustrates the phenomenon of scattering. The windshield appears very bright with light and is difficult to peer through because the dirt particles scatter the sun's incoming light into many other directions. The scattered light obscures those objects that you are trying to see.

Absorption is the process by which the incoming light is not redistributed, but removed and absorbed by the particle or gas molecule, thus increasing its internal energy. Diesel exhaust contains carbon particles which are very effective at absorbing light. It is difficult to see through a dense cloud of this exhaust because absorption reduces and removes the light coming from the direction the observer is looking.

The attenuation of light by both scattering and absorption processes is called extinction. The extinction coefficient, b_{ext}, is a measure of the amount of the extinction occurring in the atmosphere. This coefficient can be explained physically as follows: If a beam of light is passing through the atmosphere, 63 percent of the beam's light energy is lost in a distance of $1/b_{ext}$. Because $1/b_{ext}$ has the units of distance or length (e.g., kilometers or km), it follows that b_{ext} has the units of one divided by length, or "inverse kilometers", 1/km or km^{-1}. The fractions of the extinction coefficient that are due to scattering and absorption are called respectively, the scattering coefficient (b_{scat}) and the absorption coefficient (b_{abs}). The larger the value of these coefficients, the more obscured is the atmosphere. Even in an extremely clean and pollution free atmosphere, there is still extinction caused by the scattering of air molecules. In the case of this very clean atmosphere, b_{ext} has a value of about 0.01 km^{-1}. A very polluted atmosphere may have extinction coefficients on the order of 0.10 km^{-1}.

Contrast is a second quantity considered in the measurement of visibility. Our eyes are able to see objects such as a distant mountain because it is brighter or darker than its background (e.g., the sky). The contrast of the mountain or other object is defined as the percent difference between the brightness of the mountain and its background. Contrast values may be positive or negative. A negative object/sky contrast indicates that the object is darker than the background sky. Conversely, a positive contrast indicates an object brighter than its background. Objects become indistinguishable from their backgrounds when contrasts are in the range of .02 to .05. A contrast value of 0.5 is considered large.

The NPS has measured contrast at many National Park Service units using teleradiometers. These instruments were phased out by 1986 and, beginning in 1987, replaced by long path transmissometers which directly measure extinction. Several National Park Service units are using nephelometers which directly measures scattering.

Visual range is a quantity that has been used as a measure of how far one can see. It is defined as the greatest distance at which a large black object can be seen against the horizon sky background. Thus, the visual range has units of distance such as kilometers. Making various assumptions, one can derive equations relating visual range to b_{ext} and contrast. Thus, the visual range can be calculated from measured values of extinction and contrast. As extinction increases, visual range decreases, and conversely.

Considering all the assumptions used to derive the expressions for visual range, it is probably better to interpret the visual range as a measure of the clarity of the atmosphere rather than as an absolute distance.

The visual range is often expressed in a special form called "standard visual range" or SVR. Even in a perfectly clean atmosphere consisting only of air molecules, an observer can see farther at higher elevations than at sea level. This is because the scattering caused by these air molecules (referred to as Rayleigh scattering) is less at higher elevations where the density of air is less. Thus, in order to equalize the effect of altitude for all monitoring sites, the visual range data from all sites are normalized to an altitude of about 5000 feet above sea level. The SVR is this normalized visual range, and its use facilitates the comparison of visual ranges derived from sites at different altitudes. Thus, for the same averaging time, the difference between SVR's at different monitoring sites are due to factors other than altitude.

The maximum value of SVR is 391 km. This value is associated with an extremely clean atmosphere, in which the extinction is due solely to the scattering of light by air molecules. (Because Rayleigh scattering is the name given to this type of scattering, such clean days are referred to as "Rayleigh days.")

Long path transmissometers and nephelometers are currently used to monitor the optical quality of the atmosphere. Transmissometers measure the amount of light transmitted from a calibrated incandescent light source through the atmosphere over a known distance. The light source (transmitter) and light monitoring (receiver) components of the instrument are separated by a distance of from one to fifteen kilometers depending on conditions at the monitoring location. Measurements of the intensity of the light source, the distance between the source and the receiver, and the intensity of the transmitted light will allow direct calculation of the average atmospheric extinction due to scattering and absorption along the instrument path.

The transmissometers used in the NPS network calculate and report average atmospheric extinction over the path length of the instrument. Along with extinction, temperature and relative humidity are also monitored. Relative humidity is important because it affects the size of particles. In higher relative humidities, particles can grow in size and become much more effective at scattering light and obscuring visibility.

Integrating nephelometers are used in the NPS visibility network at several locations where it has been impossible to locate a transmissometer transmitter and receiver. Nephelometers measure the light scattered by gases and particles in a small volume of air at one point in space. An air sample is drawn into an enclosed chamber, where it is illuminated. The scattered light is detected by a phototube. The instrument measures the light scattered over an angular range covering nearly 0 to 180 degrees. The instrument is calibrated to record the scattering coefficient and allows for automated, continuous day and night operation. The scattering coefficient can be converted to a visual range if the atmosphere is assumed to be uniform over a distance as long as the visual range, the target is viewed horizontally, and the effect of absorption can be neglected.

View Monitoring Summary

View monitoring documents the general appearance of a specific scene and the presence of plumes, layered, or uniform hazes. The NPS monitoring program uses automated 35mm photographic systems to monitor the visual resource of the class I area. This is very important because the transmissometers and particle monitors only sample a small part of the scene. View monitoring literally provides the needed description of what is happening within "the big picture."

The photographic system consists of a 35mm camera, lens, camera databack, timer, and shelter. The time and day a particular exposure was made is imprinted on the film using the camera databack. A battery powered timer is used to trigger the camera to take a photograph three times per day (9:00 a.m., noon, and 3:00 p.m. local time). Kodachrome ASA 25 36 exposure roll slide film was used in the program through May 1989. In June, 1989, a switch was made to Kodachrome ASA 64 film because of the lack of availability of camera data backs capable of writing to ASA 25 film. All tests indicate that quantitative analysis of Kodachrome 64 is comparable to Kodachrome 25-based analysis. The color response of Kodachrome 64 is slightly different than Kodachrome 25, and there will be a perceptible change in slide color. The design of this camera system allows unattended operation for at least ten days.

The slides are not routinely used for quantitative analysis. The SVR and extinction can be derived from contrast measurements from color slides. Specifically, the contrast between the sky and a suitable target can be measured off the slide using an instrument called a scanning microdensitometer. The extinction and SVR can be calculated from these contrast measurements. Extinction and SVR data determined in this way are subject to a greater uncertainty than those available from the transmissometer. However, studies have shown that there is good agreement between SVRs calculated using teleradiometer data and those calculated using microdensitometry.

Slides are considered a valuable source of information for interpretation of concurrent measurements, for documentation of perceived visual conditions, and for future qualitative and quantitative investigations. To aide in the use of the slides, a computer index is maintained which contains qualitative information on scene appearance, meteorology, air quality, and identification information for each color slide.

The entire set of color slides taken at each NPS camera monitoring site were reviewed recently, and five subsets of them were chosen to represent the spectrum of observed visual conditions. Two spectrum slide sets illustrate the range of uniform haze conditions observed at both 9:00 a.m. and 3:00 p.m. The slides represent a range of SVR's. The SVR values were derived from contrast measurements on the color slides.

A smaller third set of slides describes the appearance of layered hazes. The fourth and fifth subset respectively included slides taken on days when the measured fine particulate matter concentration was relatively high or low.

Particle Monitoring

Particle monitoring in the NPS network is accomplished by a combination of particle sampling and sample analysis. The sampler employed was originally designed for the IMPROVE (Interagency Monitoring of Protected Visual Environments) monitoring program by the NPS and the Environmental Protection Agency. It collects four simultaneous samples: one PM-10 sample (particles less than 10 micrometers [or μm] in diameter) on a teflon filter and three PM-2.5 samples (particles less than 2.5 micrometers in diameter) on teflon, nylon, and quartz filters. Each of the four samples is collected by a separate subsystem (or module) including everything from the inlet to the pump with only the support structure and controller/timer in common. The particle size segregation for the PM-10 module is accomplished by a wind insensitive inlet with a 10 micron cutoff, while the PM-2.5 segregation is produced by passing the sampled air through a cyclone separator. Constant sample flow (18.9 liters per minute for the PM-10 module and 21.7 liters per minute for each of the PM-2.5 modules) is maintained by a critical orifice in each module. The IMPROVE sampler is programed to automatically collect two 24-hour duration samples per week on Wednesday and Saturday.

This IMPROVE particle monitor more completely characterizes the chemical composition of the particulate matter, as compared to the stacked filter unit (SFU) monitors previously used by the NPS prior to 1987. (The SFU monitor was programmed to collect 72-hour samples prior to June, 1986 and 24-hour samples after that date.) The samples collected by the IMPROVE monitor are analyzed for total (0-10μm diameter particles) and fine (0-2.5μm diameter particles) mass concentrations; concentrations of over 50 chemical elements; ion (sulfate, nitrate, ammonium, and chloride) mass concentrations; and carbonaceous mass concentration and optical absorption. Additionally, a filter pack using a chemically treated quartz filter can be attached in series with the PM-10 module to measure sulfur dioxide concentrations. The above data are necessary for investigating the origin of the pollution responsible for visibility impairment.

Figure 1 illustrates those sites within the NPS visibility monitoring network that each have optical, view and particle monitoring. Sixteen of these sites are formally part of the federal IMPROVE monitoring program. The remaining sites, while not part of IMPROVE, are nonetheless equipped with the same IMPROVE network instrumentation. Figure 2 shows those NPS visibility monitoring sites that are equipped only with an automatic 35mm camera.

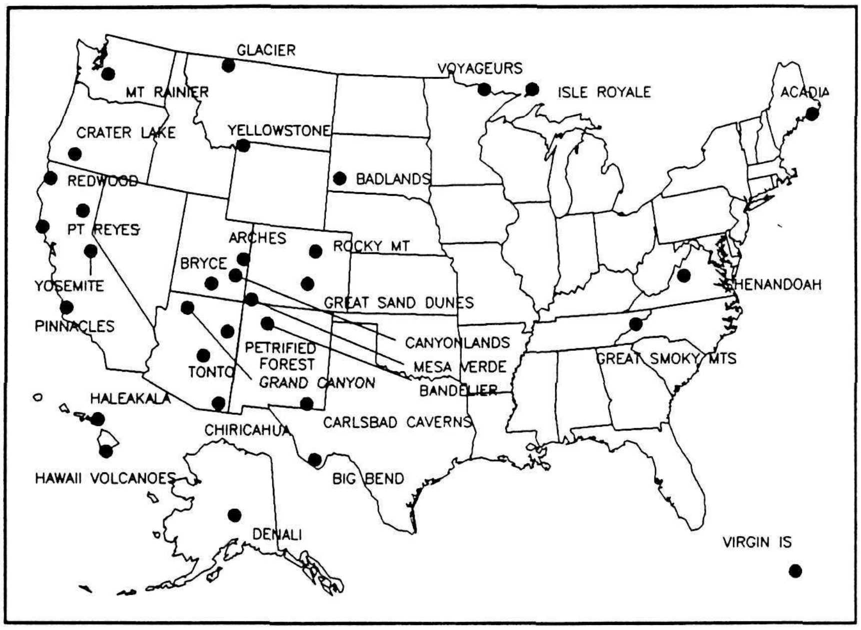

Figure 1. NPS Visibility Monitoring Sites

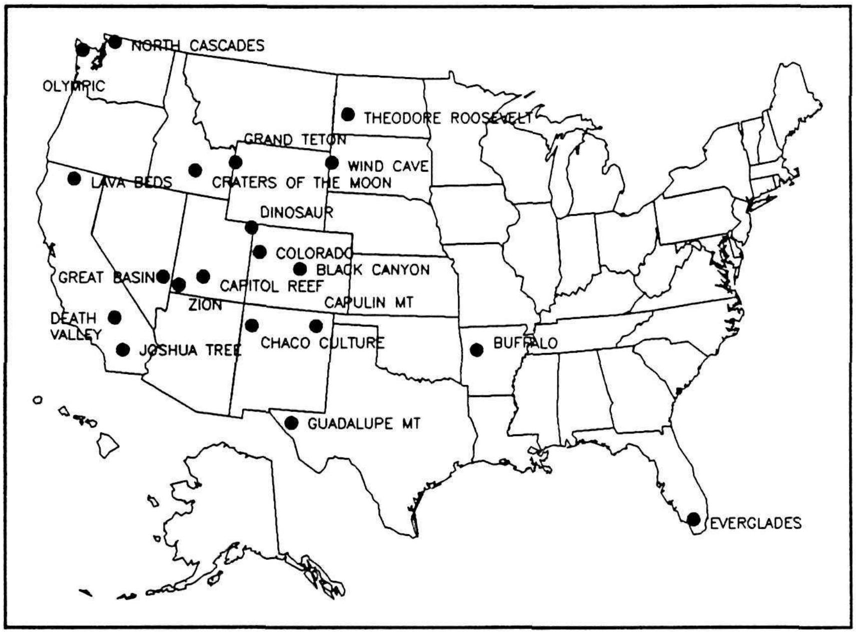

Figure 2. NPS Camera Only Sites

Gaseous Pollutants and Meteorology

Ozone

Ozone and other photochemical oxidants are not emitted directly into the atmosphere, but rather are formed there as products of reactions involving organic compounds, nitrogen oxides and sunlight. In high enough ambient concentrations, ozone can affect the health of humans and vegetation. Ozone can cause eye and lung irritation in people, and potentially serious foliar injury and growth damage to native vegetation such as certain species of pines and hardwoods, and commercial salad and citrus crops. Additionally, its effects include damage to textiles, discoloration of dyes and disintegration of rubber. The National Park Service has been operating an ozone and sulfur dioxide gaseous pollutant monitoring network consisting of about 40 stations with various combinations of ozone, sulfur dioxide and meteorological monitoring equipment. Ozone is monitored continuously by the ultraviolet photometric method. The concentration of ozone is determined in an absorption cell from the measurement of the amount of light absorbed at the ultraviolet light wavelength of 254 nanometers. The ozone analyzer contains an ultraviolet light source and a detector on opposite sides of the cell. An air sample is directed through a scrubber that removes any ozone present. The ozone free sample flows through the absorption cell, and the amount of ultraviolet light transmitted through it is measured. At a preset time, a second air sample flows directly into the absorption cell, bypassing the scrubber, and its ultraviolet light transmittance is measured. The ozone concentration is determined from the two measured transmittances, the optical path of the absorption cell, the temperature and pressure of the samples, and the ozone absorption coefficient at 254 nanometers.

Sulfur Dioxide

Sulfur dioxide is an air pollutant that in sufficiently high concentrations can affect human health and welfare. This gas can cause or contribute to respiratory system problems in people. Sulfur dioxide can cause serious injury and growth loss to lichen, Douglas fir, ponderosa pine, white pine, forest shrubs,and various crops including alfalfa, grains, squash, cotton, grapes and apples. It is also extremely corrosive to a variety of materials, including metals, building materials, paints, and electrical equipment. The gas is monitored continuously by the pulsed fluorescence method. The air to be sampled is drawn in to a chamber and is exposed to a short-pulsed, high-intensity ultraviolet light source with a wavelength of about 210 nanometers. The ultraviolet light excites the sulfur dioxide molecules and causes them to emit a characteristic 350 nanometer wavelength light. This light is detected by a photomultiplier tube and processed electronically to yield a voltage that is directly proportional to the sulfur dioxide concentration of the sample being analyzed.

Meteorology

The meteorological monitoring station consists of instruments to measure hourly wind speed, wind direction, temperature, dew point, solar radiation, and precipitation by event.

Figure 3 indicates which units in the National Park System are collecting gaseous and/or meteorological data. Ozone, sulfur dioxide, and meteorological monitors are indicated in the figure's legend as O_3, SO_2, and MET, respectively.

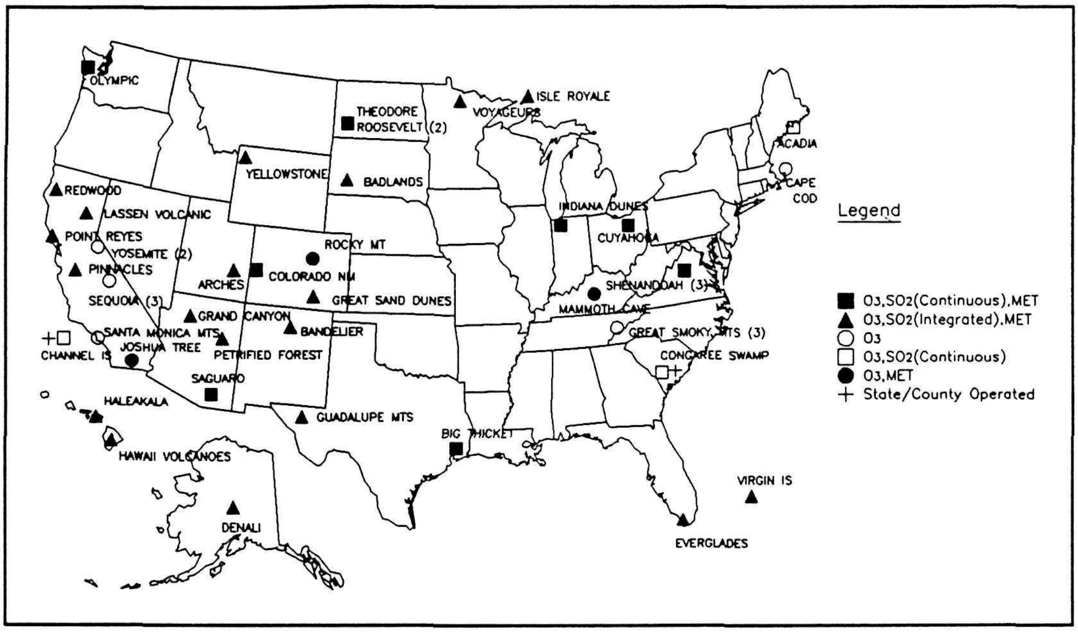

Figure 3. NPS Gaseous and Meteorological Sites