PROTECTING VISIBILITY

AN EPA REPORT TO CONGRESS

CHAPTER 3

3 METHODS FOR MEASURING ATMOSPHERIC VISIBILITY IMPAIRMENT

Measurements of visibility-related parameters in class I areas will be an important component of programs for making progress toward the national goal. Specifically, monitoring is necessary for:

1. Establishing a base line range of visibilities for a given area to be used in evaluating potential impacts of proposed sources;
2. Determining the extent to which man-made air pollution and natural sources cause or contribute to visibility impairment;
3. Identifying specific sources of air pollution that cause or contribute to visibility impairment; and
4. Monitoring the effectiveness of visibility protection programs over time.

Meeting these objectives will require measurement of optical parameters, pollutant levels, meteorological variables, and scenic characteristics. This chapter discusses the applicability of various visibility monitoring approaches and outlines current efforts to establish class I area visibility monitoring networks.

3.1 VISIBILITY-RELATED PARAMETERS

Because visibility involves human perception of the environment, no instrument truly measures visibility (Malm, 1979a). Thus it is essential to select appropriate measurable parameters, which can be related to both air quality of the environment and human visual perception. Important optical indices of visibility discussed in Chapter 2 include visual range, apparent contrast, extinction coefficient, and the variation of these parameters with wavelength (color) .The major categories of impairment (Chapter 1) to be dealt with include plume blight, general haze, and elevated layers of discoloration.

The most important indices for visibility measurements are apparent contrast and atmospheric extinction coefficient. In practice, the scattering component of the extinction coefficient, b_{scat}, is usually reported. Preliminary measurements in non-urban areas suggest that the scattering coefficient is 90 percent of the extinction coefficient (Charlson, 1979). Extinction coefficient is directly related to the visual air quality and represents the optical characteristics of the pollutants along an optical path that contribute to visibility impairment. The extinction coefficient, plus the optical effects of the target and illumination, determines the apparent contrast (visibility) of a target (such as plume or mountain) against a background (sky or other surroundings). Thus, extinction coefficient is the optical parameter related to air quality, and contrast is the optical parameter that describes visibility. Both extinction coefficient and apparent contrast are measurable at several wavelengths.

Contrast and light scattering measurements are directly applicable to visibility impairment caused by general haze. Plume blight and layers of discoloration might be assessed by employing contrast measurements and aircraft mounted extinction measurements. Direct observation of these kinds of impairment may, however, be the most practical approach for recording such conditions.

Measurement of aerosol parameters is a useful adjunct to optical measurements. Fine-particle concentrations, detailed size distributions, and chemical composition can be used to calculate extinction coefficient. More importantly, such data, when coupled with meteorological information, permit assessment of the contribution of anthropogenic and natural sources to visibility impairment.

3.2 MEASUREMENT METHODS

Regardless of the specific monitoring application, there are four components useful in characterizing visibility impairment and providing information that may link visual effects to their sources: human observations and measurements of optical, meteorological and pollutant parameters.

3.2.1 Human Observations

Since visibility is an interpretation of what is perceived by the human eye, it is essential that any monitoring effort have some relation to human observations. Human eye observation is the sole source of long-term visibility (visual range) data. Unfortunately, human eye observations depend not only on illumination, target characteristics, and air quality, but also include the effects of varying visual perception and subjective judgment. Nevertheless, with the development of observer-based visibility indices (Craik, 1979) and an adequate training program, human observations can provide useful information about visibility and can complement instrumental measurements.

The Federal Land Managers of parks and wilderness areas represent an important resource for human observation of visibility in class I areas. Although the traditional observation for visibility has been "visual range," i.e., the farthest point that can be seen, the U.S. Forest Service has incorporated more elaborate visual judgments into their Landscape Management System (USFS, 1973). The visual elements of a vista are described in terms of "form, line, color, and texture. " These elements represent subjective descriptions of contrast, the basic optical parameter. Meaningful judgments made by a trained observer about the contrast and coloration of a vista and about the presence of plume blight can be invaluable in assessing visibility impairment.

3.2.2. Optical Measurements

In order to quantify scenic contrast as perceived by the eye, optical measurements must be made. The visual air quality along the optical path must also be measured in order to determine the effect of atmospheric contaminants on the perceived scene.

A number of optical devices are available or under development that measure some property of visibility. The most obvious optical device is the standard photographic camera. Visibility monitoring should always include photography in some form, at least for documentation of existing good visibility conditions or impairment problems. The two general film formats are: negatives (from which prints may easily be made) and reversal film ("slides"). Both slides and negatives produce about equal color rendition. Prints made from negatives, however, are subject to quality control uncertainty during the additional laboratory printing process and are one more generation removed from the original image. Slides are more cumbersome to use but normally are more economical and more visually accurate than prints.

The chief use of photographs or slides is in preserving a scene in a form similar to the view as originally perceived. A secondary use is photogrammetry, the measurement of the density of color of individual sections of the picture to determine quantitative contrast values of different elements of the scene. The accuracy of this process, however, is sensitive to variations in film density and exposure and requires a densitometer closely matched to the response curve of the particular film being used.

Photometers measure light intensity and range in complexity from the photographer's light meter to a television camera. The principle of operation for each instrument is the same and is somewhat analogous to the human eye. The heart of a photometer is the photodetector, which converts brightness into representative electric signals. By the use of combinations of lenses and filters, different optical properties, such as color, may be determined.

Photometers designed specifically to measure properties of atmospheric visibility over an optical path to a target are *telephotometers*, so named because they resolve visual detail at a distance. Telephotometersprovide an output proportional to the absolute brightness of a target within the optical field of view. The human sensation of seeing, is however, produced not by absolute brightness levels of light, but by *contrast* in brightness or color between two objects. Therefore, the most practical application of a telephotometer is as a contrast measuring device-comparing the brightness of color of an object to a background. The visibility of a target can be quantified in terms of its contrast at a given distance from the observer and is dependent upon the inherent contrast of the target, uniformity of the atmosphere along the sight path, angle of observation, and illumination of the sight path. A disadvantage of using telephotometers is that it is difficult to separate the different effects from each other. This disadvantage is important if the goal is to isolate the contribution of anthropogenic air quality on visibility.

A transmissometer may be used to measure the optical characteristics over a given path. This instrument is comparable to an application of a telephotometer in which a known light source becomes the target. Transmission instruments measure the amount of light transmitted from a specified source to a receiver, allowing the direct calculation of the average extinction coefficient of the air along the instrument path. The light lost along the path is either scattered out of the path or absorbed by gas molecules and aerosol in the path. The path for transmission instruments is long compared to the small volume measured by scattering instruments and short compared with the 20 to 100 km paths used by telephotometers.

Transmissometers use artificial light sources; either the receiver or reflectors must be placed at one end of a base line and the transmitter at the other end. This fixed base line does not allow flexibility to measure visibility-related variables in different directions. When transmissometers are used in very clean atmospheres, such as class I areas in the Southwest, their critical sensitivity to atmospheric turbulence can introduce error. Additionally, these instruments are usually limited to a single wavelength and not very portable.

Scattering instruments are used to measure a basic optical property of the air sample: the volume scattering function. The measurement is independent of target properties, natural illumination of the atmosphere, and distance between the observer and the target. Scattering instruments include integrating nephelometers, back-scatter meters, forward-scatter meters, and polar nephelometers.

Integrating nephelometers perform a point measurement of the light scattered over a range of angles and permit determination of the scattering component of extinction, $b_{scat.}$ Since the contribution of air itself to b_{scat} is known, the b_{scat} measurement permits determination of light scattering by particles. In clean areas where light scattering dominates extinction, b_{scat} approximates the extinction coefficient, b_{ext}. Because b_{scat} is measured at a point, it can be directly related to simultaneous point measurements of aerosol properties. The air sampled by the integrating nephelometer is enclosed and illuminated indirectly by an artificial light source, allowing automated continuous day and night operation. Enclosed instruments also allow control of ambient air conditions; such control permits study of the influence of relative humidity. Nephelometers have been used in a variety of applications, including to a limited extent, applications in class I areas (Charlson et al., 1978). Models differing in wavelength response and sensitivity are available. Since nephelometers involve point measurements, care must be taken to minimize the influence from local sources, such as automobiles or cigarette smoke. Unless nephelometers are physically moved through a plume, inhomogeneous impairment, such as plume blight, cannot be detected. Nephelometers cannot be used to measure absorption and cannot detect discoloration caused by NO2.

3.2.3. Meteorological Variables

Meteorological conditions largely determine the extent and speed with which pollutants disperse, and thus have a major effect on visibility. Four specific meteorological parameters that strongly influence visibility include: wind speed and direction, mixing height, and relative humidity. Solar illumination and cloud cover affect atmospheric stability and are also important. Instrumentation for meteorology is standardized and will not be discussed here

3.2.4. Pollutant Measurements

A number of methods and instruments can be used to measure the size distribution, mass concentration or number concentration of the airborne particles that usually dominate the scattering of light. Nitrogen dioxide gas can also be measured. The Mie theory of light scattering allows measurement of the aerosol size distribution to be used to compute the scattering of light. These relationships allow a calculation of contrast, visual range and color change, but not as precisely as by more direct measurements. The most important advantage of measuring aerosol mass, size, and chemical properties is that when combined with meteorological data, such measurements aid in the identification of natural and anthropogenic aerosol sources in order to determine which are most important in affecting visibility.

The most useful particle monitoring instruments for visibility studies include those that permit analysis of chemical composition and particle size. Although multistage cascade impactors can be useful for detailed studies, samplers that permit separation of optically important fine (<2 *.5.um)* and coarse particles (>2 *.5.um)* are acceptable. These latter samplers, which are termed dichotomous samplers, have several arrangements for size separation, including direct and "virtual" impaction. (Stevens et al, 1978).

3.3 COMPARISONS AND RECOMMENDATIONS

Each of the visibility-related methods described above has inherent strengths and weaknesses, which limit its optimal application and utility. The characteristics and applicability of important methods are compared in Table 3-1. No single instrument or approach can provide sufficient information for meeting class I area visibility monitoring objectives. A significant limitation for most of the methods is securing locations in class I areas that are reasonably accessible and can accommodate instrument power requirements.

Recently, EPA sponsored a workshop on visibility monitoring to discuss alternate monitoring methods and make recommendations for further work (Malm, 1978). A number of technical experts and managers from industry, Federal and State agencies, and contractors participated in these discussions. As interim guidance for developing visibility monitoring programs in class I areas, this report adopts the recommendations of the workshop participants. Specifically:

1. Base line monitoring should be conducted for at least I year, preferably a meteorologically typical year;

2. Visibility measurements should include:

    a. Color photographs or slides and human observations of selected vistas,

    b. Multiwavelength telephotometer measurements of sky and target contrast of the selected vistas,

    c. Integrating nephelometer measurements of aerosol scattering;

3. Evaluation of source-receptor relationship requires:

a. A two-stage size-segregating particulate sampler compatible with gravimetric and chemical analyses techniques,

b. Sensors of wind speed and direction, representative of meteorological transport,

c. Relative humidity sensor,

d. An NO_2 detector, if necessary.

TABLE 3-1. VISIBILITY MONITORING METHODS*

Method	Parameters Measured	Advantages	Limitations	Preferred Use
Human observer	Perceived visual quality Atmospheric Color Plume blight Visual range	Flexibility, judgment; large existing data base (airport visual range).	Labor intensive; variability in observer perception; suitable targets for visual range not generally available.	Complement to instrumental observations; areas with frequent plume blight, discoloration; visual ranges available target distances.
Integrating nephelometer	Scattering Coefficient (b_{scat}) at site	Continuous readings; unaffected by clouds, night; b_{scat} directly relatable to fine aerosol concentration at a point; semi-portable; used in a number of previous studies; sensitive models available; automated.	Point measurement, requires assumption of homogeneous distribution of particles; neglects extinction from absorption, coarse particles > 3 to 10 um; must consider humidity effects at high RH.	Areas experiencing periodic well mixed general haze; medium to short viewing distances; small absorption coefficient (babs); relating to point composition measurements.
Multiwavelength telephotometer	Sky and/or target radiance, contrast at various wavelengths	Measurement over long view path (up to 100 km) with suitable illumination and target, contrast transmittance, total extinction, and chromaticity over sight path can be determined; includes scattering and absorption from all sources; can detect plume blight; automated.	Sensitive to illumination conditions: useful only in daylight; relationship to extinction, aerosol relationship possible only under cloudless skys; requires large, uniform targets.	Areas experiencing mixed or inhomogeneous haze, significant fugitive dust; medium to long viewing distances (¼ of visual range); areas with frequent discoloration; horizontal sight path.
Transmissometer	Long path extinction coefficient (b_{ext})	Measurement over medium view path (10-25 km); measures total extinction, scattering and absorption; unaffected by clouds, night.	Calibration problems; single wavelength; equivalent to point measurement in areas with long view paths (50-100 km); limited applications to date still under development.	Areas experiencing periodic mixed general haze, medium to short viewing distance areas with significant absorption (babs).

TABLE 3-1. VISIBILITY MONITORING METHODS[a] (continued)

Photography	Visual quality Blume blight Color Contrast (limited)	Related to perception of visual quality; documentation of vista conditions.	Sensitive to lighting conditions; degradation in storage; contrast measurement from film subject to significant errors.	Complement to human observation, instrumental methods; areas with frequent plume blight, discoloration.
Particle samplers	Particles	Permit evaluation of causes of impairment.	Not always relatable to visual air quality; point measurement.	Complement to visibility measurements.
Hi Vol	TSP	Large data base, amenable to chemical analysis; coarse particle analysis.	Does not separate sizes; sampling artifacts for nitrate, sulfate; not automated.	Not useful for visibility sites.
Cascade impactor	Size segregated particles (> 2 stages)	Detailed chemical, size evaluation.	Particle bounce, wall losses; labor intensive.	Detailed studies of scattering by particles < 2 um.
Dichotomous and fine particle samplers (several fundamentally different types)	Fine particles (< 2.5 um) coarse particles (2.5 to 15 um) inhalable particles (0 to 15 um)	Size cut enhances resolution, optically important aerosol analysis, low artifact potential, particle bounce; amenable to automated compositional analysis; automated versions available; large networks under development.	Some large-particle penetration; 24 hour or longer sample required in clean areas for mass measurement; automated version relatively untested in remote locations.	Complement to visibility measurement, source assessment for general haze, ground level plumes.

[a](Charlson et al., 1978; Malm, 1978b, 1978c; Tombach, 1978).

Comprehensive monitoring of this kind will not be needed in all class I areas. Over the next several years, visibility monitoring in various regions of the country may indicate a smaller set of measurements, which can be used for most monitoring goals. In the interim, in programs with limited resources, the limitations and strengths outlined in Table 3-1 should be considered when choosing monitoring sites and methods. EPA is preparing detailed guidance on visibility monitoring.

3.4 VISIBILITY MONITORING PROGRAMS

The only substantial visibility monitoring program to date has been the National Weather Service hourly visual range observations. These observations have proven useful in identifying trends at particular locations but more accurate optical measurements and additional air quality parameters will be necessary for visibility modeling and source identification. Various optical qualities of the atmosphere have been studied in a number of short-term programs, generally with the use of turbidity and/or nephelometer measurements.

One of the first major instrumental monitoring programs designed to study visibility, air quality, and meteorological variables near class I areas was the Cedar Mountain, Utah visibility program which was begun in 1976 by NOAA and EPA (Allee, 1978). The site is north of several major class I areas in southeast Utah. Many measurements were taken with different instruments and much of the data is still being analyzed. The general conclusion thus far is that northerly air masses bring in substantially cleaner air than from other directions, causing base line visibility to vary dramatically. In addition, some information about the limitation of visibility monitors and spatial homogeneity of the surrounding atmosphere has been gathered.

The Cedar Mountain Study has been incorporated into EPA 's project VIEW (Visibility Investigative Experiment in the West), which is now is operation in the Southwest with 14 additional monitoring sites (Figure 3-1). The VIEW program is a prototype visibility-monitoring network that may be suitable for monitoring visibility in and near class I areas in the Southwest. At each site, a telephotometer records apparent contrast of different targets in different directions (denoted by the arrows at each location on the map in Figure 3.1). Where practical, sites are outfitted with additional visibility-related devices, such as nephelometers, particle samplers, photographic cameras, and meteorological instruments. Most of the sites are operated by personnel of the National Park Service, who also record visual observations.

Data from the VIEW network are currently being processed. Preliminary results appear similar to those reported at Cedar Mountain. The most obvious result so far is the strong correlation between observed visibility and air mass movement. Figure 3-2 is a sample plot of target contrast at Canyonlands National Park for September, 1978. Passages of weather systems from the Pacific Northwest, which generally bring in cleaner air, correlate closely with better visibility, measured as increasing target contrast. Further analysis of pollutant composition is needed to identify the causes of reduced visibility.

Visibility monitoring is also planned by the Electric Power Research Institute, the National Park Service, the Tennessee Valley Authority, and other groups. Most of these projects are now in the planning or initiation stage.

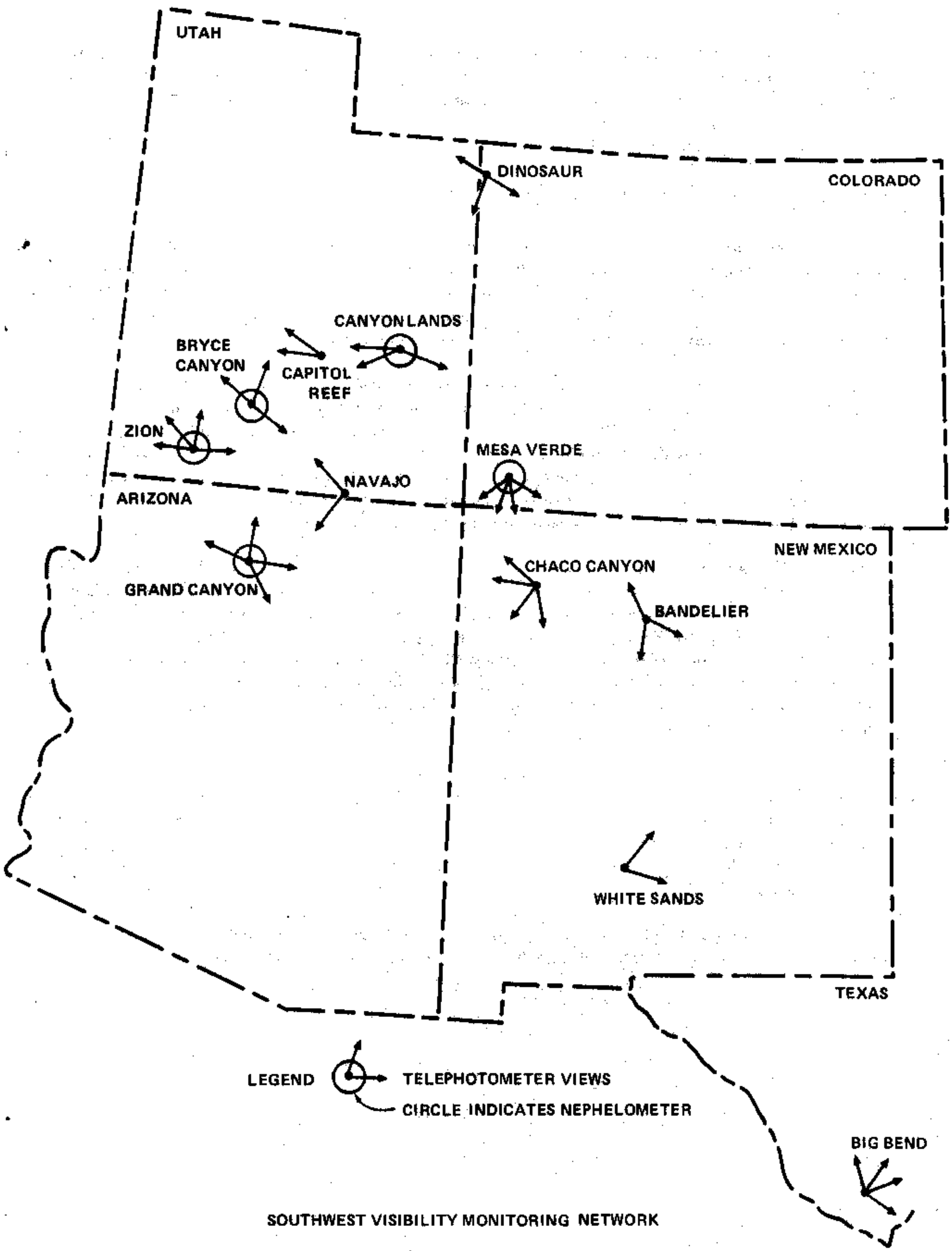

Figure 3-1. Project VIEW—EPA/NPS Southwest visibility monitoring network.

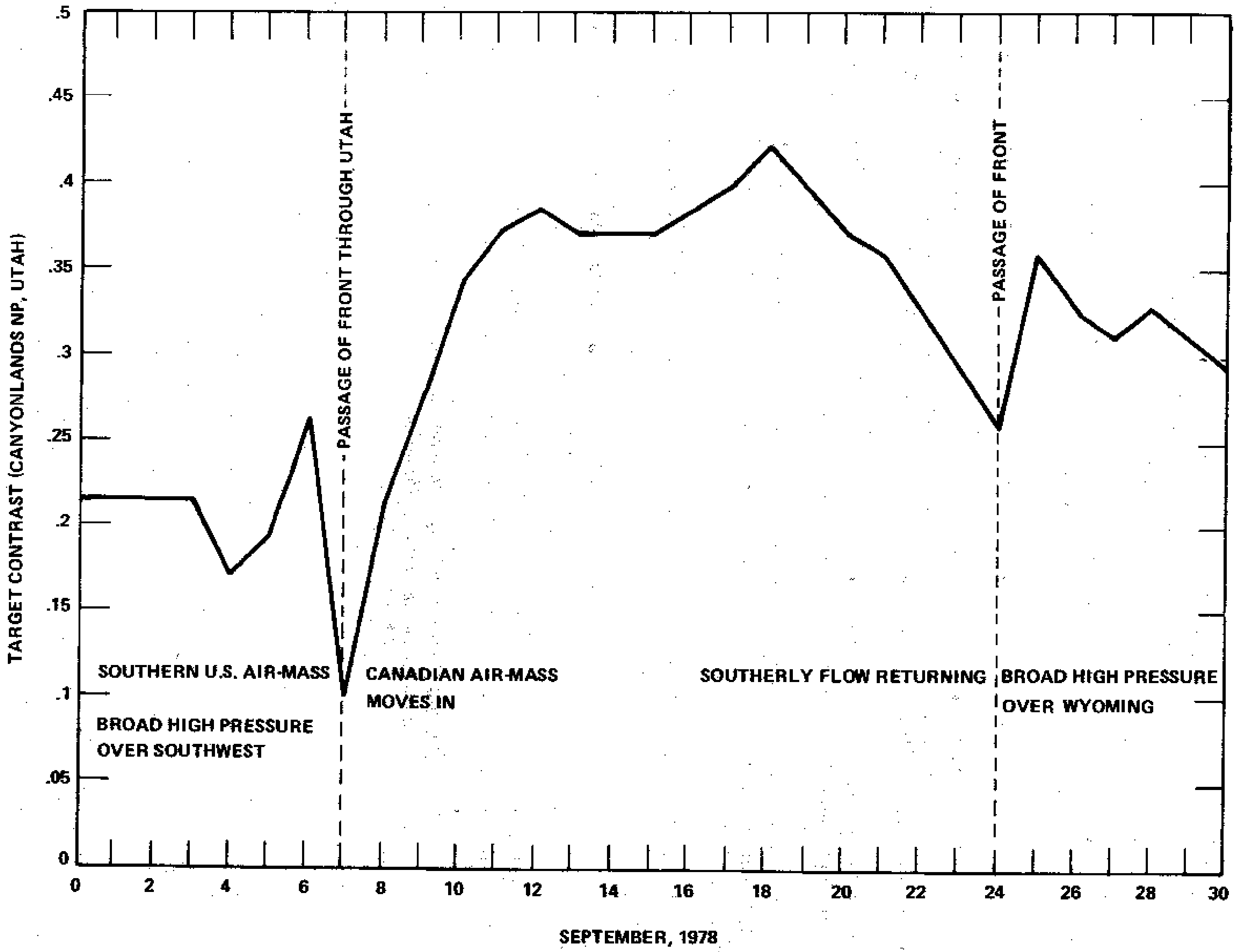

Figure 3-2. Target contrast at Canyonlands National Park, Utah, for September, 1978 (Malm, 1979b).

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