

Use of Historic Images as a Tool for Estimating Haze Levels—Natural Visibility and the Role of Fire

Gordon Andersson¹

Abstract—The Regional Haze rule addresses visibility impairment in 156 Federal Class I areas. The goal of the rule is to remove all anthropogenic air pollution from the National Parks and Wilderness areas. Determining natural visibility conditions is an interesting and complicated problem. There is a large archive of pre- and early-settlement narratives, landscape paintings, and photographs that could be used as part of a weight-of-evidence demonstration in regional haze State implementation plans (SIPs), especially for Western States. With an understanding of inherent limits, these materials could be used for qualitative evaluation of the early American atmosphere. Despite large uncertainties and with knowledge of film properties, application of quantitative analysis of contrast in photographs is possible and could provide estimates of visual range. These issues are introduced here as a theoretical treatment with some reference material for further investigation and practical application.

Background

The Regional Haze Rule (RHR), published July 01, 1999 (64 FR 35714), addresses prescribed fire as one sector of visibility impairment (with stationary, mobile, and area sources). The national goal expressed in the Clean Air Act is “the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class I Federal areas which impairment results from manmade air pollution.” States need to establish “reasonable progress goals” for each Class I area with the objective of achieving natural visibility conditions by 2064. The 20 percent worst visibility days must be continuously improved, and the 20 percent best days must not deteriorate. The VIEWS Web site (Visibility Information Exchange Web System at <http://vista.cira.colostate.edu/views/>) serves as the national repository of visibility data and analysis, and incorporates the IMPROVE database (Interagency Monitoring of Protected Visual Environments, the national monitoring network of air samplers and database to implement the regional haze program: <http://vista.cira.colostate.edu/improve/>). VIEWS provides estimates of natural component concentrations at the Class I areas based on measured values at the IMPROVE monitors. Natural visibility is also sorted into 20 percent best and worst days.

In the preamble to the RHR, the Environmental Protection Agency (EPA) writes that States should not attempt to recreate historical (pre-Euro-American settlement) conditions, but rather determine current natural conditions. In related guidance documents, EPA allows considerable flexibility in the use of the IMPROVE and other air monitoring data as well as weight-of-evidence arguments addressing aspects of modeling and source attribution.

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¹ Planner Air Policy, Minnesota Pollution Control Agency, St Paul, MN. gordon.andersson@state.mn.us

Although it addresses concentrations of fine particle (PM_{2.5}) in the air, the RHR is not a NAAQS (National Ambient Air Quality Standards, which are established by EPA for six “criteria” pollutants). NAAQS primary standards are human health-based, and secondary standards are welfare-based. Welfare includes ecological effects and visibility, among other effects, and so the RHR is similar to a secondary standard. The RHR is basically an esthetic rule about what you see. It is appropriate to include photographs and art work as records and representations in reviews of visibility. Photographs are used in signage about diminished views at many National Parks, and they are part of the documented daily record at a number of Class I areas. This paper proposes that some of these esthetic media can also be used for analysis of historic visibility conditions.

The Historical Record

A large body of 19th century historical evidence bears on this issue—written narratives, landscape paintings, and landscape photographs—that, especially in the West, records conditions before the widespread use of internal combustion engines, large industries, and other human-made pollution sources (with the exception of fire). Despite the position expressed by EPA, such images would include depictions of natural visibility at that time, which would resemble in most part the contribution of natural sources today. It is somewhat unexpected that so many of these records describe or portray some amount of haze on the landscape.

The Western Class I areas would benefit most from a review of historic images (fig. 1). In general, they include more extreme topography and vertical surfaces with longer views and measurable “targets” than Eastern areas. (It is these same features that resulted in their designation as Parks or Wilderness areas.) Also, natural contributions were then (and are now) a larger component of haze in the West than in the East and, therefore, more likely to appear in the records than haze due to human-made sources.

Both Western landscape photographers and painters were instrumental in establishing National Parks in the West based on these same productions. William H Jackson’s photographs and Thomas Moran’s paintings convinced Congress to protect Yellowstone as a National Park in 1872 and Jackson’s and Albert Bierstadt’s pictures of Yosemite played a large part in its designation in 1890. This presentation will mostly address the use of depictions in landscape painting and photographs with a few examples.

Written Records

Written narratives can provide descriptions of relative haziness or clarity, but they would best be used as accompaniment to photographs, paintings, or sketches made of that same scene on the same day, or, with less specific application, the same season. Notebooks by the painter or photographer that describe the view would either support or qualify the conditions presented in the rendered image. Albert Bierstadt, for example, on each of his trips to the West made numerous notes that described the scenes painted in his oil sketches. In these he recorded from direct observation the colors, light, clouds, and atmospheric conditions.

Travelers’ descriptions of landmarks in diaries and letters could provide independent dated information or might supplement recorded images. The overland migrants to the West Coast traveled chiefly through summer and



Figure 1—“Picture Rock at Crooked Lake” by Francis Lee Jaques, 1947 (courtesy of Minnesota Historical Society © 2003). A location in the Boundary Waters Canoe Area Wilderness, Superior National Forest, Minnesota, a Class I area. The vistas in the Class I areas in the Great Lakes region are seen across large lakes or the length of long lakes. These cliffs in the BWCAW provide vertical surface—a rare topography. Note the obscured view to the left of the cliffs.

used the same routes. Such limits of time and place provide for comparisons that include similar season, feature orientation, and position of sun. In addition to such records, compilations of regional histories based on primary materials concentrate descriptions to a place. Stegner (1982), for example, includes extensive quotations of Clarence Dutton, a geologist and companion in John Wesley Powell’s exploration, and a description from 1882 of the haze in the Grand Canyon, a present day Class I area. The review of written records would be fairly labor-intensive requiring extensive filtering of texts to find pertinent descriptions.

Landscape Paintings

More than narrative descriptions, the use of pictorial media have limitations that must be understood and applied to estimating haze levels. This is more so because they provide immediate appearances that seem to be real.

The landscape painters of this period—Frederick Church, Jasper Cropsey, Asher Durand, George Inness, Thomas Moran, Sanford Gifford, and others—painted from nature, often creating oil sketches out of doors and completing canvases in the studio (fig. 2). The painters of the old West (such as Bierstadt and Moran) were from the Mid-Atlantic States. Their paintings were a medium of communicating the grandeur and vistas of the Western



Figure 2—“A Scene on Tohickon Creek: Autumn” by Thomas Moran, 1868 (courtesy of Minneapolis Institute of Art © 2003). An early image from the East (Pennsylvania) by an artist most famous for later panoramas of the West. Due to the season, the background haze may represent smoke from vegetative burning with little biogenic contribution. (Note for this and some other figures: Images of paintings are made from scans of 35 mm slides obtained from museums. In general they are significantly degraded in sharpness and color and are for illustration only. Museum Web sites, Web searches for specific paintings, exhibit catalogues and books, available in museums and libraries, and the original paintings and photos in museum collections provide the best reference material.)

topography. For example, Bierstadt’s large-scale paintings were exhibited for paid admission on tours of Eastern cities. Moran’s huge paintings “Grand Canyon of the Colorado” (1872) and “The Chasm of the Colorado” (1874) were both purchased by Congress and hung in the Capitol in Washington, DC. There would be a natural tendency for these depictions to portray distant peaks and open spaces through clear air, whether the air was clear or not. In terms of the RHR, these paintings would more likely depict a day from among the “20 percent best days” to “20 percent middle days” than the most hazy days with greatly diminished views. Whether Eastern or Western scenics, some pieces portray crystalline air and many miles of view; some, dramatic storms and clouds over distant peaks; and many, a golden light of late afternoon with a lot of light scattering from fine aerosols. Many of these last still have a long visual range to show distant formations through the haze.

Problem of Sampling Error

The use of paintings to look at visibility must be done with a knowledge of the artist and his body of work. This may include styles and phases and the placement of a particular painting in the artist’s development. Of course, to draw conclusions from a single painting (or photo) of a single feature is

not reasonable. Any small number of records presents a large problem of “sampling error.” For comparison, the IMPROVE air monitors sample the air every third day. The RHR apportions the air data into quintiles with each 20 percent representing at maximum 24 days a year.

There are a few ways that sample size might be increased if one were to use the historic record. A series of paintings of one landscape feature by one artist over time would provide one preferred “database.” It would show the range of the artist’s representation and scene changes through the year at different seasons and times of day in different light with different sun angles.

Researchers at the University of Birmingham, England, propose this very process to analyze air pollution conditions in London from evidence in a series of paintings by Claude Monet of the Houses of Parliament in 1899 to 1901 (Baker and Thornes 2006). Monet was a master of Impressionism whose canvases include many series of the same subject in different light conditions. In all he completed 19 paintings of the Parliament buildings, and nine of them show the sun. These London paintings were made in the period of his mature style. Despite this, the authors determined that he correctly rendered the effects of sunlight on the building and they matched the solar inclination to the dates of his paintings. Having determined “elements of accurate observation” and “real quantitative information” in this series, they believe that historical conditions of air quality can be derived from the same paintings. Monet chose to paint the sun effects on the façade as they were presented to him. Every painter from nature chooses which physical elements of the subject to include and with what specificity, and which elements to omit, alter, or add.

Late Impressionist paintings are less representational than the landscape paintings of both the American East and the West. The 19th century landscapers practiced realism or naturalism in large part. On the American scene, Albert Bierstadt’s series of paintings of the Yosemite Valley (1865, 1868, 1872) might be compared to a Monet series (fig. 3). However, both Bierstadt’s large-scale paintings of the Yosemite Valley and Thomas Moran’s painting of the canyon of the Yellowstone River are composites, created from oil sketches, that include landscape features within the same view that are not present in the three dimensional world (Wilton and Barringer 2002). Right away, this should diminish the credibility of either of these paintings as physical records, including the relative clarity of the atmosphere. If one can move a mountain, one can even more easily clarify or obscure the view at a given time with less interpretation. The mountain subjects that Bierstadt painted in large format, after joining the Frederick Lander railway survey expedition to present-day Colorado in 1858, were similarly largely invented. Moran became more stylized in later years adding many atmospheric effects to his landscapes (fig. 4). To use fanciful (less realistic) representations of landscape at face value is problematic, as they depict momentary events in the artist’s imagination, whether or not they happened, or might have happened, in nature

A second approach would be to compare different artists’ renderings of the same scene, such as Sanford Gifford’s painting (1860) of Mt Katahdin in Maine (fig. 5) and Frederic Church’s (1853) picture of the same feature. If different artists portrayed the same atmosphere conditions affecting the view of a landmark, at the same season and time of day, one could argue that the similarity may be due to those actual conditions and not to the artist’s preferences. To be fair in using such a method, where different depictions show different levels of haze, one must acknowledge that the samples are too disparate to make estimates of average conditions and, at most, conclude that the differences lie somewhere within a range of actual conditions.



Figure 3— “Looking Down Yosemite Valley, California” by Albert Bierstadt, 1865 (courtesy of Birmingham Museum of Art © 2003).



Figure 4— “Grand Canyon of the Colorado” by Thomas Moran, 1892 (courtesy of Philadelphia Museum of Art © 2003).



Figure 5—“The Wilderness” by Sanford Gifford, 1860 (courtesy of Toledo Museum of Art © 2003). The view is of Mt Katahdin in Maine, now in Baxter State Park, and climbed by Henry David Thoreau.

Yet a third approach to address the issue of “sampling error” is one that adds corroborative information to photographs and paintings. The photographer William Henry Jackson and the painter Thomas Moran both accompanied the Ferdinand Hayden geological survey expedition to Yellowstone in 1871. There, Moran made numerous watercolor and gouache drawings of landscape features with an “intense concern for accuracy” (Wilton and Barringer 2002). As with many artists, a separate “reality” was later created on the final oil canvases completed in the studio, which may be quite independent of the studies, sketches, and notes that were made in the field. Jackson made numerous silver albumen photographic plates in Yellowstone (fig. 6). In 1873, Moran also traveled with the Powell expedition to the Grand Canyon of the Colorado River. And in 1892, he again visited the Grand Canyon with Jackson. In the case of these two Western Class I areas, there exist contemporary written descriptions, photographic prints, and pencil and paint sketches as well as completed oil paintings that hang in several museums. This information recording the same landscape and features could be compared for agreement, consistency, and anomaly in visibility.

Many collections and “coffee table” books include landscape reproductions with descriptive text, biographical information, and the name of the museum that owns the original artwork. Wilton and Barringer (2002) provide an extensive treatment of representations of this period in American painting.



Figure 6—“The Three Tetons” by William Henry Jackson, 1873 (courtesy of Minneapolis Institute of Art © 2003). Taken from Yellowstone National Park; one of 11 Jackson photos in the MIA collection and one of the less hazy in appearance.

Landscape Photographs

Photographs, either inside or outside Class I areas, are much less subject to “interpretation” by the artist. Photography and painting are differentiated by manipulation of subject matter and by the time to create the image. Though each present a moment in time, the one is made in an instant and the other may be completed after weeks or months of work. Landscape paintings of the 1800s too lack the intrinsic credibility of photographs and, without supplemental information, one can neither conclude that a scene is average or typical, nor that it never happened.

The preponderance of the 156 Federal “mandatory” Class I areas addressed by the RHR are in the West (112, outside of Alaska and Hawaii), and this is where, at the time, there was less anthropogenic influence on the atmosphere. William Henry Jackson and others (Carleton Watkins, Timothy O’Sullivan, Samuel Bourne, Alfred Hart) made series of photos inside present-day Yellowstone and Yosemite National Parks and other Western regions (fig. 7).

Qualitative and quantitative assessment—The paintings and photos of 19th century artists have intrinsic historic interest, but with qualitative assessment they can be useful in helping to define natural visibility conditions. Using



Figure 7—American Indians on horseback at Glacier National Park; photographer unknown, 1912 (courtesy of Minnesota Historical Society © 2003).

such historical records is a different method of reconstructing “natural” conditions and it might be used to supplement or compare the quantitative methods of natural source concentrations derived from measured filter data. If measurement is possible, the visual historical record becomes more applicable to haze research and estimation of natural conditions.

The simplest measure that might be done from images is visual range. This does require that distances from the point of view in the photograph (or painting) to features in the landscape be known to the individual who examines the image. Such distances can be approximated in the real world by a visit to the featured site or with the use of topographical maps. Visual range is demonstrated with light extinction (bext) and deciviews on the IMPROVE homepage, and it is also the visibility metric used by the “haze cams” on State and RPO Web sites across the country (fig. 8, 9). With an estimated visual range, one can calculate an estimated general light extinction and estimated deciviews.

To correctly measure visual range, one observes a large black object against a light background or the bright horizon. Simply stated, the observer visual range is the distance at which the object disappears. A painting (or a photograph) can indicate a visual range if features in the background become invisible, but this can only be an approximation of actual visual range, and it would probably be less than that measured with a black object. Actual visual



Figure 8—St Paul, MN, “haze cam” image showing “current conditions. The live image is updated every 15 minutes. Visual range, measured by nephelometer, has been reported with the met data beneath the picture on many haze cam sites.



Figure 9—“St Paul from Dayton’s Bluff, July 6, 1888” by Alexis Fournier (courtesy of Minnesota Historical Society © 2003). This watercolor shows a view of early St Paul, MN, from a location and orientation similar to the haze camera (fig. 8).

range will usually be greater than the distance to the target object. With any painting, one must bear in mind that the apparent visual range is in the painting and not in nature, although it might have been accurately recorded from the landscape at a point in time.

Large uncertainties exist in contrast measurements from transparencies (Molenaar undated). Even “live” visual range is affected by the sun angle, the target object characteristics, and sky conditions. Measuring contrast from photographs depends on these factors as well as the qualities of the film. Lack of supplementary information of archival photographic prints that includes the properties of the film, its density and response to light, and the deterioration of the prints make calculated measurements of extinction more difficult (Molenaar, pers. comm.). Quantification of visual range in photographic prints by experienced technicians with contrast instruments (densitometer that measures reflectance) can derive estimates but not fixed values.

The IMPROVE photographic record—35 mm cameras have been collocated with the aerosol monitors at IMPROVE sites in at least 46 National Parks, Refuges, and Wilderness areas. These daily images (three slides per day) have been archived as a record of visibility conditions. The VIEWS Web site includes a large number of images from these Class I areas in “spectrum” series with graduated differences in $\mu\text{g}/\text{m}^3$ of aerosols, light extinction (bext), and deciview (dv) values for each image: (http://vista.cira.colostate.edu/views/Web/IMPROVE/Data_IMPRPhot.htm)

Light extinction coefficients were estimated for each of these photographs with contrast measurements made with a transmittance densitometer. Copeland (undated) found large uncertainties using a 68 percent confidence interval when comparing measured visual range to actual visual range even where a dark target was in the frame.

William Henry Jackson—Although a number of photographers made images of the old West, Jackson was unusually prolific, including in a 1875 catalogue more than 2,000 albumen silver prints taken between 1869 and 1875 as part of the Hayden U.S. Geological Survey (Sandweiss 2002).

In addition to the catalogs published by Jackson, more recent works provide side-by-side comparisons of photographs by Jackson with contemporary photographs taken of the same scene from about the same point (Fiedler and Jackson 1999, 2005). This allows for the direct comparison of the air quality on those 2 days separated by more than 100 years. By using the same latitude/longitude and orientation, these photos provide equal distances to vertical features in the distance. It would be most useful if these images were taken on the same dates to account for seasonal differences and it does not reduce the sampling error issue discussed above. As they are largely made in summer, the chances would be about one in 100 that the images were made on the same date. However, because daily variation is often greater than seasonal difference, valid comparisons of visibility do not depend on same-day images. One could examine a large number of paired images and estimate the range and the mean of clarity/haziness for the “before” and “after” pictures. These references and others (such as Hales 1988) would seem to be useful to Colorado, with its 12 Class I areas, to supplement its air monitoring data.

The Role of Fire

Haze is apparent in many paintings and photographs from the 19th century. A good argument can be made that much of this is due to fire on the landscape. Many of the Eastern paintings (by Church, Cropsey, Durand, Moran, Gifford) might represent smoke from the felling and burning of the Eastern hardwood forest as a component of visible air pollution. Large portions of the land area were clearcut and burned for cropland by the Euro-American settlers. Primary forest was converted to log piles that burned for days, and the wood was readjusted for further combustion. Due to land-use practices, the annual net flux of carbon (C) to the atmosphere was positive from before 1850, peaked at 328.74 Tg/yr in 1881, and did not go negative until 1923 (Houghton and Hackler 2002) (fig. 10).

In the East, emissions from coal-burning factories and some coal-burning trains, and residential cooking and heating would also be a component of visible air pollution especially after 1850. In 1850, some 5,402 1000 metric tons (mt) of carbon were produced by coal burning in the United States; 15,775 1000 mt were generated in 1865; and 101,603 1000 mt in 1890 (Marland and others 2006). The amount of carbon added to the atmosphere by land-use changes in 1881, however, was six times that added by coal burning in that year.

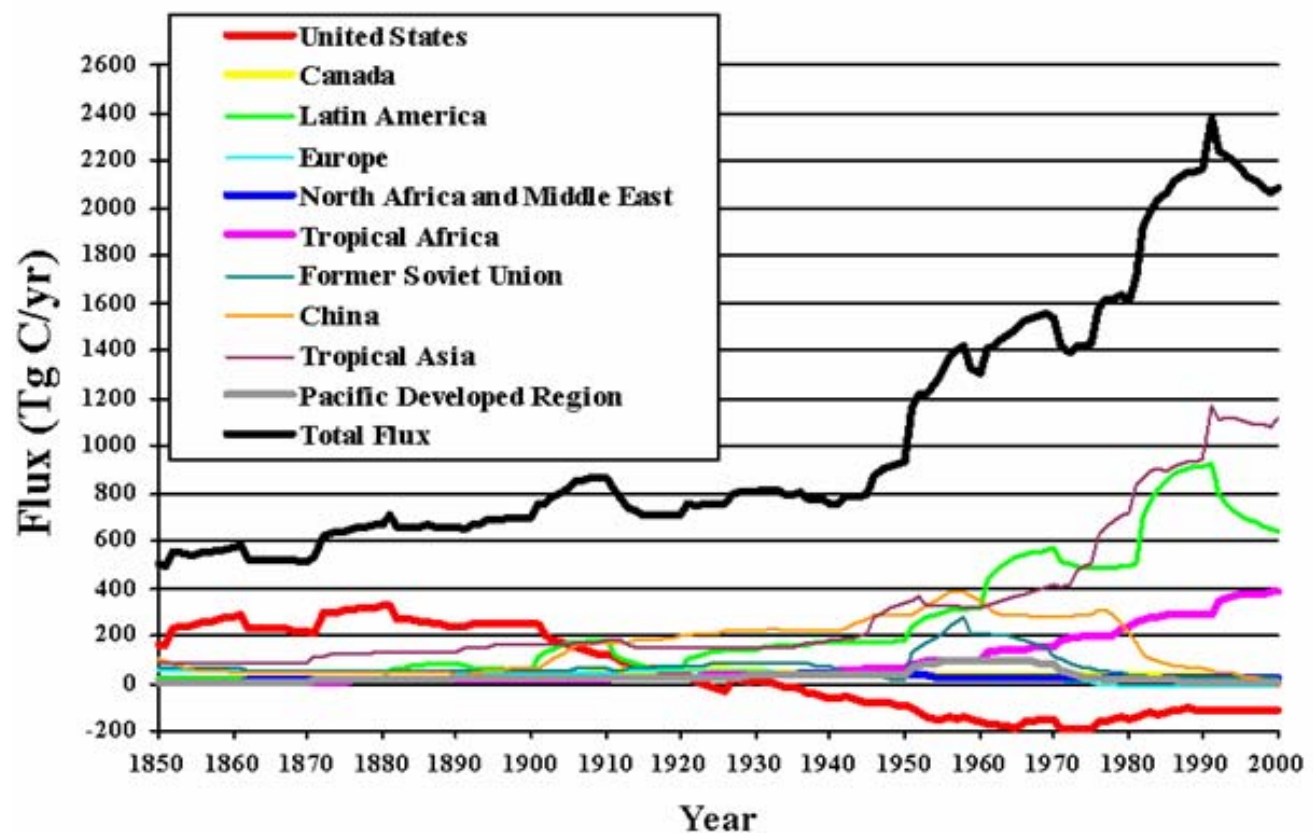


Figure 10—Annual net flux of carbon to the atmosphere from land-use changes worldwide, 1850 through 2000 (Houghton and Hackler 2002). Note that carbon release peaked in the United States in 1881 from clearing and burning the Eastern forest.

With little industry or transportation sources in the West, much of the visibility impairment would be due to biogenic sources, including wildfire, and intentional burning. American Indians used fire extensively for multiple purposes (see Pyne and others 2000).

According to Leenhouts (1998), wildland fires burned 34 to 86 x 10⁶ ha (megahectares) annually in the preindustrial era, consuming 530 to 1228 teragram (Tg) of biomass. By comparison, he calculates that contemporary wildland, prescribed, and agricultural fires combined burn 4.5 to 7.4 Mha per year and consume 24 to 136 Tg of biomass per year (data are from his “Results” section). He added that about 10 times more landscape was burned, eight times more biomass was consumed, and seven times more emissions were produced in the preindustrial conterminous United States than at present due to biomass burning.

The pollutants that affect visibility and that are derived from vegetative burning are PM₁₀, PM_{2.5}, nitrogen oxides (NO_x), ozone, organic carbon, and elemental carbon. Ozone, which can form “smog” or haze, is not directly produced by fires but from other combustion products (NO_x and volatile organic compounds or VOCs). Nitrates too are not primary products of burning but are formed by the chemical transformation of NO_x. About 90 percent of smoke particles are PM₁₀ and 70 percent are PM_{2.5} (EPA 1998).

EPA Treatment of Fire in Rules

The Clean Air Act Amendments (1977 and 1990 parts 169A & B) and the Regional Haze Rule (1999) require that human-made pollution that affects visibility be prevented and reduced. In a regulatory sense, whether the smoke component of haze is natural or anthropogenic is a fundamental issue. The convention among fire agencies is that lightning-ignited fires are natural. This is a source-based definition of emissions determined by the mode of the fire ignition. Reasonably, arson fires are clearly anthropogenic. Accidental fires (such as cigarette, railroad, and escaped camp fires) too are considered human-caused. Extending this logic to prescribed burns classifies them too as anthropogenic. Fire emissions are usually treated as area sources in air quality emission inventories, and the emission components from vegetative burning are similar, regardless of the mode of ignition (fig. 11).

Despite this, sec. 1.15 of EPA “Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Rule” (Sept 2003) states, “In some cases, regional organizations [RPOs] have found it useful to classify fire emissions into two categories, natural and man-made, for the purposes of estimating natural visibility conditions. While EPA is not expressing an opinion on the importance of classifying fires, it supports those organizations who wish to do so for the purposes of estimating visibility conditions. However, the EPA does not require the distinction between natural and man-made fires.” Apparently, this means that EPA could consider all fires as natural (and part of natural haze) or all fires as man-made (and subject to the RHR). This lack of clarity is perpetuated by the final Exceptional Events (EE) Rule (72 FR 13559) published March 22, 2007. Congress passed the SAFE-TEA-LU bill (2005) that revised sec. 319 of the CAA to address exceptional events and defined them in part as “not reasonably controllable or preventable.” In the EE rule, EPA says that prescribed fires may qualify as exceptional events if they meet the statutory definition and a State smoke management program (SMP) is in place. This confusion might be addressed in part when EPA releases new guidance to replace the “Interim Air Quality Policy on Wildland and Prescribed Fires” (April 23, 1998), due in July 2008.



Figure 11—Burning the piled brush and debris after lumbering has been completed, Minnesota National Forest Reserve; photo by W.E. LaFontain, November 18, 1904 (courtesy of Minnesota Historical Society © 2003). Slash burning after clearcutting the red and white pine forests of Minnesota for construction of Midwestern cities. Lumbering began in the 1830s and peaked at more than 1 billion board-feet in 1900. The last sawmill closed in 1930.

Summary

A number of artistic, technical, and regulatory issues attend an effort to use the large archive of descriptions and representations of the early American landscape as a tool to estimate natural visibility conditions and regional haze in early settlement (East) and presettlement (West) America. The haze seen in many paintings and photographs could contain a large component of fire emissions that would combine both natural and human-ignited sources. Estimating the proportions of each by region presents a problem. Further, EPA has not formally separated fire emissions by source in RHR implementation, in apparent conflict with the Clean Air Act Amendments.

Despite these problems, work could be done on each of these topics by individual States to derive or to support the values that it includes in the regional haze SIP. In particular, a number of the Class I areas in the West are supported by a large history of narratives, drawings, paintings, and photographs that describe or portray the atmosphere at different times in those areas or regions. Each of these media has limitations that must be considered. The fire science literature on natural and Native American fire could be correlated to the historical writings and images. Despite large uncertainties, application of quantitative analysis of contrast in photographs can provide estimates of haze concentrations and light extinction. In many locations, qualitative analysis of the image archive and additional research could be used to supplement the calculations of natural visibility based on current concentrations of air pollution.

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