

Simulation of the Visual Effects of Power Plant Plumes¹

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Abstract: The Los Alamos Scientific Laboratory has developed a computer-assisted technique that can predict the visibility effects of potential energy sources in advance of their construction. This technique has been employed in an economic and environmental analysis comparing a single 3000 MW coal-fired power plant with six 500 MW coal-fired power plants located at hypothetical sites in southeastern Utah. As part of this analysis, area residents were asked to express their preferences for computer generated scenes depicting visibility degradation as well as indicate the importance of visibility vis-a-vis the other impacts examined.

INTRODUCTION

As the U.S. strives for energy self-sufficiency, the use of coal as an energy source is becoming more widespread. Coal has always been viewed as a dirty energy source compared to oil or natural gas. Even with sophisticated pollution control devices, the airborne emissions from coal-fired power plants are greater than those from oil or natural gas. If we must use more coal, how can we mitigate some of the air quality impacts associated with burning coal? Our ability to mitigate these impacts will depend in part upon our ability to predict the impacts when new power plants are proposed.

The air quality effect addressed herein is visibility degradation in the form of plume blight. The paper describes a technique developed at the Los Alamos Scientific

Laboratory to simulate the visual impact of a power plant plume in an observer's field of view and the use of that technique in a comparison of large and small coal-fired power plants in the West. Using hypothetical power plants in southeastern Utah, photographs were created to depict the plume blight from locations in Capitol Reef and Canyonlands National Parks from a single 3000 MW power plant and, alternatively, from six 500 MW power plants dispersed throughout the area. The discussion concludes by describing the method used to evaluate visibility impacts through the use of photographs to discern the values and preferences of southeastern Utah residents.

With the passage of the 1977 amendments to the Clean Air Act, visibility has become more than an aesthetic issue. The amendments are "to preserve, protect, and enhance the air quality"⁶ in all existing national parks over 6000 acres, national memorial parks over 5000 acres, national wilderness areas over 5000 acres, and all international parks. These areas are designated by the act as "mandatory Class I," a classification which allows virtually no degradation in air quality. This classification will undoubtedly have significant impacts on the siting of future power plants in the Southwest--an area rich in national parks.

SETTING

The national parks of southern Utah are well known for their unique scenic features. It is a land of arid mesas and canyons, lush

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⁶Clean Air Act, Sec. 160(2).

river bottoms, forested mountains, and boundless vistas. In this land of little moisture, what rain has fallen has helped erode the layered rocks into unusual formations, grace-

There is more than sculptured sandstone in southeastern Utah, there is coal, both in the headwaters of the Price and San Rafael Rivers and to the southwest of Capitol Reef National Park in the Kaiparowits Plateau. Two coal-fired power plants, Huntington Canyon (800 MW) and Emery (1600 MW), already exist in the area and others have been proposed. Based upon numerous power plant siting studies made for this area, six potential sites were identified and two alternative electrical generation plans were developed. One siting plan would involve a single 3000 MW plant (four 75 MW generating units) located near the town of Green River. The other would involve two 250 MW units at each of six sites. These two sitings plans and the nearby national parks they could affect are illustrated in figure 1.

The national parks most likely to be affected by either power plant scenario are Arches, Canyonlands, and Capitol Reef. The dominant formations of these areas are multi-hued sandstones, which have been weathered into a myriad of forms. Arches' main attraction are its graceful red stone arches. Canyonlands contains sinuous canyons, stone arches, and towering spires, while Capitol Reef is a gold and white land of steep-walled gorges and rolling domes. The clear air, expansive vistas, and feeling of wide-open

spaces have always been major attractions of the national parks of the area. Without this unpolluted air, an important part of the experience these parks provide would be lost. The potential loss of this resource to air pollution from coal-fired power plants in the region was important to the inclusion of the visibility and non-degradation provisions in the 1977 Clean Air Act Amendments.

Two sites were selected for simulating visibility impacts. The first is a view to the east from a point within Capitol Reef National Park. The other is a vista to the northwest from Island in the Sky in Canyonlands National Park. Only the view from Capitol Reef will be discussed with regard to the simulation of coal-fired power plant plumes. The simulations for Canyonlands can be found in Ford and Flaim, eds. (1979).

VISIBILITY SIMULATIONS

There are two situations in which visibility effects may be important. One occurs when the plumes from one or more power plants become dispersed in the atmosphere and cannot be readily identified with their sources. The result is regional haze and normally occurs during plume travel times from the plant which range from a few hours to days. In this case, the effects in a region are primarily determined by the total emissions that occur upwind and by the effectiveness of the removal processes active during the plume travel from the source to the affected region.

The other situation occurs when the plumes from one or more plants are visually obvious and can be identified with their sources. This usually occurs at points within a few hours of plume travel time from the source. This is called plume blight and may be simulated through a technique that produces a photograph of a scene with the smoke plume from a hypothetical power plant.

The simulation of plume blight begins with an actual color slide that is digitized as film densities to provide a background against which the plume calculations are performed. A modification, of this scene will result in a new image that incorporates either a plume, a general haze condition, or both. Next, a computer simulation of the brightness of three representative wavelengths (blue, green and red) in the background atmosphere is performed. A solution to the radiative transfer equation is found for a series of infinite planes oriented normal to the line of sight. Next, to perform this modification concentrations of atmospheric materials that scatter or absorb light are calculated along each line of sight using Gaussian plume dispersion relations. Calculated light scattering and transmission

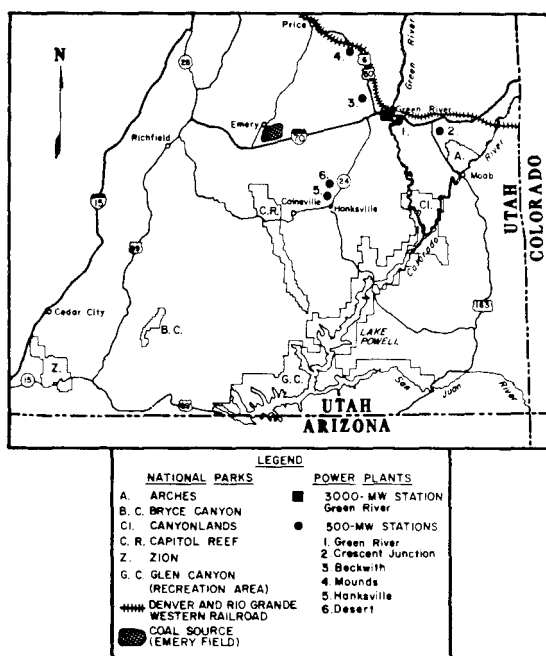


Figure 1--Location of hypothetical plant sites in southeastern Utah.

values for each line of sight are interpolated over the entire picture. The digitized film densities of the original scene are modified to include light transmitted through atmospheric materials and light scattered by atmospheric materials towards the observer. The revised densities in the simulated scene are converted to equivalent brightnesses and are displayed on a TV screen, which is subsequently photographed. A more detailed description of this technique and the calculations involved may be found in Williams et al. (1978).

Power Plant Characteristics

A number of source characteristics influence the visibility impact produced by a power plant: the emission rates of oxides of nitrogen, sulfur oxides, and fly ash, the stack height, the stack radius, the stack gas velocity and the stack gas temperature. Nitrogen oxide emissions are important because the colorless gas nitric oxide (the form in which the bulk of the nitrogen oxide emissions occurs is converted in the atmosphere to nitrogen dioxide--a red brown gas. Nitrogen dioxide may itself be converted to particulate nitrate, which scatters lightly. Sulfur dioxide is a colorless gas that converts to light scattering particulate sulfates. Fly ash is also a light scatterer. The stack parameters--height, radius, gas velocity, and gas temperature--determine the height at which the pollution will drift with the wind.

Both large and small power plants in this study are assumed to achieve 90 percent control of SO_2 and 99.5 percent control of fly ash while burning low sulfur, low ash coal. The emissions assumed for the large plant are those projected for a 3000 MW facility actually proposed for the region (the Intermountain Power Project). The emission rates for each small plant were calculated by multiplying the large plant emission rates by the ratio of the plant capacities and the ratio of the plant heat rates (heat rate refers to the number of Btu's of coal which must be burned to produce 1 KWH of electricity). The heat rate of the small plants is 15 percent higher than that of the large plant. The assumed emission rates along with the stack parameters are listed below:

<u>Source Characteristic</u>	<u>Small Plant</u>	<u>Large Plant</u>
NO_x emission rate	506 g/s	2640 g/s
SO_2 emission rate	71 g/s	368 g/s
Fly ash emission rate	10.2 g/s	53 g/s
Stack height	152 m	183 m
Stack radius	2.64 m	6.47 m
Stack gas velocity	16 m/s	16 m/s
Stack gas temperature	355 °K	355 °K

Meteorological Conditions

The principal meteorological parameters that influence the visual impact of pollutants from a source at a specific site are the atmospheric stability, the wind speed and the wind direction. The atmospheric stability determines the rate at which material disperses in the atmosphere. With stable conditions, air temperature increases or slightly decreases with height. As a result, vertical plume spread is inhibited. Under these circumstances the plume is relatively obvious because it appears as a small band of dirty air extending across the clean sky. During unstable conditions the smoke spreads rapidly in both the vertical and the horizontal. Neutral conditions are intermediate between stable and unstable.

Low wind speed and stable conditions present the most obvious plume to an observer downwind of a power plant. Based upon temperature distributions measured at 1000 to 1300 feet (305 to 396 meters) above the ground (the expected plume height of a large plant during stable conditions) in an area east of Capitol Reef National Park, two-thirds of the mornings exhibited stable conditions (IPP 1977). Measurements of wind speed near Lake Powell at 1000 feet (305 meters) above the ground during the morning hours found that one-half of the wind speeds were under 2.5 m/s (Dames & Moore 1972). Based upon these studies, slightly stable conditions with wind speeds of 2 m/s are assumed to be adverse conditions for this analysis.

Wind directions were chosen that would bring the plume centerline from the sources to within 10-30 kilometers of the observer in Capitol Reef National Park. This would be a relatively adverse situation. The effects would probably be greater if the plume traveled directly toward the observer, but this would be a less frequent situation. Thus, the meteorological conditions assumed in the analysis do not present the worst situation, but an adverse condition that could be expected to occur occasionally. Sufficient data for the region are not available for a precise evaluation of the frequency of assumed conditions, but data from the Lake Powell area (Dames & Moore 1972) may be used to estimate their frequency.

At the Capitol Reef site, approximately comparable effects to those modeled from the large plant would be expected' on about 5 percent of the mornings. Higher wind speeds of 4-6 m/s would give effects somewhat greater than those in the small plant case and would occur about 4 percent of the time. Thus, we would expect effects of magnitude comparable to, or greater than, those in the small plant case to occur on about 9 percent

of the mornings. The two small plants near Hanksville would be expected to have similar effects on about 9 percent of the mornings also.

The neutral condition was chosen primarily to illustrate the role of atmospheric stability. A wind speed of 5 m/s is typical for this condition.

Description of Photographs

From a knoll on the east-facing slope of Waterpocket Fold in Capitol Reef National Park, the views to the north, east and south are magnificent. To the north and south, the buttes and mesas are visible for more than 30 kilometers. The view to the east, past Thompson Mesa toward the Henry Mountains, was selected as the background for modeling the power plant plumes (fig. 2*).

From this location, plumes from both the large plant at Green River and the two small plants near Hanksville (Desert and Hanksville sites) would be visible when the wind is from a northeasterly direction. Plumes from both the large plant and the small plants are modeled with meteorological conditions that would be expected during the morning hours before the air and the ground have been warmed and mixing of the air layers has occurred. Figure 3* shows the plume expected from the single large plant under these stable conditions, while figure 4* shows the plumes from the small plants. The color of the plumes is caused by a predominance of NO_x particles. The appearance of the plume will also be affected by the position of the sun relative to the plume and the observer. If the sun is behind the observer, the plume will appear darker than if the sun were in front of the observer because less light is scattered back towards the observer. The same position of the sun, mid-morning during February, has been assumed in the simulations.

Figure 5* shows the 3000 MW plant with a neutral atmosphere. Hence, the pollutants are more dispersed and less visible as a result of increases in wind speed and in mixing of the air. For the small plants under neutral conditions, the plumes are so dispersed that they are not discernible and figure 2 suffices as an adequate representation.

PREFERENCES OF AREA RESIDENTS

Visibility effects were among twenty-six different environmental, economic and social impacts of coal-fired power plants examined in a workshop held in southeastern Utah during the summer of 1978. The eight

area residents selected for the workshop provided a sounding of local concerns, such as ranching and farming. Using Multi-Attribute Utility Measurement (MAUM), workshop participants were asked to express quantitatively the relative importance of the twenty-six different types of impact as well as their preferences of different magnitudes of the same impact. MAUM is one of a family of multi-attribute evaluation procedures (Raffia 1969, Keeney 1972, Gardiner and Edwards 1975). The relatively simple version used here was chosen because previous applications had indicated its ease of use with busy public officials (Gardiner and Edwards 1975, Gardiner and Ford 1976). Moreover, decision analysts have argued that more sophisticated and time-consuming procedures do not necessarily produce significantly better results than the simple procedures used here (von Winterfeldt 1975).

The photographs shown in the workshop were generated for an earlier small plant siting plan consisting of three 1000 MW plants rather than the six 500 MW plants shown in figure 1. Although the photographs used in the workshop were not the photographs shown in figures 2-5*; the workshop illustrates one manner in which simulated photographs of plume blight have been used in comparing large and small power plants.

Four photographs depicting a view from within Canyonlands National Park were presented to workshop participants for evaluation. These photographs showed "clean" conditions (no plumes or haze), the plume from a single 3000-MW plant under stable conditions, the plumes from three 1000-MW plants (one out of view behind the observer), and a general haze condition. Participants were each asked to indicate their relative preferences for the four photographs by placing them along a rating scale ranging from 0 to 100 where 0 is the least preferred and 100 the most preferred. Participants' responses are illustrated in figure 6. All participants placed the four photographs in the same rank order, preferring the 3000-MW plant's effects to those of the two 1000-MW plants and both to the hazy conditions. Six participants indicated that both power plant scenarios were much less preferable than clear conditions; two participants gave the opposite response saying the two power plant scenarios were only somewhat less preferable than the clear photograph but much more preferable than the hazy condition.

Participants were also asked to indicate the importance of visibility impacts in general relative to the other twenty-five types of impacts included in the survey. Participants were instructed to place the twenty-six types of impacts in rank order of importance, and then through pair-wise comparisons attach

*See color illustration on page 395.

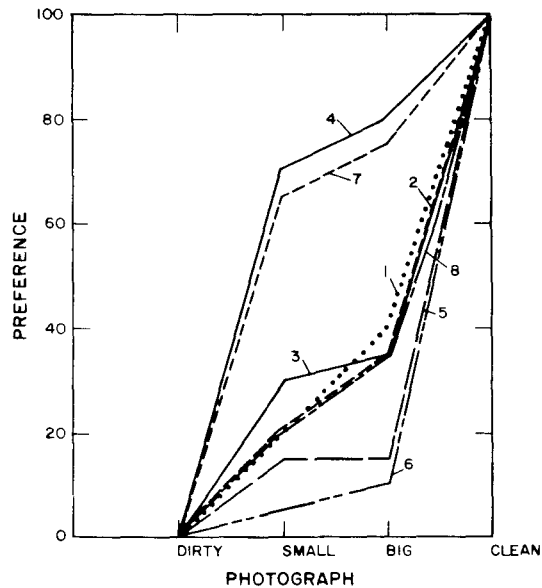


Figure 6--Response curves of six workshop participants.

numerical weights to each impact reflecting the ratio of its importance to the other impacts. These weights were later normalized to a common 0 to 100 scale by expressing each as a percentage of the total weight assigned to all twenty-six impacts by an individual. The average importance assigned to visibility was 3.3, while the median for all twenty-six attributes was 3.7. The range of importance attached to visibility was from 0.28 to 7.8. Overall, visibility ranked 16th in importance behind most of the boom town impacts (e.g., shortage of public facilities, fraction of housing in mobile homes) and air pollution related health impacts, but ahead of agricultural impacts resulting from transfers of water use (e.g., loss in production) and the visual impact of the power plant buildings and transmission lines. A more detailed description of the MAUM Workshop and the large versus small power plant project can be found in Ford and Flaim, eds. (1979).

SUMMARY

A technique has been developed for simulating the visual effects of smoke plumes on a scenic vista. The technique involves digitizing the information on a color slide and modifying the digitized film densities to correspond to the light scattering and absorption by the plume as indicated by the solution to the radiative transfer equation. The modified densities are displayed on a color TV console and

photographed to provide a picture of the simulated scene.

This technique has been applied to compare the plume blight resulting from hypothetical large and small coal-fired power plants in southeastern Utah. Residents of the area were queried as to their preferences for the photographs generated.

With visibility protection in most national parks and wilderness areas now a national goal under the Clean Air Act Amendments of 1977, this methodology could become especially useful in evaluating proposals for new coal-fired power plants near these areas.

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