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ABSTRACT

Clear, clean air is one of the natural resources of the Rocky Mountain West. The visibility provisions of the Clean Air Act of 1977 were intended to protect this natural resource in certain Federal class I areas, for example, national parks and wilderness areas.

There are a number of potential issues which arise due to the possible reduction of visibility caused by emissions from energy facilities. A number of these issues are briefly discussed. The issues are highlighted by computer generated color photographs showing the effects on a clean landscape of several coal-fired power plant scenarios discussed in the text.

The study suggests that visibility may be the limiting factor in energy facility siting in clean air areas. The unique method of displaying the results makes the visibility calculations comprehensible to general audiences.

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THE VISIBILITY ISSUE IN THE ROCKY MOUNTAIN WEST

I. INTRODUCTION

The Rocky Mountain West is characterized by clear, clean air and unique scenic beauty. Visibility limited only by the curvature of the earth is not uncommon. Visitors from throughout the country and the world come to this part of the country to experience the awesome sights which cannot be found elsewhere. Deserts, prairies, colorful canyon lands and snow covered mountain peaks all combine to produce a spectacle of beauty. For this reason, much of the area under discussion has been designated as National Parks, National Forests, National Monuments and Wilderness areas.

Federal primary and secondary ambient standards for the criteria air pollutants have been established to protect the health and welfare of the population. Adherence to these standards can result in a severe degradation in visual range. For example, a recent forest fire near the town of Los Alamos, New Mexico caused the town to be engulfed in smoke for a day. Mountains less than five miles away were obscured, yet the air quality monitoring station in town reported particulate concentrations within the federal ambient standards. These federal standards do not take into account the fact that the tool which most laymen use to determine air quality is visibility.

Many urban areas of the country are continually subjected to visibility reducing concentrations of air pollutants. Five miles visibility is considered quite good in some places. It should be pointed out that the visibility in these areas even without air pollution is considerably less than that experienced in the Rocky Mountain West. This is due primarily to larger concentrations of water vapor in the air.

The exceptional visibility in the Rocky Mountain West is a regional resource which is not protected and was never meant to be protected by the ambient air quality standards. Visibility has been acknowledged as a quantity worthy of protection by the visibility provisions of the Clean Air Act of 1977. This act "declares as a national goal the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class I Federal areas which impairment results from man-made air pollution." The mandatory Class I areas are determined by The Act as follows:

(1) international parks

(2) national wilderness areas exceeding 5000 acres in size

(3) national memorial parks exceeding 5000 acres in size

(4) national parks exceeding 6000 acres in size

(5) all areas previously designated Federal class I areas

National parks and monuments are shown in Figure 1 and Wilderness and primitive areas in Figure 2. Primitive areas are reviewed periodically to determine their suitability for inclusion into the Wilderness System. Only an act of Congress can add an area to the System. Under the Prevention of Significant Deterioration provisions of The Clean Air Act, visibility would not be protected in those areas which became wilderness areas after enactment of the act.

Figure 3 is a composite of Figures 1 and 2. It shows those areas in which the visibility provision of the Clean Air Act will have to be met. The primitive areas have been included in this figure. If these primitive areas are added to the Wilderness System some time in the future, special amendments may be passed giving these areas visibility protection.

Although mandatory buffer zones around the class I areas are not required by the Act, meteorological and terrain conditons will require a certain distance between sources of pollution and class I areas.

Definition of visibility

The terms visibility and visual range will be used interchangeably throughout this paper to mean a distance at which a black object can be seen against the

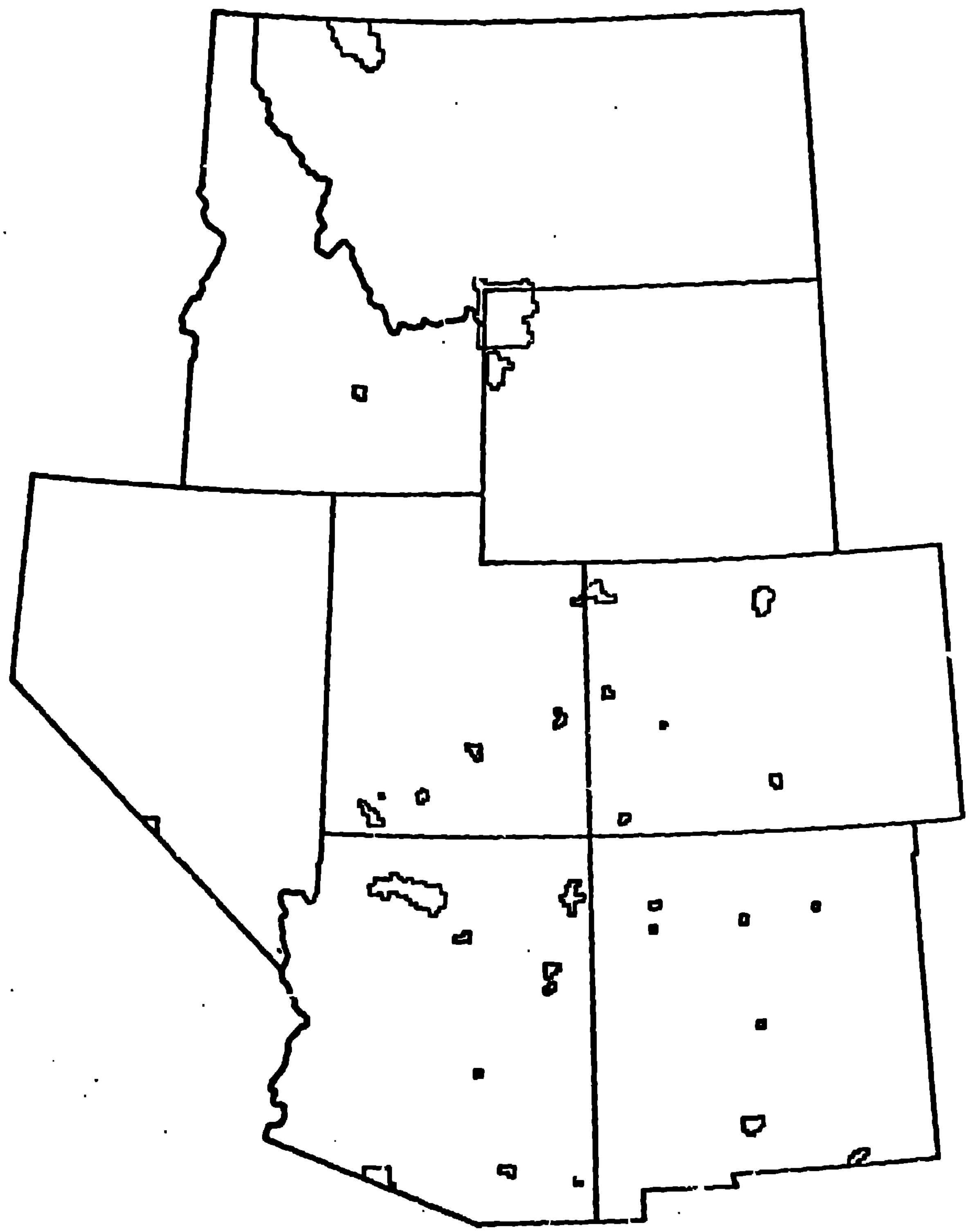


Fig. 1. National Parks and Monuments of the Rocky Mountain Region.

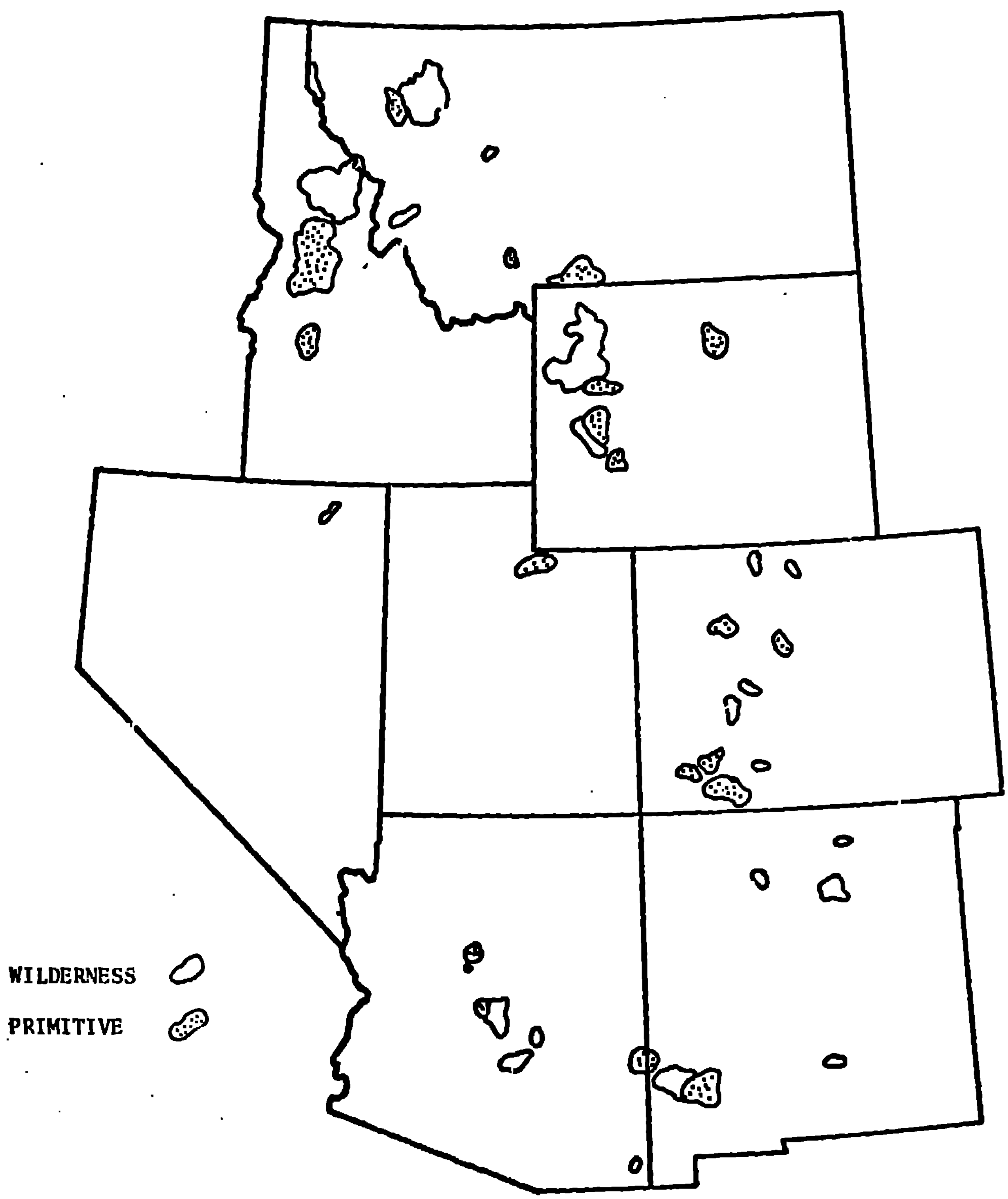


Fig. 2. Wilderness and primitive areas.

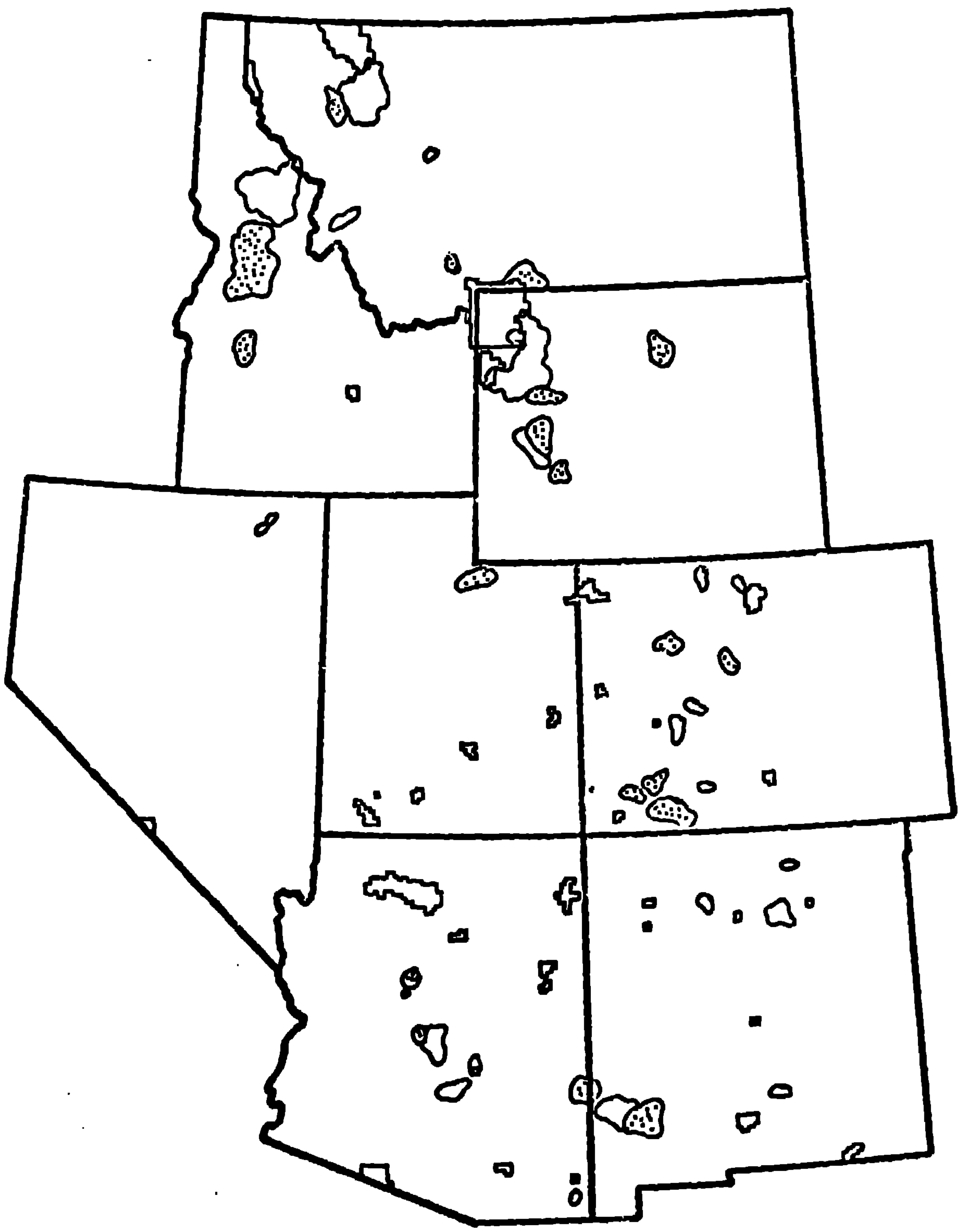


Fig. 3. Possible Class I areas with visibility protection.

horizon sky. When airport weather observers refer to visibility, they mean the average prevailing visibility. This is determined by a team of trained observers who look at preselected objects along the entire horizon. Prevailing visibility is that for which equal or greater values exist over at least half the horizon.

Visual range on the other hand usually refers to runway visual range when used at an airport. This is an actual measurement made with a transmissometer looking down the runway.

Visibility can be quantified in terms of the distance at which a certain amount of contrast is discernible, usually with respect to a dark object against the horizon sky. In general the normal observer is assumed to be able to perceive a contrast of 2%. The following simple formulation is possible:

(1) $$\frac{c}{c_o} = .02$$, where c is the contrast between the object and the horizon sky in the case where scattering and absorption of light are present, and c_o is the contrast for the case where there is no scattering or absorption.

(2) $$c = c_o e^{-\sigma R}$$, where R= visual range or distance to the object which can be just barely seen (2% contrast)

σ= extinction coefficient

The contrast ,c, of an object against a background is defined as

$$\frac{B-B'}{B'}$$

where B is the luminance of the object and B' is the background luminance. Luminance can be defined as the lumens per unit area arriving at a receiver divided by the solid angle defining the source region considered.[1]

The extinction coefficient, σ , depends upon the concentration and the chemical compositions of the absorbing and scattering species. The size distribution of the aerosols is an important parameter. This quantity takes into account both Rayleigh and Mie Scattering. A more complete description of this quantity will be given in the Appendix describing the computer program PVIS.

To get the usual form for the limit of visibility from (1) and (2) it follows that (taking logarithms of both sides)

$$(3) \quad 3.9 = \sigma R$$

or

$$R = \frac{3.9}{\sigma} \quad .$$

Laser or inverse square law techniques can be used to measure σ directly under certain circumstances.

A plume can appear light or dark depending upon the amount of light scattered toward the observer relative to the Rayleigh background light. The same plume can appear light when viewed from one side and dark from the other side. This is the case for optically thin plumes in which only one scatter occurs within the plume. Optically thick plumes on the other hand will have the same probability of light scatter in either direction since many scatters occur within the plume.

Optical thickness as it relates to plume darkness is shown in Figure 4. In the final analysis, whether an observer sees a light plume or a dark plume will depend upon the background light scattering. For this reason one often observes the same plume to be light against certain terrain features, but dark against a background of blue sky.

The above discussion relates to light scattering only. Light can also be absorbed in a plume if NO_2 is present, for instance. Light absorption always leads to a darkening of the plume, although the darkened plume may still appear light compared to a darker background.

The Visibility Issue

The nation's ever-increasing demand for energy combined with stricter enforcement of air quality standards is resulting in energy facility siting in low population areas where the air is relatively clean. For example, there are a number of power generation facilities in operation or in the planning stages in the Rocky Mountain Region which would provide power for Southern California. California's own air quality standards and regulations make siting within the state difficult. There is a feeling on the part of some residents that they must suffer the effects of air pollution so that Californians can have power. On the other hand the power plants are bringing a certain amount of economic activity to the area, the benefits (and disbenefits) of which are the subject of much controversy.

It is the purpose of this paper to look at visibility as an issue in the Rocky Mountain West. Visibility, the ability to see distant objects, is usually thought to be an aesthetic consideration and is therefore a good deal harder to value than something which produces sickness, death, or dirty windows. High enough concentrations of visibility-reducing air pollutants will produce quantifiable damage. But we will concern ourselves here with those lesser amounts which have not been shown to cause other than aesthetic degradation of the environment. Some indication of this aesthetic degradation will be obtained from the use of the computer model developed for this purpose.

The computer model utilizes the color capability of the Los Alamos Computing Facility to depict the effect of various plumes on an otherwise clean landscape. The computer model is described in some detail in the appendix and the results of the cases considered here are discussed in the next section.

It is not the purpose of this paper to make aesthetic judgements, but rather to indicate the impacts visibility reduction may have on various aspects

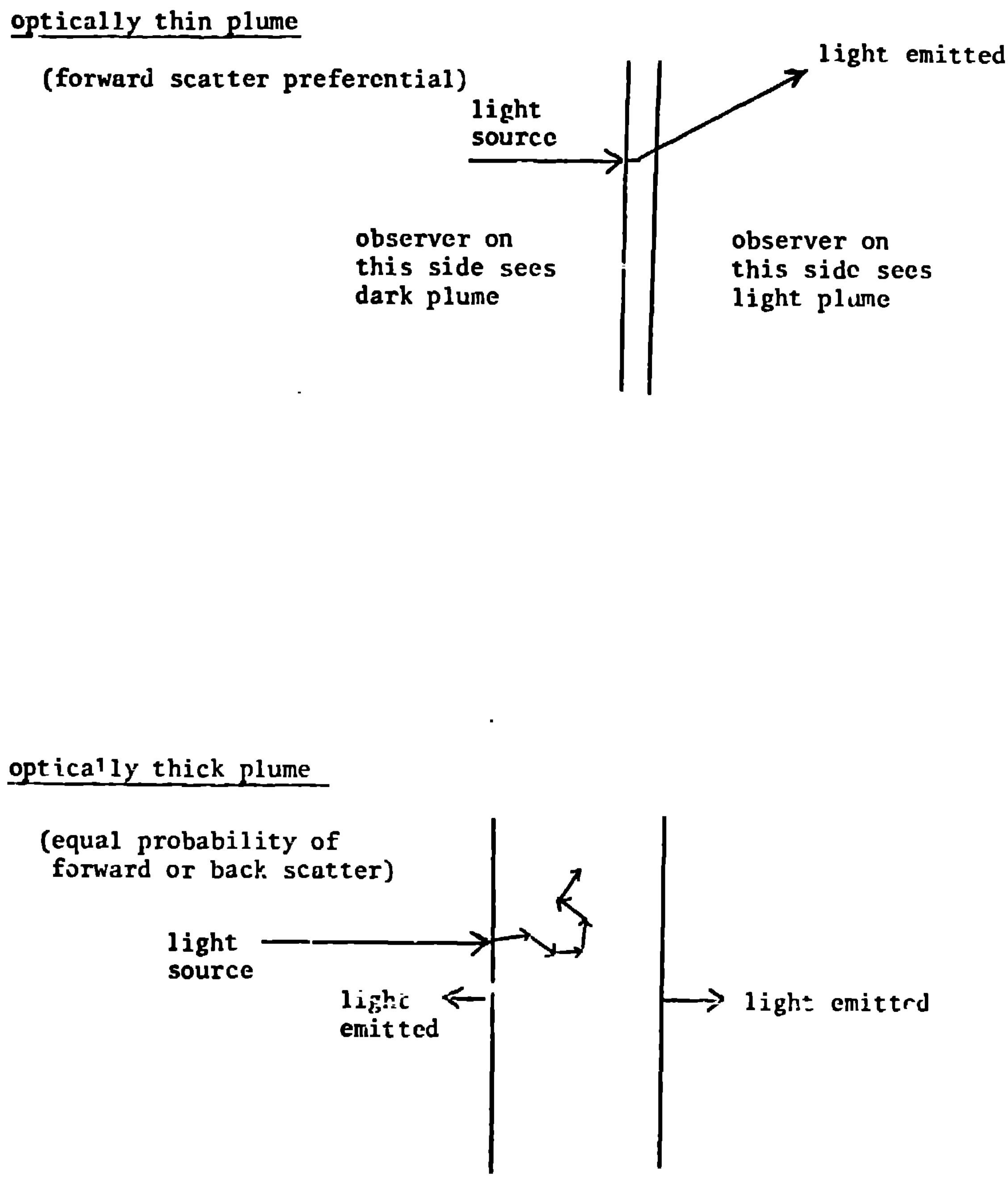


Fig. 4. Optically thick and thin plumes.

of life in the Rocky Mountain West. Studies have been done which indicate that a cost can be associated with loss of visual range. These studies will be briefly discussed later in this paper. The psychological and sociological effects of haze have to our knowledge not been studied except as a part of more general studies of the effects of weather as a whole.

Good visibility is an important consideration for people who engage in certain activities. Photographers will have fewer really good days during which to work. Tourists wanting to get some spectacular photos or enjoy the magnificent views may be disappointed. Recreational pilots may not get as much business on days when the visibility is poor, and residents may not get the full enjoyment they anticipated from the great outdoors. These and similar effects are diffucult to quantify and it is not apparent that they are entirely separate questions from the general question of the total economic impacts of visibility reduction.

The effects of visibility on the night sky and how this relates to the study of astronomy is discussed in some detail in the following section.

II. ISSUES RELATED TO VISIBILITY REDUCTION

A. Indian Lands as Class I Areas

The Indian reservations of the Rocky Mountain region are indicated in Figure 5. Under the Clean Air Act Amendments of 1977 (Part C, Sec. 164) the tribes have the authority to designate their reservations as Class I areas. This has already been accomplished by the Northern Cheyenne in Montana. The Native American Indians are a group whose cultural heritage may dictate a different set of priorities when it comes to energy development as opposed to a pristine environment. An indication of the importance of visibility was given by Herman Bear Comes Out, a Northern Cheyenne Tribal Councilman. In commenting on the redesignation of the Northern Cheyenne Indian Reservation as a class I area, he

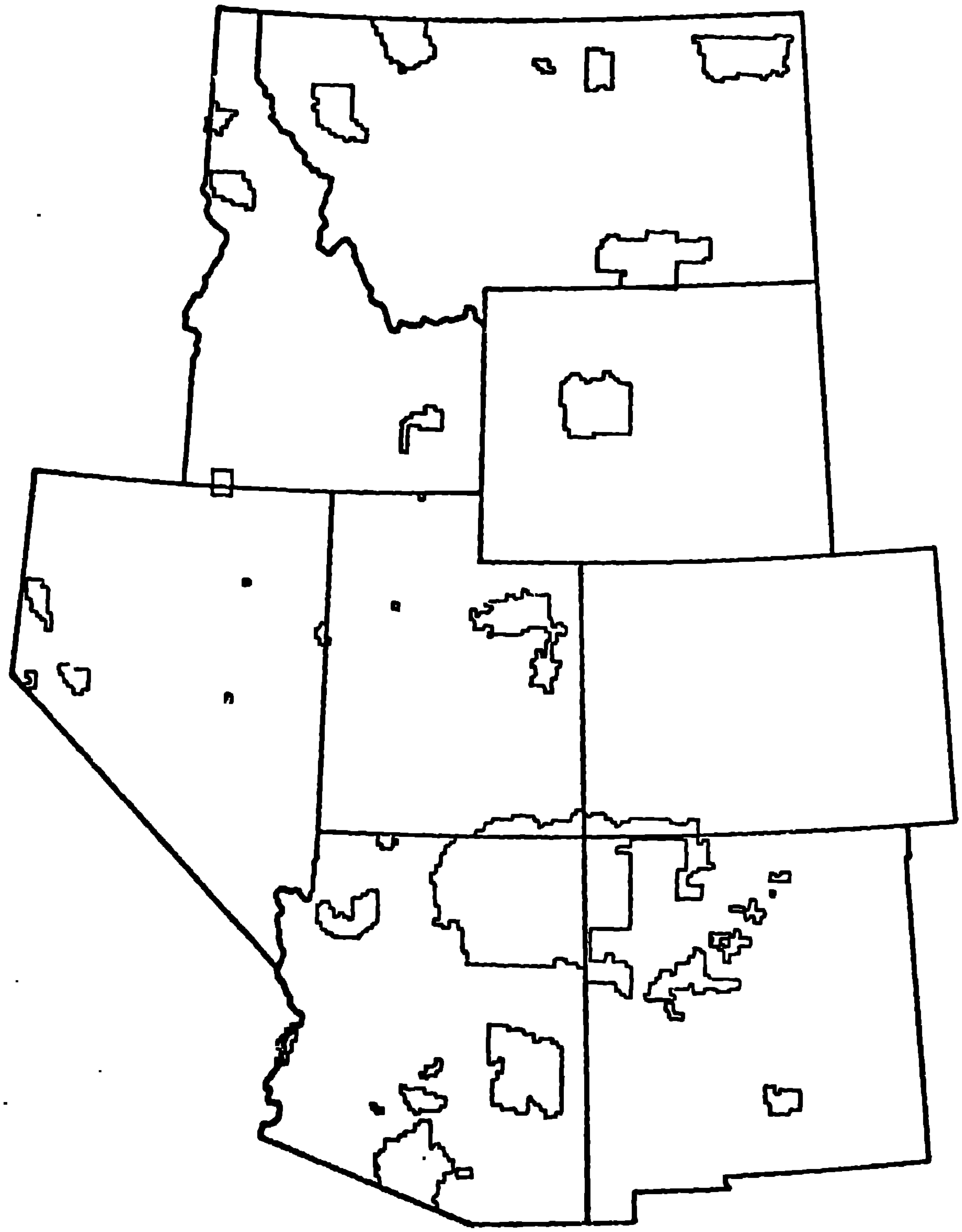


Fig. 5. Indian Reservations of the Rocky Mountain Region.

said, "Now we stand a better chance to continue living on land where you can still see the sky and smell sage and pine."[2] It should be added that not all Indian tribes share his view. There is some feeling on the neighboring Crow reservation that development on Crow tribal lands will be jeopardized because of the redesignation of the Cheyenne lands.

The traditional clean, clear air enjoyed by his ancestors is important to the Indian. The need for protection from visibility degradation becomes greater as more energy industries make plans for the Rocky Mountain West. Visibility protection is now included in the Clean Air Act for mandatory class I Federal areas. Mandatory class I Federal areas are those which were class I at the time of enactment of the Clean Air Act amendments. It is not unreasonable to assume that any Indian tribes that do reclassify their lands as class I will demand the visibility protection enjoyed by those Indian lands which were classified before enactment.

Figure 6 is a composite of Figures 4 and 5 showing possible class I areas if all Indian lands in the region are reclassified. A significant impact could be made as energy development plans should this case arise.

B. The Effects of Atmospheric Pollution on the Night Sky

Historically, the apparent brightness of stars has been measured using the magnitude system. In this system stellar brightness decreases as magnitude, m, increases. For example, one of the brightest stars, Aldebaran, has m=1.1 while the faintest stars observable with the naked eye have m=6 approximately; the exact value of this limit depends upon the observer's sight, the darkness of the sky, and atmospheric clarity. Stated more exactly the change in magnitude, Δm, between any two stars of brightness B_1 and B_2 is given by

$$\Delta m = m_1 - m_2 = 2.5 \log (B_2/B_1).$$

The zero point of the system is determined by a selected set of standard stars

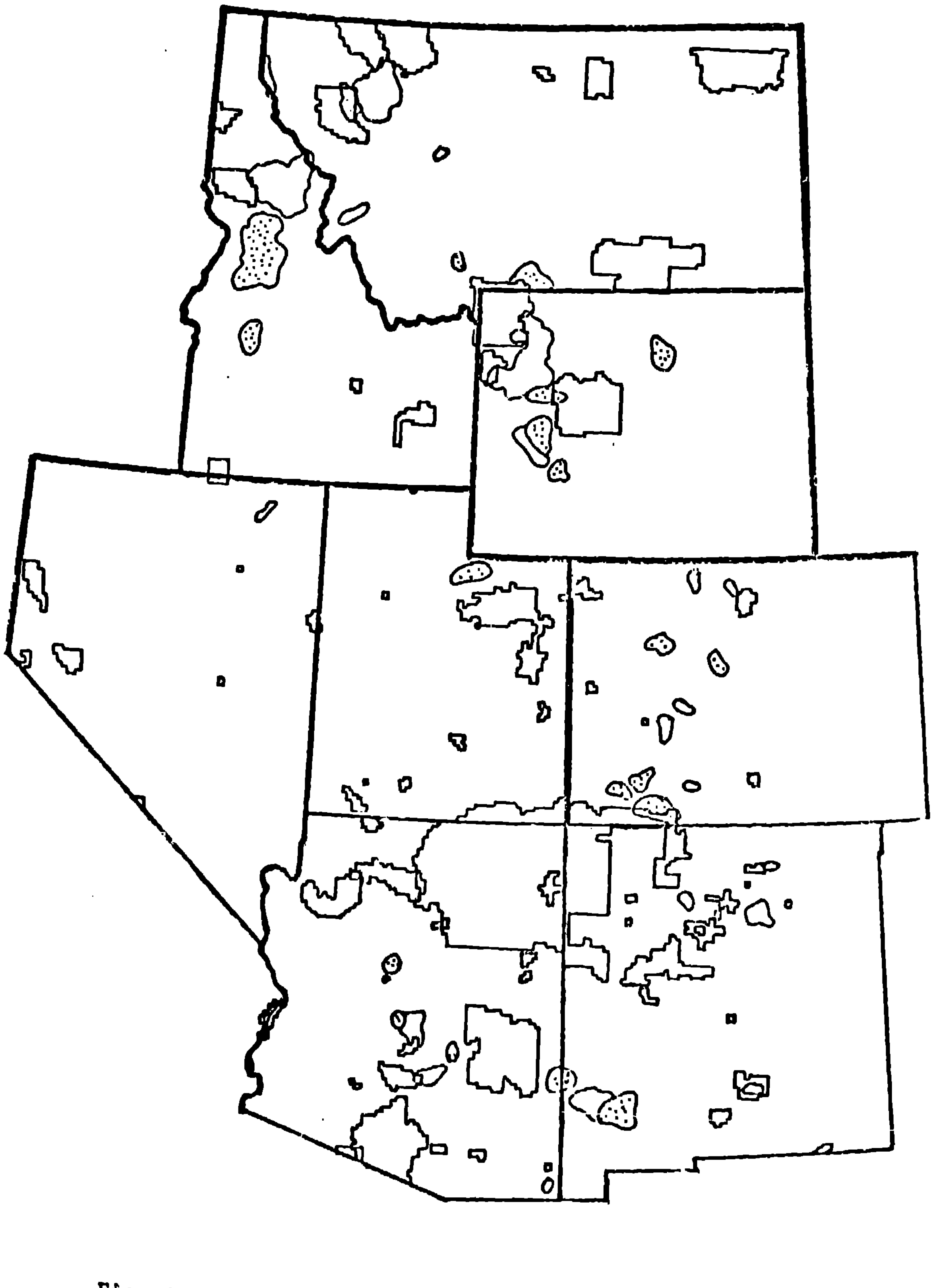


Fig. 6. Possible Class I areas including Indian Reservations.

adopted by international agreement. The limiting magnitude of stars visible through a telescope of aperature D (in inches) is roughly

$$m = 9.1 + 5 \log D.$$

For example, a typical amateur instrument with D=6 inches would permit observation of stars down to about 13th magnitude.

The limit of visibility of stars is set by the diffuse brightness of the night sky against which a star must show sufficient contrast to be visibile. It should be noted that moonlight is omitted in natural sky brightness. The natural night sky brightness has three components:

(1) airglow due to excited molecules in the upper atmosphere,

(2) scattering of sunlight by interplanetary dust (the zodiacal light is the brightest component of this), (3) very faint background stars and starlight scattered by the dust in the earth's atmosphere. These three components contribute in roughly equal amounts; the total brightness of the night sky at the zenith is equivalent to about 300 10th magnitude stars per square degree or about 2×10^{-8} lumens/cm^2 steradian.

Atmospheric pollution will affect the visibility of stars in three distinct ways. First, the starlight will suffer extinction due to Mie extinction by particles and Rayleigh scattering by molecules. If the optical thickness of the pollution layer in a particular direction is τ, the increase in magnitude of a star seen through this layer will be

$$\Delta m = 2.5 \log (B/Be^{-\tau})$$

or

$$\Delta m = 1.086\ \tau,$$

where B is the unaffected stellar brightness. The transparency of the path through the pollution layer is

$$T = e^{-\tau}.$$

For example, a dense layer with T=0.5 will give Δm = 0.75. Figure 7, based upon data from Landolt-Bornstein[3], shows the extinction due to dust and molecular scattering in magnitude versus wavelength of light for a path with a zenith angle of 0°. The attenuation increases with zenith distance since the extinction occurs over a longer slant path through the pollution layer. This is illustrated in Figure 8.

The second effect of atmospheric pollution is the reddening of starlight due to the increasing extinction at shorter wavelength both by Mie and Rayleigh scattering; this effect is seen in Figure 7. The redding of sun, moon, and stars is obvious near the horizon of course.

The third effect of atmospheric pollution is an increase in the brightness of the night sky due to the greater number of scattering particles. Some of the increase will result from increased scattering of starlight but in most urban or near-urban areas the increase will result primarily from greater scattering of artificial lights. The latter effect has been termed "light pollution" and is generally the most important cause of night sky deterioration. Light pollution decreases the limiting visual magnitude by decreasing the contrast between stars and sky. It also decreases the limiting photographic magnitude by producing a fog if exposures are made too long. The extent of these effects will depend upon both the amount of upward directed artificial light and the amount of scattering materials in the pollution layer.

Professional and amateur astronomers have been greatly concerned with degradation of the night sky by light pollution and other effects, not to mention visitors and residents alike who are denied the breathtaking views experienced in the past. Examples of studies are those of Riegel[4], Hoag, Schoening, and Coucke[5], Kalinowski, Roosen and Brandt[6], and Turnrose[7]. Turnrose indicates a relatively recent increase in the brightness of the night sky at Mount Wilson Observatory by about two magnitudes over that at Mount Palomar.

One additional influence on the apparent brightness of stars is the scintillation of a star's image. This effect is produced by turbulence in the earth's atmosphere and is termed "seeing". Thermal pollution accompanying particulate pollution will tend to degrade the seeing quality but it is unlikely that this will persist for any large distances from the pollution source.

As an example of the effects of atmospheric pollution Figure 9 presents the Orion region of the sky with the standard visual limit of about sixth magnitude and with a reduction of the limit to fifth magnitude[8]. The substantial decrease of the richness of the sky is evident. This level of effect, $\Delta m = 1$, could result for example, from Mie scattering by aerosol particles having an assumed extinction cross section $\sigma = 7 \times 10^{-9}$ cm^2 and a number density $N = 130$ cm^{-3}. We assume the particles to be distributed uniformly throughout the troposphere which has a height of 10 km and that the observer is at an altitude of about 1.5 km above sea level. Then we use

$$\tau = N \sigma L$$

with

$$L = H \sec z$$

and

$$z = 35°,$$

resulting in

$$\tau \simeq 0.94$$

or

$$\Delta m \simeq 1.0.$$

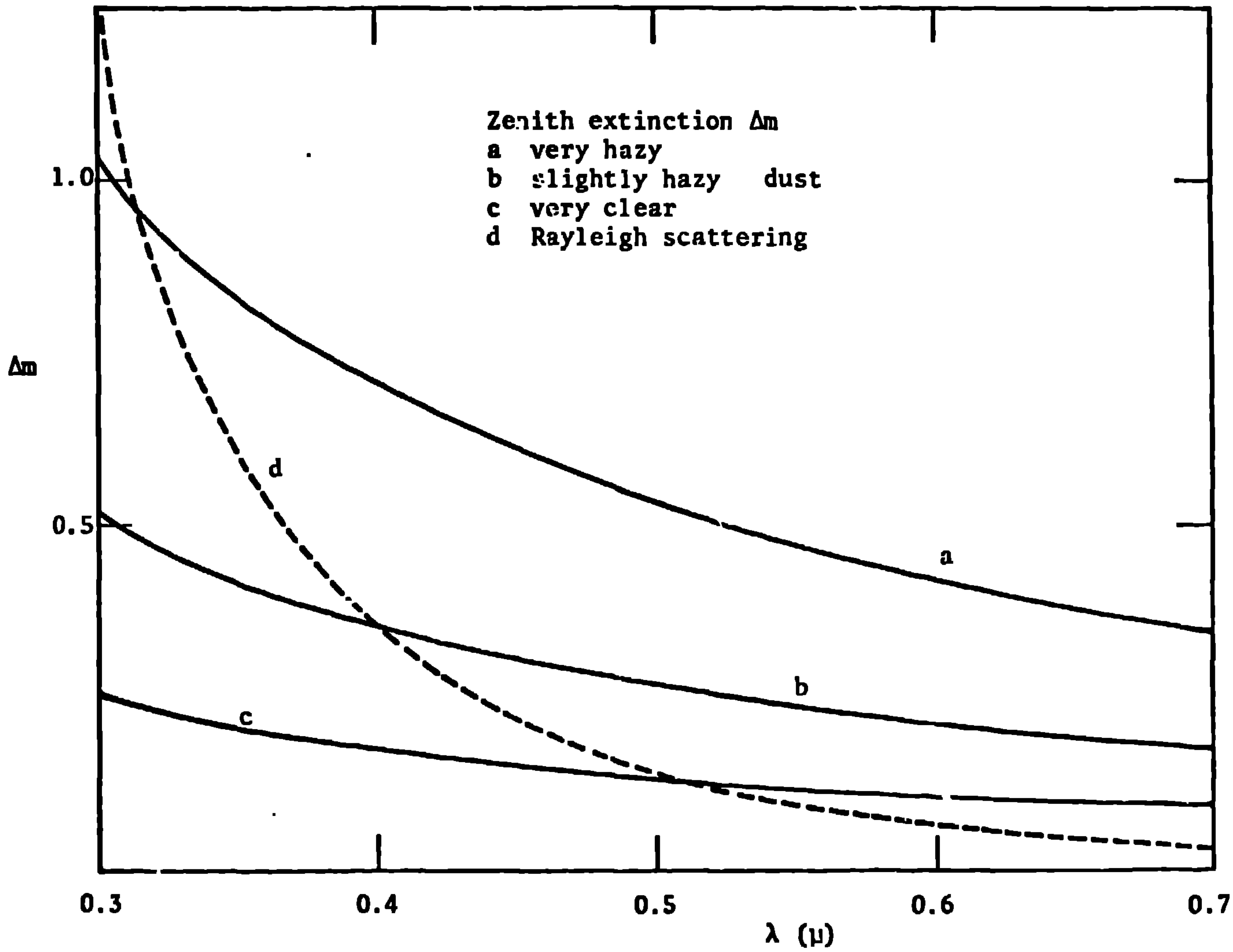
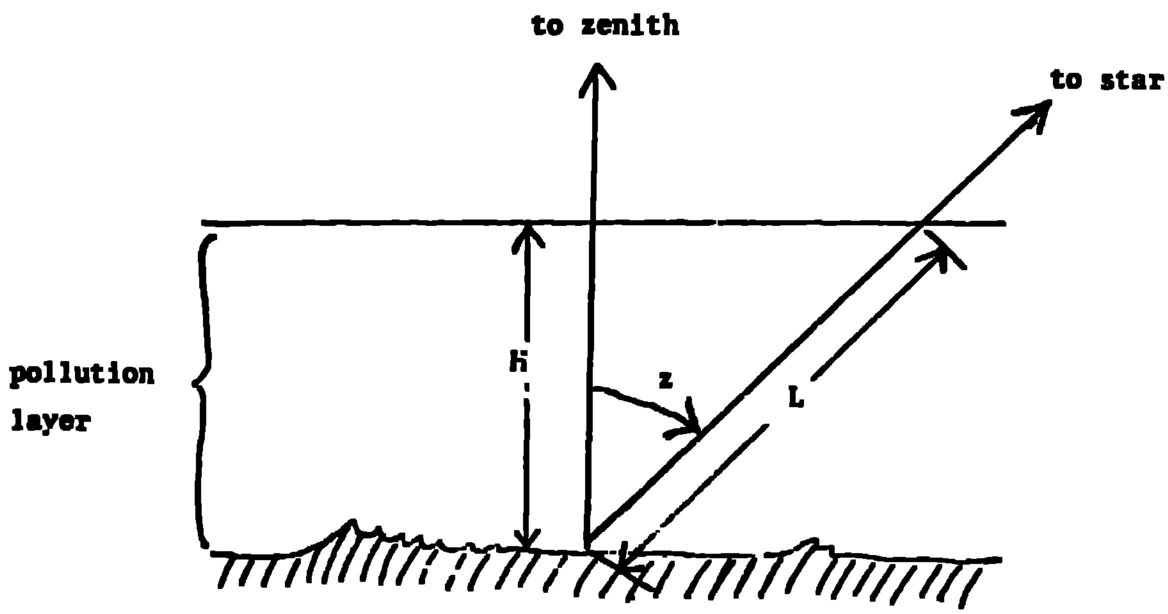
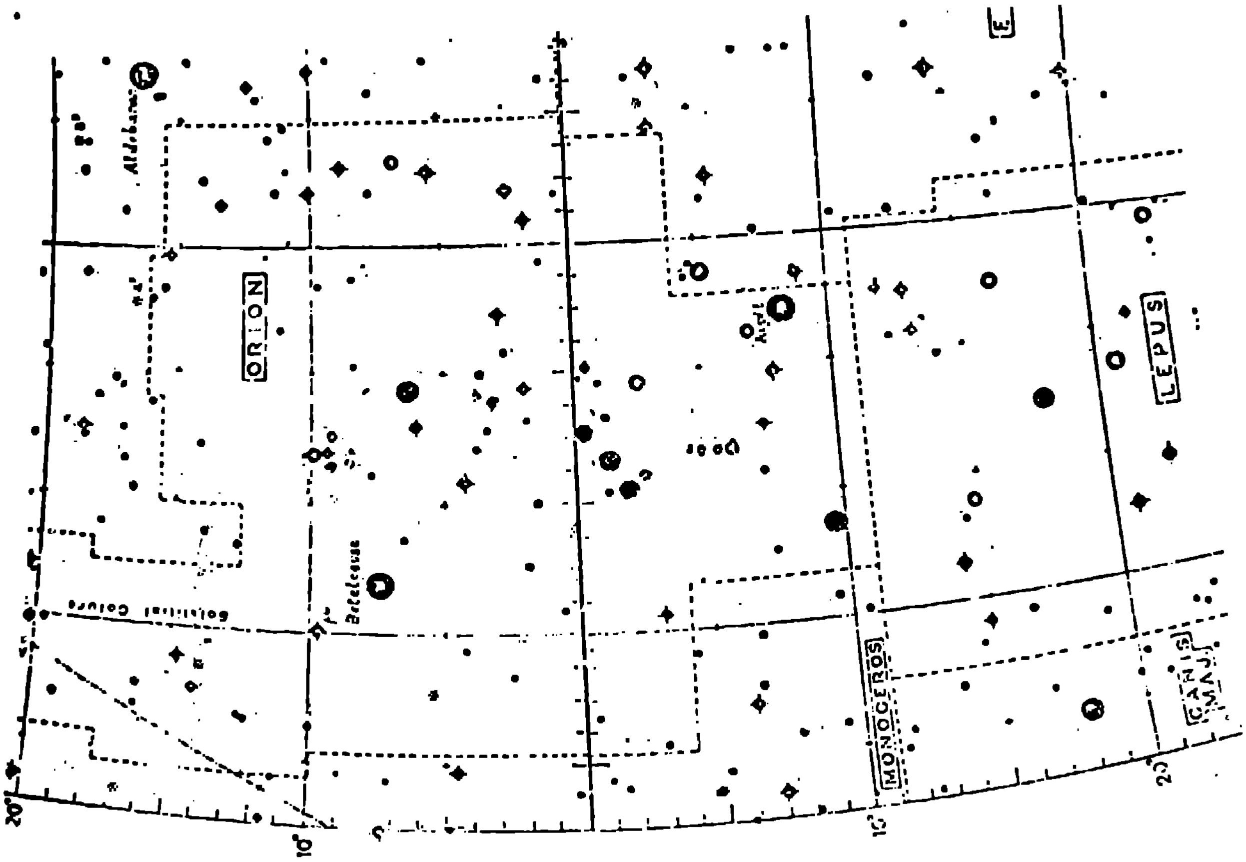


Fig. 7. Zenith extinction vs wavelength.

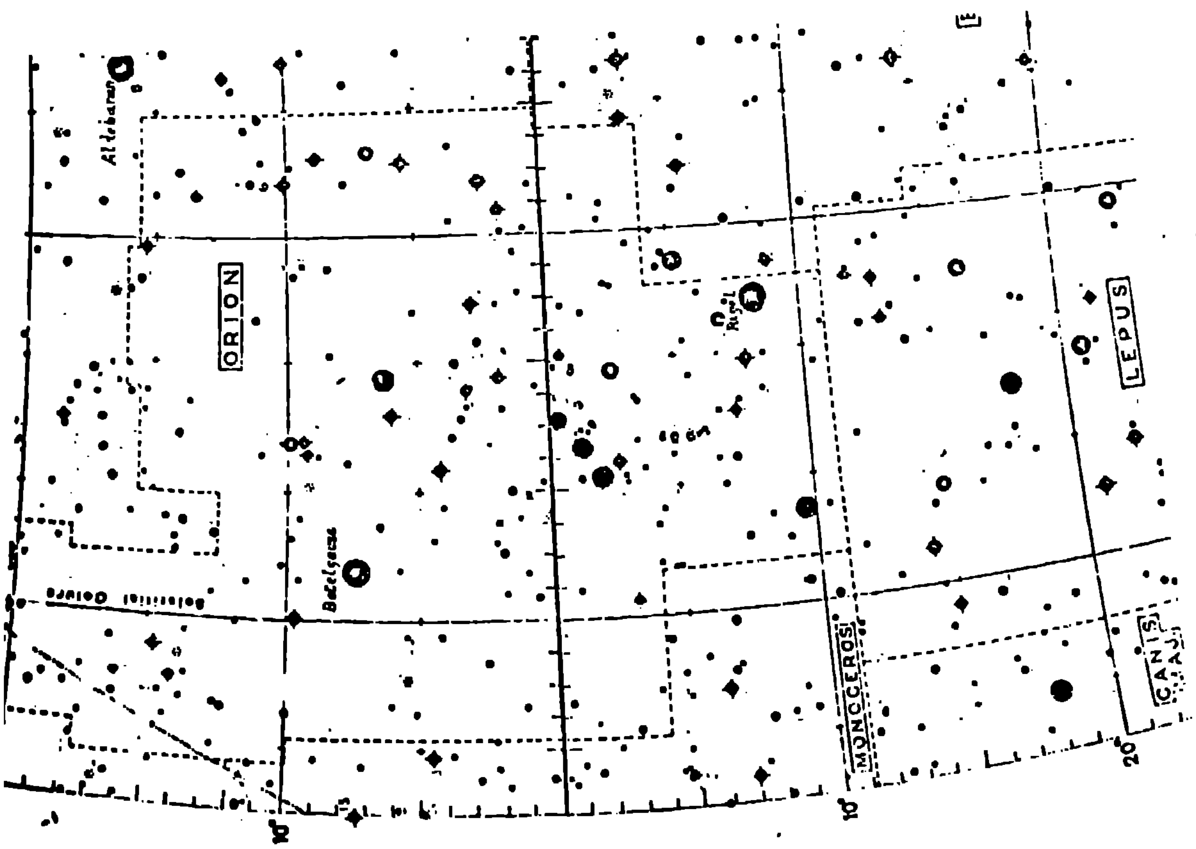


L = H sec z

Fig. 8.



Attenuation of $\Delta m = 1$ $m_{vis} \approx 5$



Standard Night Sky $m_{vis} \approx 6$

Figure 9.

C. The Effects of Sulfates and Other Particulates

There is recent evidence to the effect that sulfates may be responsible for a good deal more visibility reduction than was previously thought. A number of Copper Smelters are located in the Southwest. The smelters in Southeast Arizona alone emitted 5000 tons/day of SO_2 before 1972 when control equipment was added. SO_2 is known to convert to sulfate with time, but the rate of conversion and the particulate size distributions are presently impossible to predict.

From July, 1967 to March, 1968 there was an industry-wide copper strike which shut down the smelters in the Southwest. A recent study[9] looked at SO_4 concentrations and visibilities in the Southwest over many years. This study has revealed a remarkable increase in visibility even at great distances from the smelters during this strike. For example, Phoenix showed a total visibility increase of 24% and Tucson an increase of 23% during this period.

Historical trends were also analyzed as a part of the study referred to above. Four urban sites and eight non-urban sites were considered. In all but one case visibility worsened from 1954 to 1971. There was a slight increase in visibility from the mid 1940's to the mid 1950's reflecting the switch from coal to oil and gas.

Another interesting result of the above-mentioned study has to do with visibility-pollutant relationships. In Phoenix, for instance, 44% of the light scatter was due to sulfates, 31% to nitrates, 17% to blue sky scatter and 8% was unaccounted for. These results were extended to non-urban areas. In the Grand Canyon 36% was sulfate-caused, 9% nitrate, 12% other particulates and 43% blue sky scatter. In general 1/3 to 1/2 of the extinction in non-urban areas can be attributed to sulfates.

Another study conducted in the St. Louis area led to the conclusion that sulfate particles in the .1μ - 1.0μ size range were the dominant light-scattering aerosol.[10] The authors of that study speculate "That these compounds, which dominate the light-scattering hazes in eastern Missouri, may also extend to the entire Midwest. Such visible, turbid air is noted in summer from perhaps Topeka, Kansas, to the East Coast and from Chicago, Illinois, to Little Rock, Arkansas, and only really disappears with massive intrusions of Canadian air in Winter."

Figure 10 indicates the increase in haze over a 26 year period in New York City.[11] Haze is distinguished from fog in that the latter is composed primarily of water droplets, whereas the aerosols associated with haze are primarily solids and other liquid materials emitted into or produced in the atmosphere. It should be noted in Figure 10 that a poor visibility day is one with less than 7 miles visibility.

Visibility has been deteriorating rapidly all over the country during the past 25 years. The East and Midwest have gotten most of the large scale effects, but the Rocky Mountain region has not been immune to the problem.

Dr. Raymond Chaun a resident of the Los Angeles area who has made a number of flights over the Four Corners power plant in Northwest New Mexico commented that, "This looks so much like the Los Angeles basin that it is almost scary." The context for this statement was an afternoon view of Shiprock immersed in smoke emitted from the Four Corners power plant.

D. The Economic Impacts of Reduced Visibility

The valuation of aesthetic preferences is not an easy task. Surveys have been conducted by researchers at New Mexico State University [13] and the University of New Mexico[14] to determine willingness to pay to avoid visual insult due to power plant plumes and stacks in one's field of view. The New Mexico State Study involved residents and recreationists in the Four Corners Area, while the University of New Mexico study covered only recreationists in the Lake Powell National Recreation Area. In both studies the interviewees were shown a series of photographs and various techniques were used to determine how much they would be

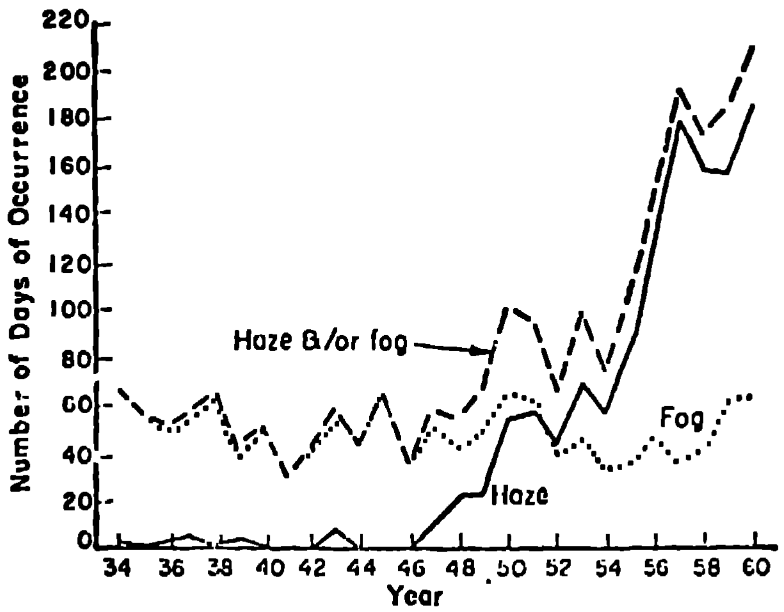


Fig. 10. Frequency of poor visibility days in New York City attributable to haze and fog.

willing to pay in order to improve visual conditions.

There are distinctions between the studies as reported. In one case the question was phrased as a willingness to pay to prevent degradation, while in the other case it was phrased as a willingness to pay to achieve improved air quality. These differences may alter the response. It is not the purpose of this issue paper to offer a critique of the economics literature in this area. There are a number of very serious problems with the data collected in the surveys to date. It is our purpose only to indicate what is available, and to point out the importance of a continued effort to acquire information of this type.

Another important question is who has the rights. Both of these studies assume that the utilities have the rights and the public must pay to maintain or achieve air quality goals. However, the public may choose to acquire the rights through legislation. For example, the Navajos have recently adopted an emission fee. In this case the question is how ch must the Navajo Tribe be paid to accept a given level of air quality degradation. The Clean Air Act of 1970 also did this to an extent. In the case of pollution beyond ambient standards the Clean Air Act says that the public has the right to at least the level of the standards while at levels below the standards the polluters have the rights. The most recent amendments alter this pattern. Under the most recent legislation the public rights have been extended further particularly in the case of national parks or wilderness areas and the simpl below or above standards distinction has been blurred. In both cases however, some apportionment of the right to visibility has been made.

Recently studies (as yet unpublished)[15] have been conducted which assume that the public has the rights and must be compensated for any degradation. These numbers tend to be somewhat larger than those indicated by the studies reported above. These two assumptions give the range of economic impacts. The estimates reported below are based on the willingness to pay studies alone.

TABLE I

VISIBILITY DAMAGES IN FULLY DEVELOPED RESOURCE AREAS[16]
(1975 dollars)

Resource Area	Households per plant in fully developed region in 2000.	Total Households (10^3) in fully developed region in 2000	Aesthetic Damage* Neglecting Income Change to 2000 (from no plant to opaque plume) ($\$10^6$)	Income Effect $(2.5)^{.65}$ x (4) ($\$10^6$)	Visiting Party Days (10^3) 1974	Visiting Party Days (10^3) 2000	Recreation Damage in 2000 (from no plant to opaque plume) ($\$10^6$)
Four Corners	5500	209	32	58	3060	7500	20
Kaiparowits	4400	13	2	4	840	2100	5.7
Central Utah	5800	116	18	32	2870	7000	19
Piceance	5000	10	2	4	340	830	2.2
Eastern Colorado	5200	62	10	18	1340	3300	8.9
Green River-Washakie	4100	176	27	49	1530	3700	10
Powder River-Wyoming	4000	200	31	56	570	1400	3.8
Powder River-Central MT	4100	213	33	59	410	1000	2.7
Northern Gr. Plains	4000	220	34	61	30	70	.2
			TOTAL	341			72

Overall total \$413 million damage

* Aesthetic damage refers to the willingness of residents of the areas to pay to avoid the visual insult imposed by the presence of power plants and their plumes.

The visibility damages shown in Table I were calculated using both the Four Corners and Lake Powell Surveys along with a scenario supplied at one time for The National Coal Utilization assessment for fully developed resource regions in the year 2000.[17] Each of the columns is fairly self explanatory except perhaps for the one titled "Income Effect". The OBERS income ratio is 2.5, and .65 is the income elasticity. This number multiplied by the values in column 4 gives a new value for aesthetic damage. Note that this is still in 1975 dollars. These damage figures are very large, comparable in fact to all other air pollution effects combined.

These numbers are very approximate. We are arbitrarily extrapolating the desires of present day residents to those of future residents, many of whom will, no doubt, be employed by the energy industries. Another point that must be made is that the damages are small compared to the value of the energy produced and the regional income resulting from plant operations. However, these damages may not be small compared to the costs of abating the pollution.

The important issue is the determination of the best level of emission control. The trade off between cost of emission control and air pollution damages, including aesthetic damages, must be considered. There is an indication from the Four Corners Survey that visual impacts may not vary linearly with the number of plants built in a region. The first few plants may saturate the aesthetic damage in a particular region leading to a decline in the willingness of people to pay for pollution abatement from subsequent plants.

In considering the economic impacts of reduced visibility, it is also necessary to look at some of the more conventional items such as losses to the airline industry due to delays resulting from air pollution episodes. A good deal of research has been done relating fluctuations in retail trade to weather conditions, including air pollution episodes.[18] It is well known that more people go shopping on nice days than go shopping on days when the weather is poor.

There are a number of visibility sensitive industries: agriculture, fishing, construction and tourism to name just a few. But the visibility reduction to which this paper is addressing itself is, as was mentioned previously, of an aesthetic nature. We are not talking about a pollution episode which will make it difficult for a surveyor to measure the distance across a road. The question we need to look at is this-- at what point will the family from New York City decide that the Grand Canyon, the Painted Desert and Monument Valley no longer offer the spectacular view which makes it worth their while to drive 3000 miles to see it? Tourism then would be the industry most affected by visibility reduction.

Residential property values and city planning can be subject to change when visibility decreases or when power plant stacks or plumes become visible. A piece of property over-looking a valley will suddenly go down in value if a plume makes its way down the valley each morning.

E. Psychological and Sociological Impacts of Visibility Reduction

Research into the sociological and psychological effects of weather has revolved for the most part around those aspects of the weather which cause physical discomfort. There seems to be a good correlation between riots and high temperature and humidity, for example. The surveys which have been conducted in the past in urban environments can not justifiably be extrapolated to the visibility issue as it exists in the Rocky Mountain West. Here the concern is not with an air pollution episode which makes it difficult to breathe on one's way to the grocery store. For the most part it is a desire to keep some small part of the planet as a pristine refuge. It is important to know that there exist places which are untouched by man's polluting activities. One does not want to backpack into a wilderness area only to be confronted with the view of a power plant plume in the distance.

> "In God's wilderness lies the hope of the world-- the great fresh, unblighted, unredeemed wilderness. The galling harness of civilization drops off, and the wounds heal ere we are aware." (John Muir, 1838-1914)

> "The richest values of wilderness lie not in the days of Daniel Boone, nor even in the present, but rather in the future." (Aldo Leopold, 1887-1948)

> "In wildness is the preservation of the world." (Henry David Thoreau, 1817-1862)

The need to experience the planet earth in her virgin form is deep within us. Witness the fact that vacation homes are usually in mountains or on the seashore, rarely in the downtown area of a large city. The vacation home may be anything from a tent to a villa. It may leave no scar at all upon the land, or it may irrepairably mar the landscape. But one thing that all have in common is a view of some natural, untouched portion of the planet. As this type of land becomes more and more costly, it follows that vacation homes will spring up around man-made natural beauty, such as artificial lakes.

The need to know of the existence of wild, untamed areas is important to one's peace of mind. Even if one never goes to the mountains to get away from it all, one can at least talk about it or dream about it. Having the option is the important thing; whether or not the option is exercised is secondary.

At this point it might be informative to mention the so-called capsule syndrome. "The designers of space capsules have observed that the technical problems of providing food and air and other physical necessities are trivial beside the problem of keeping the capsule's inhabitants human. The greatest difficulty seems to be the stress of confinement. The totally man-made character of the capsule environment and the inability to escape appear to produce unbearable nervous stress.

At present humanity can still escape from man-made cities. But when man assumes responsibility for the whole earth, and the control of every part of it, a syndrome comparable to that found in the capsule may develop."[19]

The unique characteristics of the wilderness are the effects on one's senses-- seeing, hearing and smelling. Noise, odor and haze assault one's senses day after day in the city. It is no wonder that deviant social behavior is rampant in many large cities. Imagine living one's life in an environment of street noise, odors from auto exhaust and garbage, and the all-encompasing claustrophobic haze in which most cities are immersed. The importance of nature and natural beauty to the well being of a city's residents is indicated by the existence of parks in every city--large or small.

The need to be out-of-doors and to experience the sensation associated with natural light may be more than psychological. Recent experiments[20] on plants and animals have led to the discovery that the quality of light is of great importance in certain physical processes such as photosynthesis. These processes occur most efficiently in the presence of the complete spectrum of sunlight. From this information one could extrapolate to the needs of human beings for a complete spectrum of daylight. Visibility impairing gases and particles in the air preferentially scatter and absorb certain wave lengths. Thus creating an "unnatural" spectrum of light even out-of-doors.

Thus one could postulate a physical effect of visibility reduction on human beings. This physical effect could manifest itself as a mental disorder such as depression, or a physical disorder such as an imbalance in the endocrine system. This is a relatively new area of scientific investigation with potentially far-reaching consequences.

Clean, clear air may be more than just an aesthetic preference, it may be a real need.

F. Computer Modelling Results

Five computer generated color photographs are included at the end of this paper. Scene #1 is the computer reconstruction of an actual landscape. This photograph was taken at the Green River Overlook of Canyonlands National Park looking toward Elaterite Butte.

Scene #2 depicts the effect on the landscape of a 3000 MWe coal-fired generating station located as shown in Figure 11. The power plant is equipped with scrubbers which are 90% and 99.7% efficient for SO_2 and particulate removal, respectively. The emissions are as follows: 120g/s particulates, 500 g/s SO_2 and 1750 g/s NO_x. The particulate size distribution coming out of the stack is derived from actual measurements.[21] Six particle sizes are considered from .1μ-.6μ radius.

The SO_2 to sulfate conversion half-life is taken to be 69 hr. and the NO_2 to Nitrate half-life is 23 hr. Upon formation these particulates assume the size distribution described above.

The atmospheric conditions used for the plume dispersion calculations are E stability (stable atmosphere) and 2m/s winds.

The effects of three 1000 MWe power plants is depicted in the third scene. The placement of the plants is shown in Figure 12. Again each of the plants is equipped with scrubbers with the same efficiency characteristics described earlier. In this case the emissions of each plant are scaled by one third with respect to the previous case.

Comparing scenes 2 and 3 it is apparent that the plume is considerably lighter in the case of three dispersed sites. The impact on the landscape looking in any one direction is less for the dispersed sites, though there may be an impact over a greater portion of the horizon.

Scenes #2 and #4 are analogous except for the control technology employed. An electrostatic precipitator is used instead of a scrubber. This results in a different size distribution[21] of the particles. The plume in case 4 looks more reddish because one would expect the absorption due to NO_2 to be more dominant in this case than in case 2.

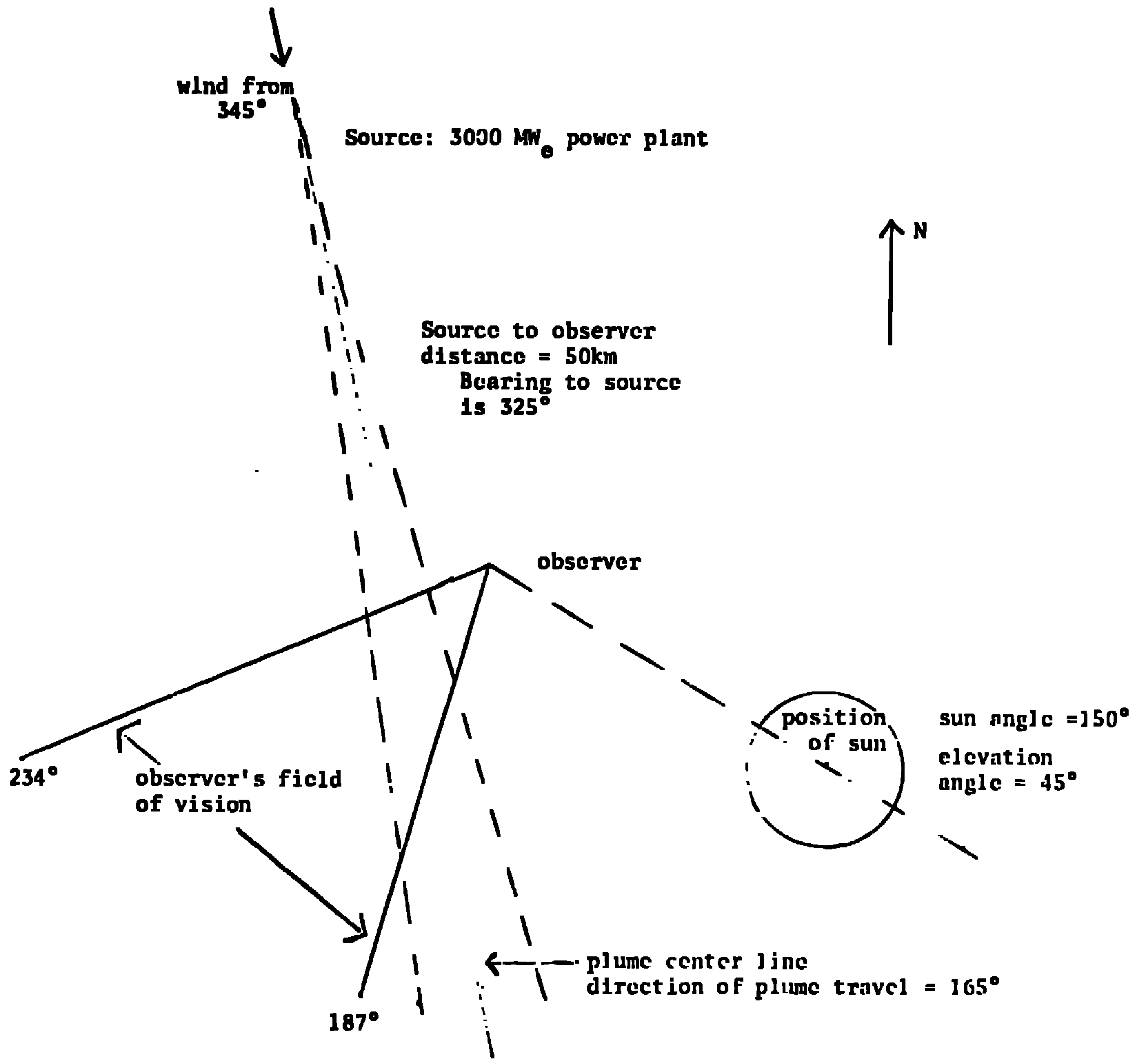
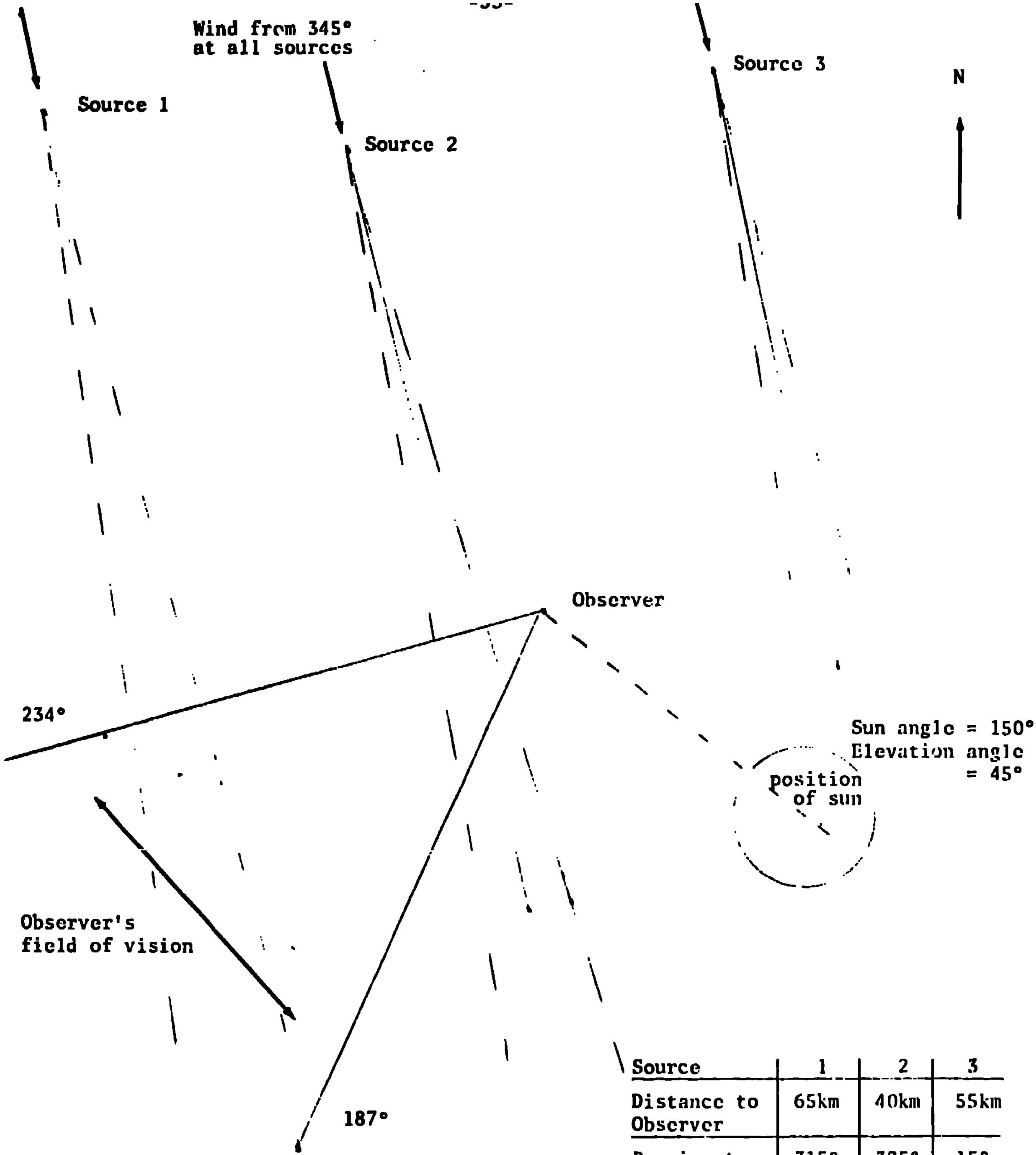


Figure 11: Geometry for Scenes #2 and #4



Source	1	2	3
Distance to Observer	65km	40km	55km
Bearing to Source	315°	325°	15°

Fig. 12. Geometry for Scene #3.

plume to be less noticeable in scene 4 than in scene 2. This is due to a reduced number of particles of a larger size.

Scene #5 superimposes a standard eastern clear day[22] (23 km visibility) on the landscape of scene #1. The visual range is less in blue light and greater in red in this case. Plumes of the type shown in scenes 2,3 and 4 would be very difficult to see under these conditons.

Scene #6 is an actual panoramic photograph taken from Los Alamos looking across the Rio Grande Valley in 1960. The visibility is estimated to be at least 200 miles (322km).

Scene #7 is also an actual photograph of the same scene taken in 1968. This time the visibility is approximately 30 miles (48km). There is some dispute as to the source of this pollution, but it is quite apparent that a reduction in visibility from 200 to 30 miles is significant.

III. REASONS FOR THE IMPORTANCE OF THE VISIBILITY ISSUE

The major effect in the immediate future will be on the siting of power plants. As stated in the introduction, the PSD amendments of the Clean Air Act of 1977 require a maintenance of existing or better visibility in certain designated areas. This requirement will lead to siting of energy facilities away from designated areas.

If a number of Indian tribes exercise their option to classify their lands as Class I, the available number of energy facility sites will fall rather sharply. Existing facilities may also be required to add additional control devices.

In addition to the question of the PSD amendments the separate question of legally mandated protection of federal resources may arise. For example, the National Park Service was concerned that the construction of the Kaiparowits power plant would impair the natural values and the scenic resources in Bryce Canyon

National Park. The Organic Act which establishes each National Park requires that the Secretary of Interior protect these values. Thus it is quite possible that federal land, water, coal or other resources could not have been used in the Kaiparowits project.

In the west much of the coal and water is under some sort of federal control. Thus questions similar to those which arose during the Kaiparowits controversy assume great importance.

There are also other cases in which visibility may play a significant role in siting of power plants. For example a group of water users may control the available water resources in an area. If the users feel that a power plant may impair values of importance to them, they may deny the regional water to the facility. A proposed power plant near Victorville, California was denied water after a local group objected to its air quality impact including its impact on visibility.

IV. INSTITUTIONS AFFECTED BY THE VISIBILITY ISSUE

The following are some of the institutions and federal agencies affected by this issue.

--- The Department of Energy will be considering alternative energy strategies. Allowable facility siting will be an important consideration.

--- The Environmental Protection Agency will be required to establish standardized techniques for monitoring visual range in mandatory Class I Federal areas. Regulations and modelling guidelines must also be issued.

--- The Department of Interior and Bureau of Land Management must revise their Environmental Impact Statement procedures to require an analysis of the impacts of the proposed facility on all surrounding Class I areas.

--- The utility companies will be required to implement new procedures for site determination such that visibility in surrounding Class I areas will not be affected by their facility.

--- Federal land managers must ascertain under the Clean Air Act amendments, whether or not a proposed facility will have an adverse effect on air-quality related values in Class I areas.

V. GROUPS WHO WILL BENEFIT FROM RESOLUTION OF THE VISIBILITY ISSUE

The recognition of good visibility as a major component of clean air is witnessed by its inclusion in the Clean Air Act of 1977. Certain areas have been designated (as described in section I) in which good visibility is considered a resource worth protecting. The following groups will no doubt benefit from this decision.

--- Recreationists want to be assured that certain areas will remain in a pristine state to be enjoyed by present and future generations.

--- Utility companies want to be able to plan for their future power generation needs. This is easier if the rules are set out in advance.

--- All governmental organizations that have as part of their charter the responsibility for planning the nation's energy future.

VI. OTHER GROUPS ADDRESSING THE VISIBILITY ISSUE

--- Concerned citizens groups (ie. New Mexico Citizen's for Clean Air and Water) want to be assured that the proper measures will be taken now to protect visibility in Class I areas. There will probably be numerous efforts made to hav more areas redesignated as mandatory Class I areas.

--- Government agencies, consulting firms and university groups are developing techniques which can be used for determining whether or not the visibility criteria are being maintained. Among these the Environmental Protection Agency and the Departments of Interior and Energy will be involved most directly.

VII. SUGGESTED PROGRAM OF RESEARCH TO ADDRESS THESE ISSUES

Five areas of research must be pursued if this issue is to be resolved effectively. First, there is a need for more information on the value of visibility. More studies like the ones at the University of New Mexico and New Mexico State are necessary. These studies should provide a foundation for making some rational decisions as to whether or not to reclassify an area from class II to class I. The next big area of conflict between the utilities and the environmentalists will be in this arena. A well defined data collection program should be embarked on as soon as possible, since this is the most expedient way in which to have unbiased data available on which to base reclassification decisions.

Secondly the capability for reliable measurement of visual range is currently lacking. Since the EPA will be charged with the responsibility of monitoring visibility in class I areas, it is necessary that the research effort be moved ahead at full speed. There are presently four basic methods for visibility measurement.

(1) the human observer

(2) photography and the contrast photometer

(3) nephelometer

(4) laser transmissometer or inverse square law method

The nephelometer, an instrument which measures visibility at a point, could be used effectively by creating a grid of instruments over a region or along a line of sight. This is a costly instrument, but has two things in its favor. It does not require the presence of a human observer and it does not require the placement of source and receptor points. Other visibility measurement techniques usually involve a source of light, possibly a laser, and, some distance away, a receptor. The amount of light reaching the receptor is then compared with the amount leaving the source thereby giving the amount of light transmitted in the forward direction. Laser transmissometers are used for this purpose, but that is also an expensive piece of equipment.

Photography is another technique which can be used. In this case differences in brightness between the horizon sky and a dark object are obtained from density differences in the film. A contrast photometer which measures the difference in brightness between two points can also be used.

The photographic and contrast photometers both give a measure of visibility along a light path.

Once a reliable measurement technique is selected, a baseline measurement program must be undertaken. It will be impossible to determine whether Class I visibility standards have been violated if the present ambient visibility is unknown.

Visibility modeling is the third area of importance. There are presently no acceptable models for predicting the reduction of visual range around a source of pollution. The primary reason for this deficiency in the modeling capabilities is the lack of necessary data. This brings us to the fourth area in which research is required. In order to effectively predict light scattering from aerosols it is necessary to be able to predict their size distribution and chemical composition. In order to do this the appropriate gas to particle conversion rates under various atmospheric conditions must be determined.

A great deal of basic research remains to be done in the areas of photochemical oxidant formation, wet and dry deposition rates, determination of mass extinction coefficients, and a whole host of plume chemistry questions involving reaction rate determinations among other things. The chemistry questions and light scattering and absorption determinations which one faces in calculating visibility are in addition to the air dispersion modeling which one must do in order to determine where the plume will go. Air dispersion modeling itself is still at a point where calculations in rough and mountainous terrain are in their infancy. In addition to this, the meteorological data necessary to run the existing models is generally not available for most remote sites in the Rocky Mountain West.

To be truly effective, an effort in modelling and measuring parameters must be carried on simultaneously. Numerous groups across the country are presently engaged in these activities, but efforts seem to be fragmented and uncoordinated. The EPA is attempting to pull things together (modelling and measurement) in their St. Louis area study, but the problem is extremely complex.

The fifth suggested program of research would be a regional study to look at the effects of the visibility provisions of the Clean Air Act on the siting of coal-fired power plants and other energy facilities.

VIII. ALTERNATIVE COURSES OF ACTION

There are essentially three courses of action which the new Department of Energy could take on this issue. No action whatsoever on DOE's part would leave the entire ballgame in the hands of the EPA and the other agencies which must evaluate proposed plant sites and take part in the writing of impact statements. This is not a reasonable alternative since DOE's role in the areas of energy policy and energy priority considerations require up-to-date knowledge of all areas which could affect choice of facility type and sites.

The second course of action would be to undertake no new research efforts in these areas, but to keep very close tabs on all research which is on-going and all decisions made by EPA and the other agencies regarding siting. A thorough literature search into those areas of concern listed in VII would be a necessity if this course of action is selected.

The third course of action would be a combination of the recommended course of action described above and those parts of section VII which are not presently receiving proper attention, specifically items one, three and five: visibility value studies, visibility modeling and a regional siting study. Numerous organizations are currently engaged in various measurement programs, including DOE to some extent. These activities will have to pick up speed by virtue of the requirements of the new provisions of the Clean Air Act regarding visibility. Item I, the need for more information on the value of visibility to residents and visitors, may fall by the wayside in the rush to meet the demands of the moment. As was pointed out previously, this type of information will be very important in making decisions regarding long range facility siting strategies. In the area of modeling, DOE should have its own modeling capability. Although work done by others in the field should be used, the in-house capabilities already developed should not be neglected. This modeling capability should be used to give some indication of the effects of energy facility siting on those Class I areas in which visibility is to be protected. This could be a part of a regional study which considers the effects on energy development in the West of both PSD and visibility provisions of the Clean Air Act.

Clearly, this third course of action is recommended.

APPENDIX

PVIS: Pollutant Visualization Program

The production of the data for a single picture requires the operation of 3 codes. The first code (LEG1) calculates the Legendre coefficients for mie scattering associated with particles of radii .1, .2, .3, .4, .5, and .6 microns for the wavelengths of light chosen. The second code solves the radiation transfer problem for the background atmosphere and in addition provides the Fourier coefficients of the phase functions to be used in the plume visibility code. It then provides the sky brightness values required by the plume visibility code.

The plume visibility code uses Gaussian dispersion relations to describe the distribution of contaminants in the atmosphere. These contaminant distributions are used to predict the changes in light transmission and in light scattering. Light scattered toward the observer comes from skylight and direct sunlight. The phase functions are used to calculate how much of the scattered light travels in any one direction. Construction of a photograph requires that a separate complete cycle be run for wavelengths appropriate to red light, green light and blue light. Translation between the film and the computer codes is obtained by relating the film density corresponding to a portion of the sky to the brightness calculated by the radiation transfer code for the same portion of the sky.

The image enhancement subroutine library developed at LASL (LADIES) was used to superimpose pollutant data, obtained from the program described above, onto a digitized image of an unpolluted landscape.

The resulting output is a computer generated picture of the original landscape on which the calculated air pollution is superimposed.

A few more words should be added about the extinction coefficient, σ, mentioned earlier. The extinction coefficient is the sum of the scattering and absorption coefficients. The scattering coefficient is the result of aerosols and is a function of the size distribution and index of refraction of the material. The principal scattering species in this paper are fly ash, particulate nitrates and particulate sulfates. Aerosols may also absorb light; however, we have used only pure scatterers in this treatment. In this work the only absorber is the gas nitrogen dioxide which effectively absorbs blue light.

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