United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park, NC 27711

EPA-454/R-92-023
(Revises EPA-450/4-88-015)
October 1992

Air

EPA

WORKBOOK FOR PLUME VISUAL IMPACT SCREENING AND ANALYSIS (REVISED)

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PREFACE

This document was first issued in September 1988 as a draft for public comment. On February 13, 1991 (56 FR 5900), EPA issued a Notice of Proposed Rulemaking to augment the Guideline on Air Quality Models (Revised) with modeling techniques including those referred to here. This document is revised to reflect these comments and is included in Supplement B to the Guideline.

CONTENTS

NOMENCLATURE

b_{abs} -- Light absorption coefficient of an air parcel, proportional to concentrations of nitrogen dioxide (NO_2) and aerosol (e.g., soot) that absorb visible radiation (m^{-1})

b_{ext} -- Light extinction coefficient of an air parcel, the sum of absorption and scattering coefficients (m^{-1})

b_R -- Light scattering coefficient of particle-free air caused by Rayleigh scatter from air molecules (m^{-1})

b_{scat} -- Light scattering coefficient resulting from Rayleigh scatter (air molecules) and Mie scatter (particles), the sum of b_R and b_{sp} (m^{-1})

(b_{ext}/m) -- Light extinction efficiency per unit species mass (m^2/g)

(b_{scat}/V) -- Light scattering efficiency per unit aerosol volume concentration (m^2/cm^3)

b_{sp} -- Light scattering coefficient caused by particles only (m^{-1})

C -- Contrast at a given wavelength of two colored objects such as plume/sky or sky/terrain

C_{min} -- Contrast that is just perceptible, a threshold contrast

C_{plume} -- Contrast of a plume against a viewing background such as the sky or a terrain feature

C_r -- Contrast of a terrain feature at distance r against the sky

ΔC_r -- Change in sky/terrain contrast caused by a plume or extra extinction

C_0 -- Intrinsic contrast of a terrain feature against the sky. The sky/terrain contrast at r = 0. For a black object, $C_0 = -1$

d -- Distance between the emission source and the observer (m)

$\Delta E(L^*a^*b^*)$ -- Color difference parameter used to characterize the perceptibility of the difference between two colors. In the context of this workbook, it is used to characterize the perceptibility of a plume on the basis of the color difference between the plume and a viewing background such as the sky, a cloud, or a terrain feature. Color differences are due to differences in three dimensions: brightness (L^*) and color hue and saturation (a^*, b^*)

F_s -- Solar insolation or flux incident on an air parcel within a given wavelength band (watt m^{-2} μm^{-1})

I -- Light intensity or radiance for a given line of sight and wavelength band (watt $m^{-2} sr^{-1} \mu m^{-1}$). Subscripts t and h refer to terrain and horizon, respectively.

I_{obj} -- Light intensity reflected from an object such as a terrain feature (watt $m^{-2} sr^{-1} \mu m^{-1}$)

$p(\lambda, \theta)$ -- Phase function, a parameter that relates the portion of total scattered light of a given wavelength λ that is scattered in a given direction specified by the scattering angle θ

Q -- Emission rate of a species, such as SO_2, or plume flux at a given downwind distance, which may be less than the emission rate because of surface deposition and chemical conversion (g s^{-1}). Subscripts refer to species considered (e.g., SO_2, $SO_4^=$, and particulate)

r -- Distance along the line of sight from the viewed object to the observer (m)

r_o -- Object-observer distance (m)

r_p -- Distance from observer to centroid of plume material (m)

r_v -- Visual range, a parameter characteristic of the clarity of the atmosphere, inversely proportional to the extinction coefficient. It is the farthest distance at which a black object is perceptible against the horizon sky (m)

r_{v0} -- Background visual range without plume (m)

t -- Time (s)

u -- Wind speed (m s^{-1})

WD -- Wind direction

x -- Downwind distance from emission source (m)

x_{min}, x_{max} -- Distance along plume axis from emission source to the closest and most distant Class I area boundaries (m)

λ -- Wavelength of light (m)

ρ -- Density of a particle (g m^{-3})

α -- Horizontal angle between a line of sight and the plume centerline

β -- Vertical angle between a line of sight and the horizontal

γ -- Plume offset angle, horizontal angle between the line between the emission source and the observer and the plume centerline

ϕ -- Azimuthal line-of-sight angle, horizontal angle between the line connecting the emission source and the observer and the line of sight

ψ -- Vertical angular subtense of plume

χ -- Concentration of a given species in an air parcel (g m^{-3})

τ -- Optical thickness of a plume, the line-of-sight integral of the extinction coefficient. Subscripts refer to the component of the total, or plume, optical thickness (e.g., particulate, $SO_4^=$, NO_2)

[ ] -- Denotes the concentration of the species within brackets

ω -- Albedo of the plume or background atmosphere, the ratio of the scattering coefficient to the extinction coefficient

θ -- Scattering angle, the angle between direct solar radiation and the line of sight. If the observer were looking directly at the sun, θ would equal 0°. If the observer were looking away from the sun, θ would equal 180°.

1 INTRODUCTION

This guidance document is designed to assist the user in the evaluation of plume visual impact as required by the Prevention of Significant Deterioration (PSD) and visibility regulations of the U.S. Environmental Protection Agency (EPA). Sources of air pollution can cause visible plumes if emissions of particulates and nitrogen oxides are sufficiently large. A plume will be visible if its constituents scatter or absorb sufficient light so that the plume is brighter or darker than its viewing background (e.g., the sky or a terrain feature such as a mountain). PSD Class I areas such as national parks and wilderness areas are afforded special visibility protection designed to prevent such plume visual impacts to observers within a Class I area.

The objective of this document is to provide guidance on the assessment of plume visual impacts, including the use of a plume visual impact screening model (VISCREEN), which can be used to calculate the potential visual impact of a plume of specified emissions for specific transport and dispersion (meteorological) conditions. VISCREEN can be applied in two successive levels of screening (Levels 1 and 2) without the need for extensive input specification. If screening calculations using VISCREEN demonstrate that during worst-case meteorological conditions a plume is either imperceptible or, if perceptible, is not likely to be considered objectionable (i.e., "adverse" or "significant" in the language of the EPA PSD and visibility regulations), further analysis of plume visual impact would not be required as part of the air quality review of a source. However, if screening demonstrates that criteria are exceeded, plume visual impacts cannot be ruled out, and more detailed plume visual impact analysis to ascertain the magnitude, frequency, location, and timing of plume visual impacts would be required. Such detailed plume visual impact analysis is called Level-3 analysis and is carried out by more sophisticated plume visibility models such as PLUVUE II. Figure 1 shows a logic flow diagram of the three levels of plume visual impact screening and analysis.

This guidance document and the screening model VISCREEN are designed to replace the procedures described in the "Workbook for Estimating Visibility Impairment" (Latimer and Ireson, 1980). The procedures described in this document are simplified by use of the screening model VISCREEN,

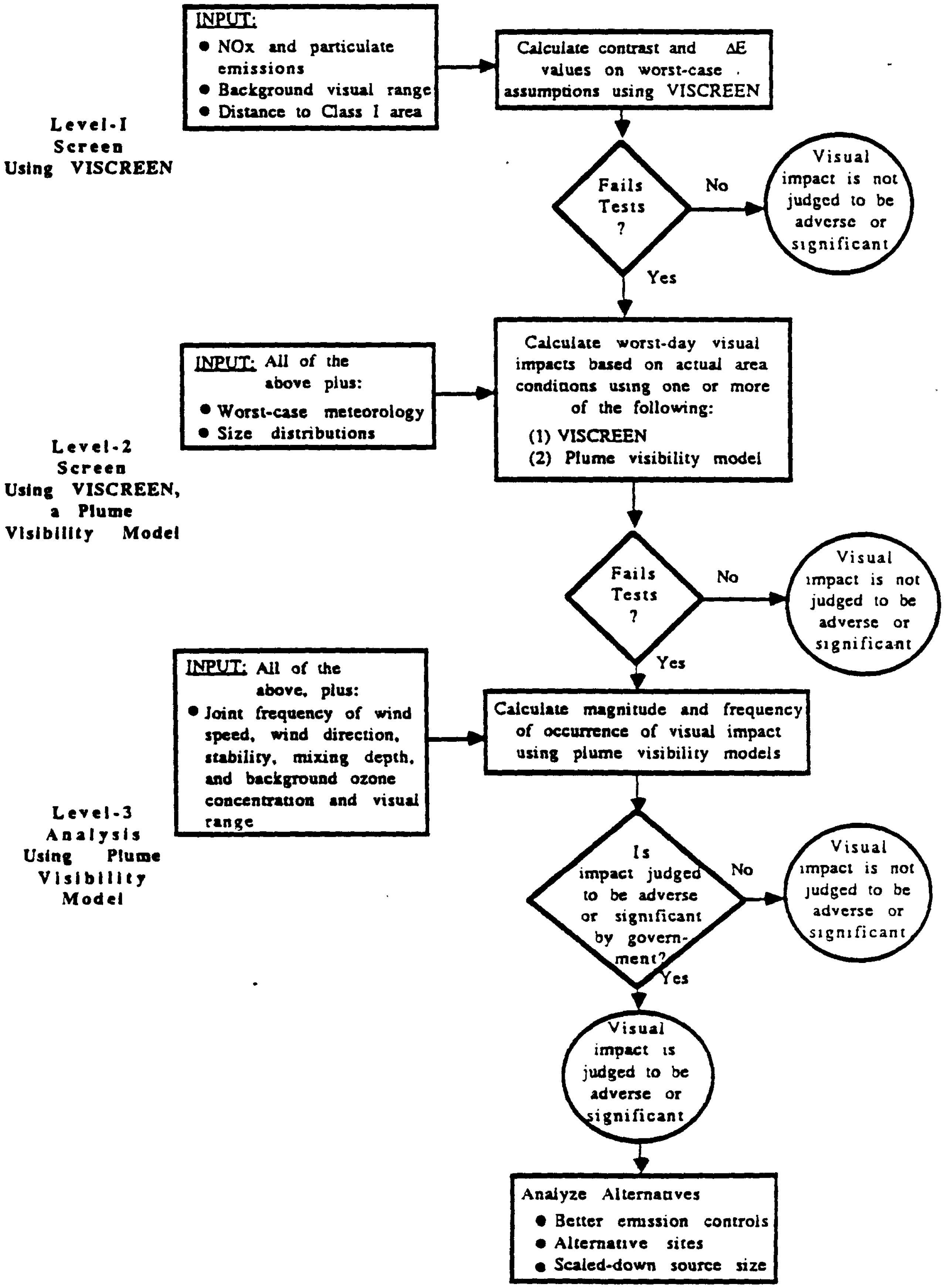

FIGURE 1. Logic flow diagram for 3-level plume visual impact analysis.

instead of the hand calculation encouraged by the earlier document. VISCREEN is designed to evaluate plume visual effects along the plume's entire length for two different viewing backgrounds and for two different sun angles. One important design feature of VISCREEN that distinguishes it from the earlier EPA Visibility Workbook is the evaluation of the potential perceptibility of plumes using recent psychophysical concepts (see Appendix A).

In addition, to simplify the plume visual impact screening and analysis process, this guidance is limited to assessing the visibility of a plume itself, not whether the plume contributes to reductions in general visibility. Thus, a source's contribution to regional haze is not considered in this guidance. Although regional haze is the most extensive and serious form of visibility impairment throughout the United States and in Class I areas, it is caused by multiple sources located throughout a region. A single emission source may contribute to such a problem but is generally not the sole (or even major) contributor. The protection and improvement of regional visibility must be achieved through broader regulatory action than is possible with the review of a single emission source. In addition, regional haze analysis requires a different analysis tool: regional dispersion models, rather than plume models. However, the process of assuring that plume visual impacts are not objectionable to visitors to Class I areas may contribute to the broader visibility protection issue by limiting industrial source siting near Class I areas.

These guidelines are designed to be brief and straightforward. The reader interested in more detail is advised to refer to the 1980 EPA Visibility Workbook (Latimer and Ireson, 1980). In addition, citations for several references regarding visibility and visibility modeling are provided in the reference section of this document. These sources can be consulted if the reader is interested in the details of visibility modeling, the derivation of formulas used in VISCREEN, and the broader regulatory, policy, and technical issues associated with visibility protection.

This guidance document is organized as follows: Section 2 provides a brief overview of the concepts used in plume visual impact screening and analysis including a description of parameters used to characterize the perceptibility of plumes. Section 3 provides a step-by-step procedure for implementation of the simplest, Level-1 screening analysis. Section 4 provides guidance on Level-2 screening, including the determination of worst-case meteorological conditions. Section 5 provides suggestions regarding the most detailed, Level-3 plume visual impact analysis that is required only if a source fails both the Level-1 and -2 screening tests. A discussion of plume perceptibility threshold research is presented in Appendix A. Technical documentation and a listing of the plume visual impact screening model VISCREEN are provided in Appendixes B and D, respectively. Examples of plume visual impact screening and analysis calculations are provided in Appendix C.

2 GENERAL CONCEPTS

In this section we present a brief overview of the concepts required to understand the technical approach used in plume visual impact screening and analysis. More detailed background information can be obtained from the references cited in the back of this document.

First, we discuss what makes a plume visible. Then, we present an overview of light scattering and absorption in the atmosphere and the emissions that are responsible. Next we describe the specific geometries assumed for plume visual impact analysis and present the basic formulas describing plume visual impact. Finally, we discuss plume perceptibility screening criteria.

WHAT MAKES A PLUME VISIBLE

The objective of plume visual impact screening and analysis is to determine whether or not a plume is visible as an object itself. To understand what makes a plume visible, we first ask what makes any object visible. Any viewed object is visually perceptible to a human observer if the light emanating from the object and impinging on the retina of the eye is sufficiently different from light emanating from other objects so that the difference or contrast between the given object and surrounding objects (its viewing background) produces a perceptible signal to the optic nerve and the brain. Visual perception requires contrast. Contrast can be large as in the case of this black type on white paper, or contrast can be small as in the case of touch-up paint that doesn't quite match.

Since the human eye responds differently to different wavelengths of light, the eye responds to color as well as brightness. The range of wavelengths to which the human eye responds is called the visible spectrum and ranges from the short-wavelength (0.4 micrometer, μm) blue to the middle-wavelength (0.55 μm) green to the long-wavelength (0.7 μm) red. Contrast can be defined at any wavelength as the relative difference in the intensity (called spectral radiance) between the viewed object and its background:

$$C = (I_{obj} - I_{back})/I_{back} \quad ,$$

where C is the contrast and I_{obj} and I_{back} are the light intensities (or spectral radiances) of the object and its background.

If the viewed object is brighter than its background, it will have a positive contrast. For example, a white cloud viewed against a dark blue sky will have a positive contrast. If the object is darker than the background, its contrast is negative. For example, a distant mountain is usually visible because of a negative contrast against the horizon sky (unless the mountain is snow-covered, in which case its contrast is generally positive).

Figure 2 illustrates the concept of contrast at different wavelengths with four hypothetical objects. Object 1 has spectral radiance distribution defined by I_1 over the visible spectrum. Because Object 1's spectral radiance is uniform over all visible wavelengths, it is nominally white. Object 2 is darker than Object 1 because spectral radiances at all wavelengths are lower than those for Object 1. In addition, Object 2 is a different color because there is relatively more light at the red end of the visible spectrum than at the blue end. The contrast of Object 2 against Object 1 is negative at all wavelengths, but blue contrasts are more negative than both green and red wavelengths. As a result Object 2 would appear dark red (brown) compared to Object 1. Similarly, Object 3 would appear as a dark blue, and Object 4 would appear as an even darker gray (or black). If Object 3 were the viewing background for Object 2, its contrast at the blue end of the visible spectrum would be negative, while its contrast at the red end would be positive. Thus, contrasts at all wavelengths in the visible spectrum characterize the brightness and color of a viewed object (such as a visible plume) relative to its viewing background.

In the plume visual impact screening model VISCREEN, contrasts at three wavelengths (0.45, 0.55, and 0.65 μm) are used to characterize blue, green, and red regions of the visible spectrum. In the plume visibility model PLUVUE II, calculations are performed for 39 wavelengths. Thus, we can ascertain whether a plume will be brighter or darker or discolored compared to its viewing background by evaluating its contrasts in the blue, green, and red portions of the visible spectrum. If plume contrast is positive, the plume is brighter than its viewing background; if negative, the plume is darker. If contrasts are different at different wavelengths, the plume is discolored. If contrasts are all zero, the plume is indistinguishable from its background (i.e., imperceptible).

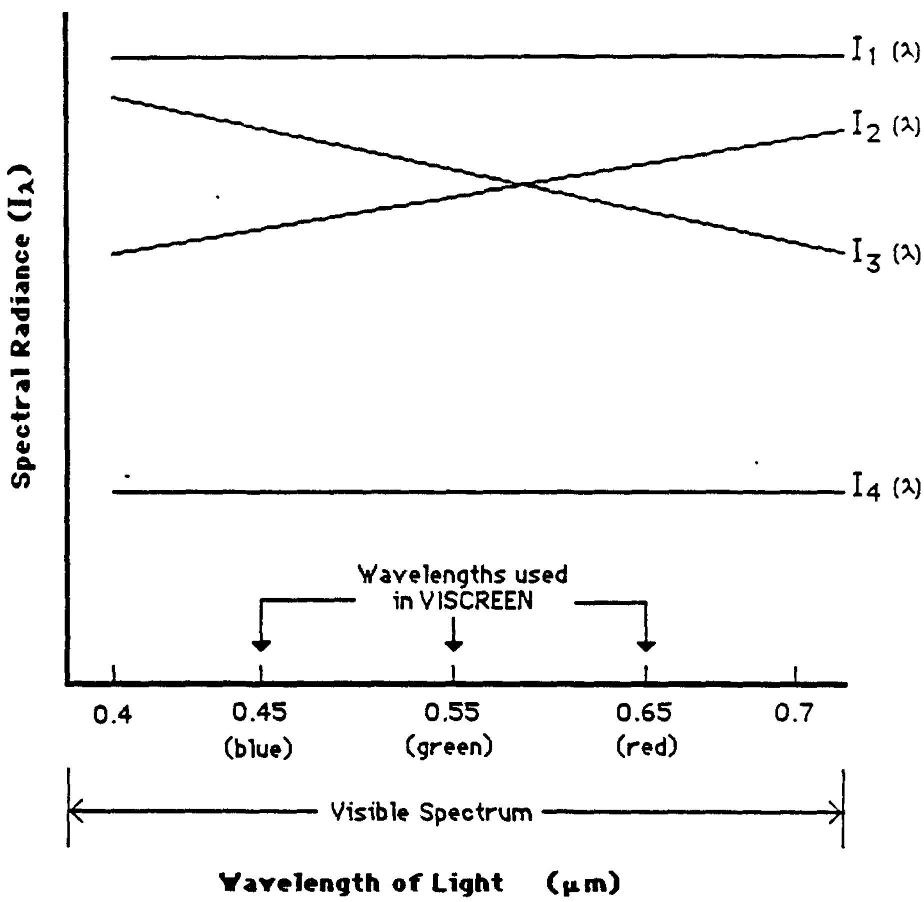

FIGURE 2. Example distributions of light intensity of four objects.

WHAT CAUSES PLUME CONTRAST

The contrast of this black text against the white paper is caused by differences in the amount of light reflected from the page. Almost all of the light impinging on the white paper is reflected, and almost none of the light impinging on the black ink is reflected; hence, the text has a large negative contrast (C = -1). Plume contrast is caused by a somewhat different set of physical processes: plume contrast results from an increase or decrease in light transmitted from the viewing background through the plume to the observer.

This increase or decrease in light intensity (spectral radiance) is caused by plume constituents that scatter and/or absorb light. There are only two common plume constituents that scatter or absorb light. Particulates, depending on their nature, can scatter light or both scatter and absorb light. Nitrogen dioxide (NO_2) absorbs light of all wavelengths in the visible spectrum but it is a stronger absorber at the blue end of the spectrum.

We can characterize the atmospheric optical properties of a plume in a manner analogous to the way plume concentrations are characterized. Instead of using mass concentration ($\mu g/m^3$), which is the mass of a given species per unit volume of ambient air, we use parameters called the light scattering coefficient (b_{scat}), the light absorption coefficient (b_{abs}), and their sum, the light extinction coefficient (b_{ext}). These coefficients are essentially the concentrations of the equivalent light scattering, absorption, and extinction cross-sectional area. They are cross-sectional area per unit volume of air; hence, their units are m^2/m^3 or m^{-1}.

These coefficients are similar to concentration in that they are proportional to the mass concentrations of the particulates and NO_2 that scatter and/or absorb light; however, since different chemical species have different light extinction efficiencies, there is no simple one-to-one relationship between mass concentration and light extinction. For example, submicron particles between 0.1 and 1 μm are much more effective in scattering light per unit mass than are either smaller or larger particles. Soot is a stronger light absorber than NO_2 per unit mass. Table 1 shows the light extinction efficiency of several common constituents of plumes and background atmospheres. Light extinction coefficient (b_{ext}) is the product of the mass concentration and the light extinction efficiency of the given species.

Plume visual impact models account for the concentrations of various species in a plume (e.g., NO_2, submicron particulate, coarse particulate, and soot) and their light scattering and absorption properties at various visible wavelengths (e.g., blue, green, red).

TABLE 1. Typical light extinction efficiencies for constituents of plumes and background atmospheres.

Constituent	Light Extinction Efficiency at $\lambda = 0.55\ \mu m$ (m^2/g)
Soot	13
Hygroscopic fine particles including ($SO_4^=$) and nitrates (NO_3^-)	4-8
Fine particles ($0.1 < D < 1\ \mu m$)	3
Coarse particles ($1 < D < 10\ \mu m$)	0.4
Nitrogen dioxide (NO_2)	0.17
Giant particles ($D > 10\ \mu m$)	< 0.04

Sources: Latimer et al., 1978, 1985; Latimer and Ireson, 1980

PLUME EFFECTS ON LIGHT TRANSMISSION

Figure 3 shows a schematic of the viewing situation that is mathematically represented in a plume visual impact model. A plume of limited dimensions is embedded in an otherwise uniform background atmosphere. The observer's line of sight intersects the center of the plume at distance r_p from the observer and it intersects a viewing background object (e.g., a mountain) at distance r_o. The direct rays from the sun are at angle θ with respect to the line of sight. The change in the spectral light intensity at any point along the line of sight (either inside or outside the plume) as a function of distance r along the line of sight is:

$$\frac{dI(\lambda)}{dr} = -b_{ext}(\lambda)I(\lambda) + \frac{\bar{p}(\lambda,\theta)}{4\pi} b_{scat}(\lambda)F_s(\lambda) \quad , \qquad (1)$$

where

r = the distance along the line of sight from the object to the observer;

$\bar{p}(\lambda, \theta)$ = the scattering distribution or phase function for scattering angle θ (see Figure 3 for definition of θ) modified to account for multiple, as well as single, light scattering;

$F_s(\lambda)$ = the solar flux (watt/m^2/μm) incident on the atmosphere,

b_{scat} (λ) = the light scattering coefficient, which is the sum of the Rayleigh scattering (due to air molecules), b_R, and the scattering due to particles, b_{sp}:

$$b_{scat}(\lambda) = b_R(\lambda) + b_{sp}(\lambda) \quad ; \qquad (2)$$

b_{ext} (λ) = the light extinction coefficient, which is the sum of the scattering, $b_{scat}(\lambda)$, and absorption, (λ) b_{abs}, coefficients:

$$b_{ext}(\lambda) = b_{scat}(\lambda) + b_{abs}(\lambda) \quad . \qquad (3)$$

On the right-hand side of Equation (1), the first term represents light absorbed and scattered out of the line of sight; the second term represents light scattered into the line of sight. The values of b_{scat} and b_{abs} can be evaluated if the aerosol and NO_2 concentrations and such characteristics as the refractive index and the size distribution of the

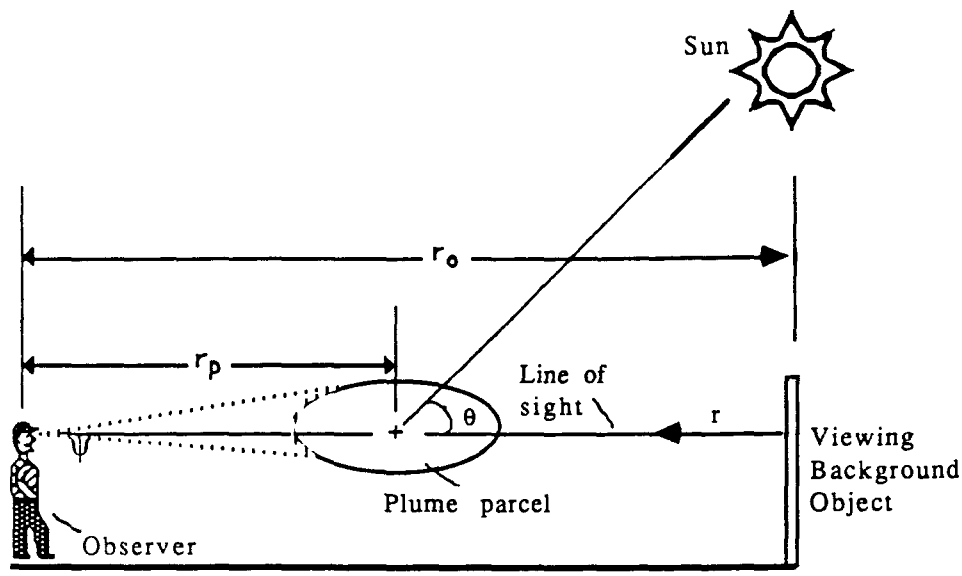

FIGURE 3. Geometry of plume, observer, viewing background, and sun.

aerosol are known. Except in the cleanest atmospheres, b_{scat} is dominated by b_{sp}; also, unless soot is present, b_{abs} is dominated by the absorption coefficient due to NO_2. Scattering and absorption are wavelength-dependent, and effects are greatest at the blue end ($\lambda = 0.4$ μm) of the visible spectrum ($0.4 < \lambda \leq 0.7$ μm). The Rayleigh scattering coefficient b_R is proportional to λ^{-4}; the scattering coefficient caused by particles is generally proportional to λ^{-n}, where $0 < n < 2$. Also, NO_2 absorption is greatest at the blue end. This wavelength dependence causes the natural blue sky coloration as well as discoloration of the atmosphere.

For a uniform atmosphere, without inhomogeneities caused by plumes (where b_{scat} and b_{ext} do not vary with distance r along the line of sight), Equation (1) can be solved to find the intensity and coloration of the horizon sky:

$$I_h(\lambda) = \frac{\bar{p}(\lambda,\theta)}{4\pi} \frac{b_{scat}(\lambda)}{b_{ext}(\lambda)} F_s(\lambda) \quad . \tag{4}$$

The perceived intensity of distant bright and dark objects will approach this intensity as an asymptote, as illustrated by Figure 4.

Atmospheric coloration is determined by the wavelength-dependent scattering and absorption in the atmosphere. The spectral distribution of $I(\lambda)$ for λ over the visible spectrum determines the perceived color and light intensity of the viewed object. The relative contributions of scattering (aerosols plus air) and absorption (NO_2) to coloration can be illustrated by rearranging Equation (1):

$$\frac{1}{I(\lambda)} \frac{dI(\lambda)}{dr} = b_{scat}(\lambda) \left(\frac{\frac{\bar{p}(\lambda,\theta)}{4\pi} F_s(\lambda)}{I(\lambda)} - 1 \right) - b_{abs}(\lambda) \quad . \tag{5}$$

Note from Equation (4) that when light absorption is negligible compared with light scattering (i.e., $b_{scat} \approx b_{ext}$), the clear horizon intensity, $I_{h0}(\lambda)$, is simply:

$$I_{h0}(\lambda) = \frac{\bar{p}(\lambda,\theta)\ F_s(\lambda)}{4\pi} \quad . \tag{6}$$

We now can rewrite Equation (5):

$$\frac{1}{I(\lambda)} \frac{dI(\lambda)}{dr} = b_{scat}(\lambda) \left[\frac{I_{h0}(\lambda)}{I(\lambda)} - 1 \right] - b_{abs}(\lambda) \quad . \tag{7}$$

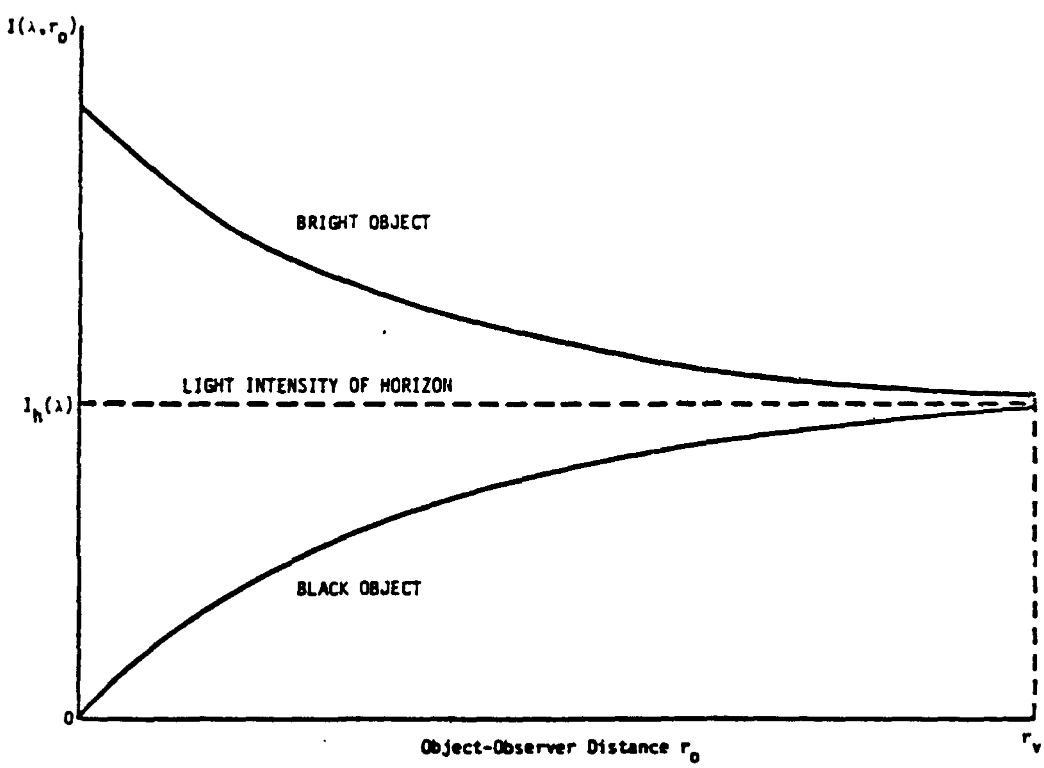

FIGURE 4. Effect of an atmosphere on the perceived light intensity of objects.

Equation (7) is thus an expression relating the effects of light scattering and light absorption to the change in spectral light intensity with distance along a sight path. On the right-hand side of Equation (7), the first term is the effect of light scattering, and the second term is the effect of light absorption (NO_2). As noted previously, since b_{scat} and b_{abs} (due to NO_2) are strong functions of wavelength and are greater at the blue end (λ = 0.4 µm), atmospheric coloration can result.

Equation (7) makes clear that NO_2 always tends to cause a decrease in light intensity since the second term in Equation (7) is always negative. However, particles may brighten or darken a plume, depending on whether the first term in Equation (7) is positive or negative. If, at a given point along the sight path, $I(\lambda)$ is greater than the clean horizon sky intensity $I_{h0}(\lambda)$, then the quantity in brackets in the first term on the right-hand side of Equation (7) will be negative, which means that the net effect of scattering will be to remove light from the line of sight. This effect would occur if a bright, white cloud or distant snowbank were observed through an aerosol that did not contain NO_2. If, however, $I(\lambda)$ is less than $I_{h0}(\lambda)$, then the quantity in brackets in Equation (7) will be positive, which means that the net effect of scattering will be to add light to the line of sight. This effect would occur if a distant, dark mountain were observed through an aerosol that did not contain NO_2; scattering would cause the mountain to appear lighter. Only light absorption can cause $I(\lambda)$ to be less than $I_{h0}(\lambda)$, and whenever $I(\lambda) < I_{h0}(\lambda)$, scattering will add light to the sight path, thereby masking the coloration caused by NO_2 light absorption.

The mathematical expressions used in this document and the plume visual impact screening model VISCREEN are simply solutions to Equation (1) for different boundary conditions and for different values of b_{scat}, b_{ext}, $\bar{p}(\theta)$ and F_s as they are affected by natural and man-made light scatterers and absorbers. The plume visibility models use similar formulations, but most account for multiple scattering effects.*

Now a plume (either ground-based or elevated) may be visible because it contrasts with a sky viewing background as shown in Figure 5(a) or it contrasts with a terrain feature as shown in Figure 5(b). The plume visual impact screening model VISCREEN evaluates both of these possible viewing backgrounds.

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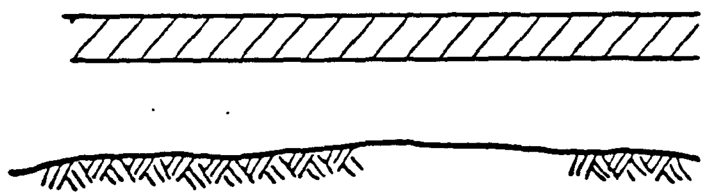
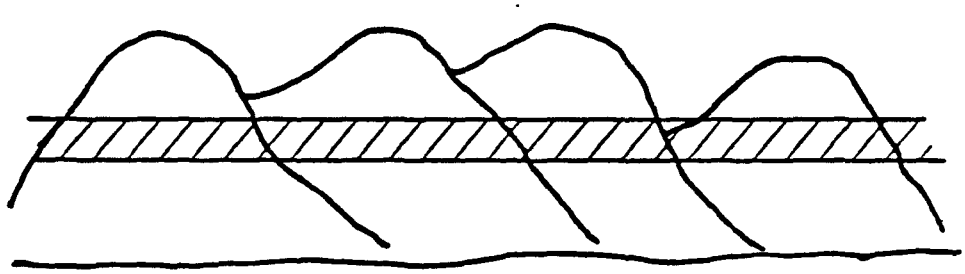
* Multiple scattering is light scattered into the line of sight after previous scattering (i.e., light reflected from terrain features and light scattered from other portions of the atmosphere).



(a) Plume Visible Against the Sky



(b) Plume Visible Against Terrain

FIGURE 5. Two viewing situations in which plumes may be visible.

Formulas for contrasts representative of both types of viewing situations can be derived by solving Equation (1) for appropriate boundary conditions.

Plume Contrast Against the Sky

Let us consider now the geometry shown in Figure 3, namely, the case of a plume embedded in an otherwise uniform background atmosphere. If we ignore the effects of multiple scattering, Equation (1) can be solved for the contrast between the plume and the horizon sky background (see Figure 5a) as observed at distance r_p from the plume as follows (Latimer and Ireson, 1980):

$$C_{plume} = \frac{I_{h-plume} - I_h}{I_h} = \left[\frac{(\bar{p}\,\bar{\omega})_{plume}}{(\bar{p}\,\bar{\omega})_{background}} - 1 \right] \left[1 - \exp(-\tau_{plume})\right] \exp(-b_{ext}\, r_p) \quad , \tag{8}$$

where

I_h = spectral radiance of horizon sky (without plume present)

$I_{h\text{-}plume}$ = spectral radiance of plume viewed in front of horizon sky

$\bar{p}$ = average phase function for the plume constituents and the background atmosphere

$\bar{\omega}$ = average albedo of plume and background, where albedo is the ratio of light scattering to total light extinction

τ_{plume} = plume optical thickness along the line of sight (increment above background)

$$= \int_{plume} b_{ext}\, dr$$

b_{ext} = background atmosphere's light extinction coefficient

r_p = distance between plume centerline and observer

Note that, depending on whether the product of the phase function and the albedo ($\bar{p\omega}$) for the plume is larger or smaller than that for the background, the plume will be brighter (C > 0) or darker (C < 0) than the background horizon sky. Also note that the contrast is dependent on the plume optical thickness (τ_{plume}); as τ_{plume} approaches zero, C_{plume} approaches zero. Plume contrast also diminishes as the plume-observer distance r_p increases.

Plume Contrast Against Terrain

To characterize the types of visibility impairment represented in Figure 5(b), we need to calculate a change in sky/terrain contrast caused by a plume:

$$\Delta C_r = C_r\Big|_{\text{with plume}} - C_r\Big|_{\text{without plume}}$$

where

$$C_r\Big|_{\text{with plume}} = \frac{I_{t\text{-plume}} - I_{h\text{-plume}}}{I_{h\text{-plume}}}$$

$$C_r\Big|_{\text{without plume}} = \frac{I_t - I_h}{I_h} .$$

C_r = the sky-terrain contrast of a terrain feature at distance r from an observer

I_t, I_h = the spectral radiances of a terrain feature and the horizon sky (unaffected by plume)

$I_{t\text{-plume}}$, $I_{h\text{-plume}}$ = the spectral radiances of plumes viewed in front of horizon sky and terrain

For simplicity we assume that the terrain that is viewed behind the plume has an intrinsic radiance, I_{obj}, which is a function of the horizon sky radiance I_h, namely, $I_{obj} = (1 + C_0)I_h$. C_0 is the intrinsic contrast. If the terrain were black, C_0 would equal -1.

Again solving Equation (1) and ignoring multiple light scattering, we can derive the following expression for the change in terrain contrast caused by the plume (Latimer and Ireson, 1980):

$$\Delta C_r = -C_0 \exp(-b_{ext} r_o) \left[1 - \left(\frac{1}{1 + C_{plume}}\right) \exp(-\tau_{plume})\right] \quad , \qquad (9)$$

where r_o = distance between the terrain object and the observer.

Equations (8) and (9) are the analytical expressions at the heart of the plume visual impact screening model VISCREEN. Careful examination of these two equations illustrates the following sensitivities:

1. Plume contrasts (against both the sky and terrain) increase with increasing plume light extinction (i.e., as concentrations of particulates and NO_2 in a plume increase).

2. Plume contrasts increase if the line of sight is oriented to intersect a larger amount of plume material (i.e., the line of sight is along the plume centerline).

3. Plume contrasts increase for sun angles and for particle size distributions that tend to maximize the difference (both positive and negative) between the phase functions for the background atmosphere and for the plume.

4. Plume contrasts increase if the plume is moved closer to the observer.

5. Plume contrasts increase with decreasing light extinction of the background atmosphere (i.e., with increasing background visual range).

6. Plume contrasts against terrain are maximum if the terrain object is relatively close to the observer and the terrain's intrinsic contrast is maximum (e.g., if it were black).

Since screening calculations are designed to be conservative estimates of worst-case conditions, situations are selected to (1) maximize the concentrations and light scattering efficiencies of optically active plume constituents, the intersection of the line of sight and the plume, the background visual range, the intrinsic contrast of terrain objects, and the difference between background and plume phase functions; and (2) minimize the distance between the observer and the plume. Once conservative estimates of worst-case conditions are specified, the plume visual impact screening model VISCREEN uses Equations (8) and (9) to calculate plume contrasts. If such contrast values are larger than screening criteria, the possibility that the plume will cause significant visual impact cannot be ruled out, and less conservative, more realistic estimates would be required.

PLUME PERCEPTIBILITY

The perceptibility of a plume depends on the plume contrast at all visible wavelengths. At a single wavelength, the contrast between the plume and its surroundings is determined by the difference in the intensity of the light reaching the observer from each. Therefore a single measure, intensity, could be used to quantify contrast if visible light were composed of a single wavelength. With a range of wavelengths, a measure of contrast must recognize both "overall" intensity, and perceived color, and so perceptibility is really a function of changes in both brightness and color. To address the added dimension of color as well as brightness, the color contrast parameter, ΔE, was chosen for use as the primary basis for determining the perceptibility of plume visual impacts in screening analyses. ΔE provides a single measure of the difference between two arbitrary colors as perceived by humans. This parameter allows us to make quantitative comparisons of the perceptibility of two plumes, even though one may be a reddish discoloration viewed against a blue sky while the other may be a white plume viewed against a dark green forest canopy.

Contrasting surfaces are detected by human vision using three types of visual information (cues). The trichromatic theory of Helson (1938) and Judd (1940) predicts colors perceived by human subjects based on the visual qualities described as brightness (intensity), lightness (saturation), and color (hue). Perceived brightness of a colored surface is dependent upon the intensity of the applied illumination. For example, the brightness of the white of a daisy is larger for a daisy in direct sunlight than for a daisy in the shade. The color or hue of a surface is dependent on the ratio of the intensity of red to green light that is reflected. The lightness of a color is the strength or density of a color and is often called the saturation. An example of this cue comes from photography: a properly or slightly underexposed color is said to be more saturated than an overexposed color which appears to be washed out by the addition of white. Color contrast is therefore made up of differences in these three visual qualities (cues).

As implied by its name, the trichromatic theory of color assumes that all shades of color are composed of three primary colors: red, green, and blue. These primary colors are not single wavelengths, but rather an envelope of wavelengths, whose peak intensities occur at frequencies we associate with each of the primary colors. The purely chromatic characteristics of a perceived color are then described by three numbers (X=red, Y=green, Z=blue) that represent the intensity of each color in the "mix". (These are computed as the integration over the visible spectrum of the product of the intensity of the illumination and the trichromatic weighting function for each primary color.)

The amounts of red, green, and blue (X,Y,Z) can be used to approximate the three cues used to quantify the contrast between colored objects. Three empirical mathematical functions of (X,Y,Z) were defined which quantitatively best capture the qualitative features of the three cues: brightness, hue, and saturation. Each of these three mathematical functions is defined relative to the one or more components of chromaticity of a reference white card under direct sunlight (X_0,Y_0,Z_0). For brightness, only a single chromatic component is needed, and since the eye is most sensitive to intensity changes in green, the function for brightness, L^*, is defined in terms of Y. Since hue depends on the red/green reflected intensity ratio, the function describing hue, a^*, is defined in terms of X and Y. The mathematical function describing the amount of saturation, b^*, is defined in terms of Y and Z (see equations in Appendix B).

For each of the three visual cues, the contrast between two surfaces is simply a difference between the values of the mathematical functions for each surface. For example, contrast due to changes in brightness is defined as the difference in the function for brightness, ΔL^*. The total color contrast, ΔE, is taken to be the sum

$$\Delta E = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\right]^{1/2}$$

This formulation is based on the following assumptions:

(1) ΔE depends only on ΔL, Δa, and Δb;

(2) Differences in contrast cues ΔL^*, Δa^*, and Δb^* are independent of one another.

Although a ΔE of 1 and a contrast of 0.02 have been traditionally assumed to be the threshold of perceptibility, a survey of the literature (see Appendix A) suggests a broad range of perceptibility thresholds. The most sensitive observers are able to detect contrasts or color changes one-half this magnitude, and the casual observer may require contrast or color changes more than two times larger than these "traditional" values. In addition, the literature suggests that perceptibility thresholds increase for very wide and for very narrow plumes, with plumes less than 0.02° being essentially imperceptible. Figure 6 summarizes the range of perceptibility thresholds supported in the literature.

The plume visual impact screening model VISCREEN is designed to ascertain whether the plume from a facility has the potential to be perceptible to untrained observers under "reasonable worst case" conditions. If either of two screening criteria is exceeded, more comprehensive (and realistic) analyses should be carried out. The first criterion is a ΔE value of 2.0; the second is a green (0.55 µm) contrast value of 0.05. In the case of sufficiently narrow or broad plumes, the higher perception thresholds (for diffuse-edged plumes) are used instead of the above criteria.

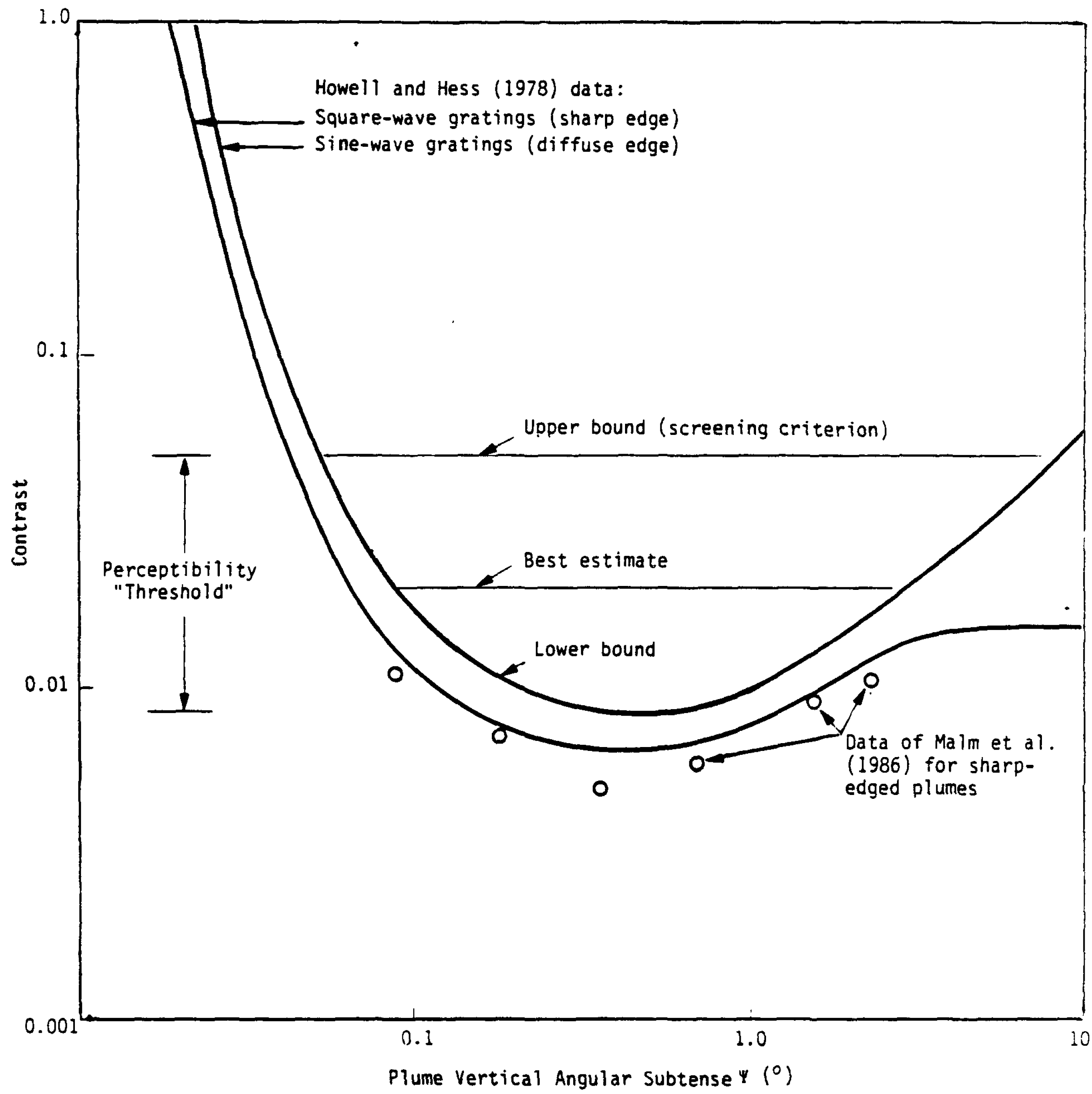


FIGURE 6. Plume perceptibility threshold as a function of plume thickness (Ψ). See definition of Ψ in the Glossary in the front of this workbook and in Figure 3.

3 LEVEL-1 SCREENING

This section describes the process of Level-1 plume visual impact screening using the screening model VISCREEN and the brief input required to initiate the screening process. Details of the plume visual impact screening model are provided in Appendix B.

ASSUMPTIONS IN LEVEL-1 SCREENING

Level-1 screening is designed to provide a conservative estimate of plume visual impacts (i.e., impacts that would be larger than those calculated with more realistic input and modeling assumptions). This conservatism is achieved by the use within the screening model VISCREEN of worst-case meteorological conditions: extremely stable (F) atmospheric conditions, coupled with a very low wind speed (1 m/s) persisting for 12 hours, with a wind that would transport the plume directly adjacent to the observer (as shown schematically in Figure 7).

PREPARING LEVEL-1 INPUT

Through the use of default parameters, the input required for Level-1 plume visual impact screening is limited to the following:

Emission rates of particulates (including soot and primary sulfate) and nitrogen oxides (including primary NO_2)

Distance between the emission source and (1) the observer, (2) the closest Class I area boundary, and (3) the most distant Class I area boundary*

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* It should be noted that although VISCREEN is designed primarily for assessing plume visual impacts in Class I areas, it can also be applied in PSD Class II areas. In such cases these distances can be specified arbitrarily.

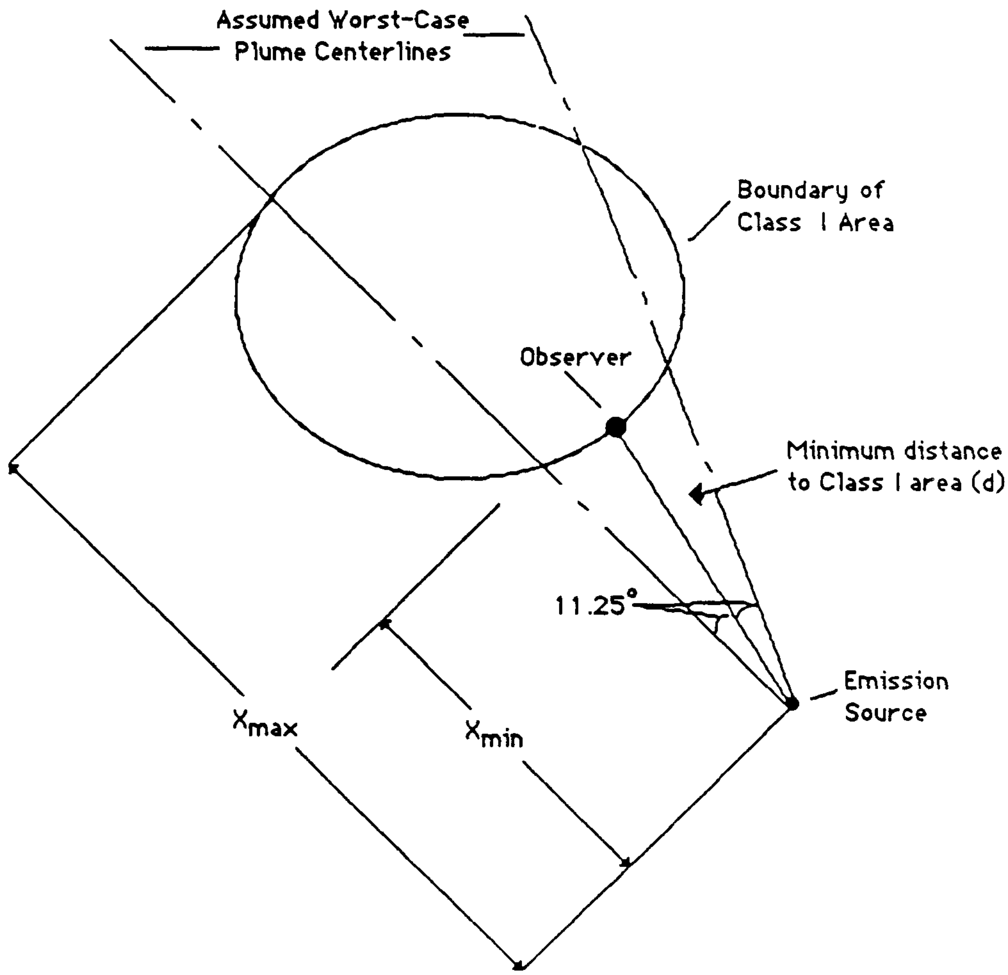

FIGURE 7. Determining distances for Level-1 screening.

Background visual range appropriate for the region in which the Class I area is located.

Before using VISCREEN, the analyst should summarize the emission rates for

Primary particulate matter
Nitrogen oxides (NO_x)
Primary nitrogen dioxide (NO_2)
Soot (elemental carbon)
Primary sulfate ($SO_4^=$)

SO_2 emissions are not required as input to VISCREEN. Moreover, the issue of secondary sulfate formation ($SO_4^=$) is not treated in VISCREEN because of the limited range of applicability of a steady state Gaussian dispersion model and because of the uncertainty of estimating the conversion of SO_2 to SO_4 in a coherent plume. More sophisticated plume visibility models treat both secondary sulfate and nitrate.

These emissions can be provided in any units convenient to the analyst since VISCREEN will prompt the analyst for his/her choice of units of mass (e.g., grams, kilograms, metric tonnes, pounds, or tons) and time (e.g., seconds, minutes, hours, days, or year). Thus, emissions can be specified in g/s or ton/yr or whatever combination is desired.

Emission rates should be the maximum short-term rates expected during the course of a year. The values used for plume visual impact screening generally would be the maximum emission rates for which the air quality permit is being applied and would correspond to those used for short-term (i.e., 1-, 3-, and 24-hour average) air quality impact analyses.

For almost every emission source, the emission rates of the last three species (primary NO_2, soot, and sulfate) can be assumed to be zero. However, if NO_2 is directly emitted from the emission source (e.g., from a chemical process such as a nitric acid plant) as opposed to being formed in the atmosphere from NO_x emissions, this primary NO_2 can be considered. Even if primary NO_2 emissions are set to zero, VISCREEN assumes that 10 percent of NO_x emissions is initially converted to NO_2 either within the stack of the source or within the first kilometer of plume transport (Latimer et al., 1978). If soot is known to be emitted (e.g., if diesel vehicles are a component of the emissions source), its emission rate should be provided separately from that of other particulates. Finally, some sources (such as oil-fired power plants or smelters) may have a significant component of primary sulfate in a size range that has maximum light scattering efficiency. If so, primary sulfate ($SO_4^=$) emissions should be specified and input separately from either particulate or soot. In summary, for most sources the analyst need only input the total particulates and NO_x emission rates (the first two categories of emissions required by VISCREEN); only the small fraction of emission sources producing nonzero primary NO_2, soot, and sulfate requires input of these emissions to VISCREEN.

Using a topographic map of appropriate scale, the analyst should identify the portion of the Class I area that is closest to the emission source and measure (or compute) the distance between the emission source and this closest boundary. This distance is the distance between the emission source and the observer that should be input to VISCREEN (d in Figure 7). Then the analyst should draw plume centerlines offset by half a 22.5° sector width (i.e., 11.25°) on either side of this hypothetical, worst-case observer location as shown in Figure 7. The analyst should determine the downwind distance (along these assumed plume centerlines) to the closest (x_{min}) and most distant (x_{max}) Class I area boundaries (even if these two distances are on opposite sides of the observer). If either x_{min} is greater than d, set x_{min} equal to d for the sake of conservatism. There may be certain shapes of Class I areas where the plume centerlines drawn on opposite sides of the observer cross boundaries more than once. In such cases the smallest x_{min} and the largest x_{max} should be used to be conservative (see Figure 8).

The last input needed to perform a Level-1 screening analysis is the background visual range of the region in which the Class I area is located. Figure 9 provides default background visual range values for the contiguous United States. In cases where there is more applicable onsite data, source owners should consult with the Federal Land Manager for the Class I area in question concerning appropriate regional background visual range values for input to VISCREEN or other plume visibility models.

With emissions, distances, and visual range as the only inputs required for Level-1 screening, the analyst can exercise the screening model VISCREEN.

EXERCISING THE SCREENING MODEL VISCREEN

The plume visual impact screening model VISCREEN is designed for use on an IBM-compatible personal computer with minimal memory requirements. VISCREEN is written in FORTRAN 77. VISCREEN can be run simply by inserting the VISCREEN program diskette in the A drive and typing A:VISCREEN. The model first requests the names of two disk files (that it will create) to which results will be written. These include a summary file, which will contain a formatted, tabular presentation of results, and a results file, which includes arrays of results that can be read into spreadsheet programs for further analyses, plotting, et cetera.

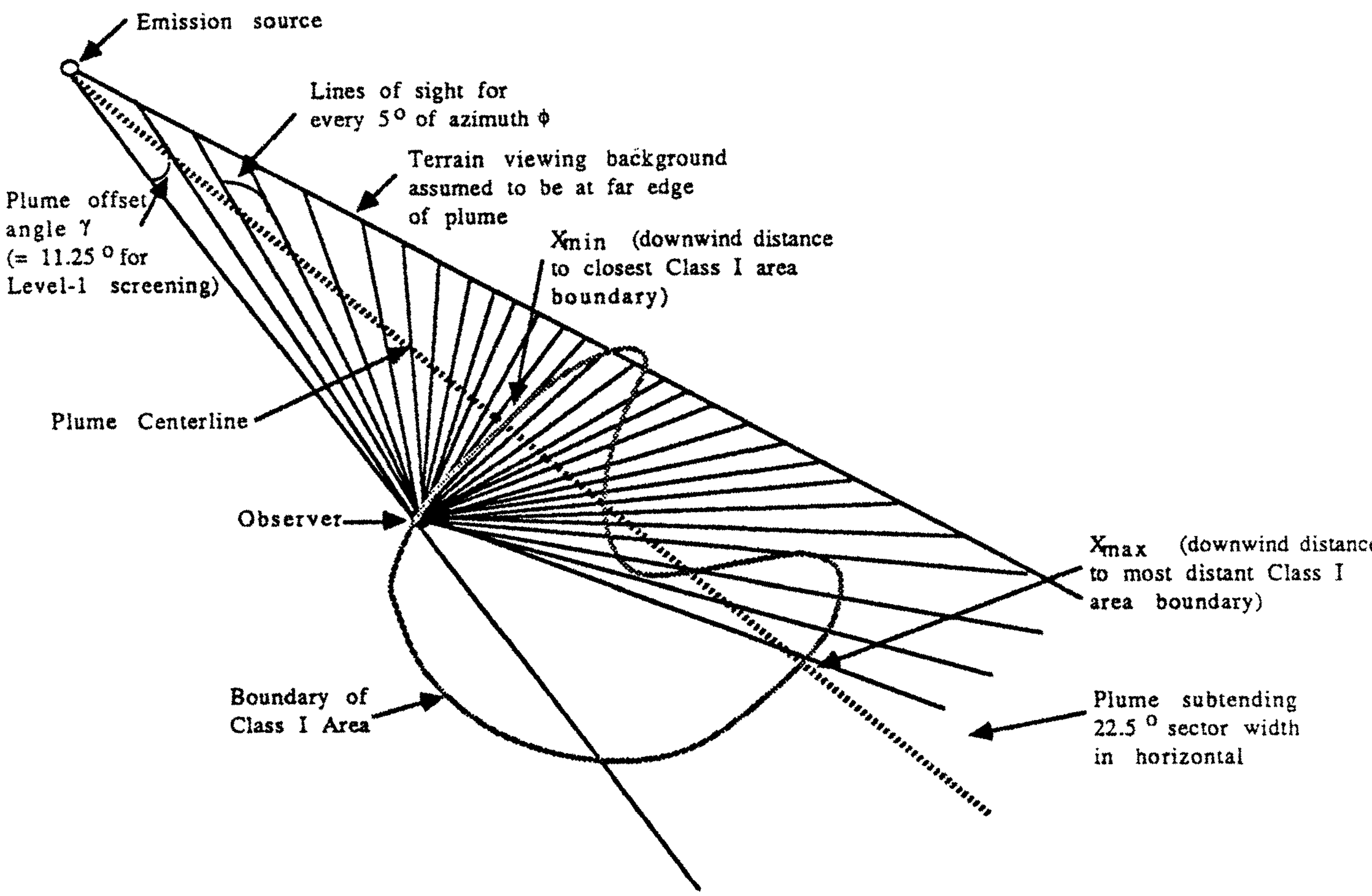

FIGURE 8. Geometry of plume and observer lines of sight used for plume visual impact screening.

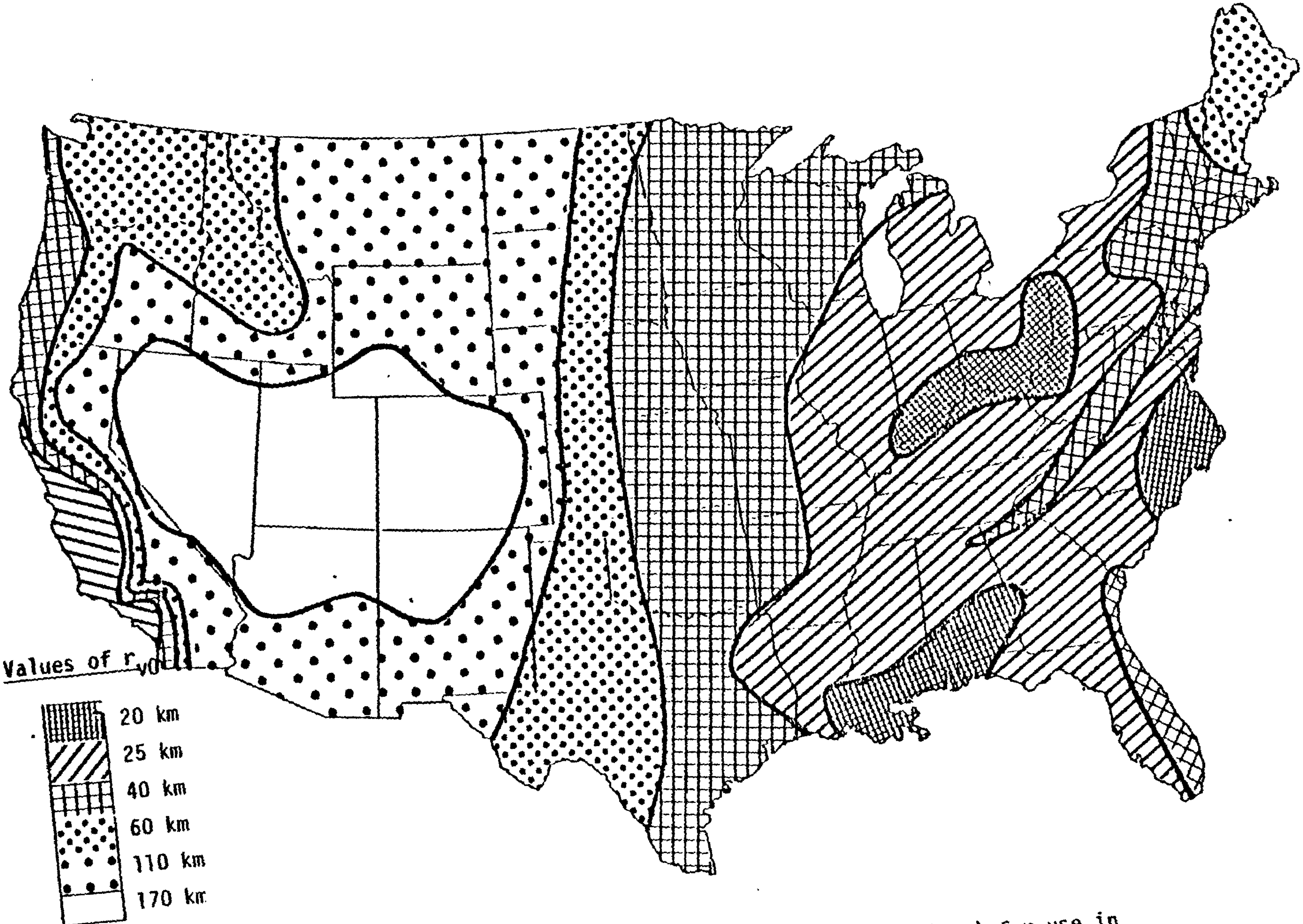

FIGURE 9. Regional background visual range values (r_{v0}) for use in level-1 visibility screening analysis procedure.

The model will request the inputs previously discussed (emissions, distances between emissions source, observer, and Class I area, and the background visual range). It will also ask whether you want default input parameters. For Level-1 plume visual impact screening, the analyst should use the default input offerred in VISCREEN. Once the analyst has provided the requested input and confirmed this selection of input, VISCREEN will begin its calculations. (Execution may take several minutes if VISCREEN is run without a math coprocessor.)

After program execution, VISCREEN will display a summary of the Level-1 screening calculations similar to that shown in Figure 10. All four tests are based on the screening criteria [$\Delta E = 2$, $Cp(\lambda = 0.55\ \mu m) = -0.05$] and the perception threshold curve for diffuse-edged plumes shown in Figure 6. VISCREEN will identify whether the given plume passes or exceeds four tests. The first two tests refer to visual impacts caused by plume parcels located inside the boundaries of the given Class I area. The last two tests are for plume parcels located outside the boundaries of the Class I area.

The first two tests are used to determine visual impacts when so-called integral vistas are not protected (or are not of concern in the given analysis). An integral vista is a view from a location inside a Class I area of landscape features located outside the boundaries of the Class I area. The Federal Land Manager for a given Class I area should be contacted to determine whether analyses for integral vistas are required. If not, the VISCREEN analysis results for plume parcels located outside the Class I area could be ignored (the last two tests), and results for parcels within the Class I area (first two tests) would be used for screening. If integral vistas are protected as well as the within-area views, VISCREEN results for parcels located inside and outside the Class I area should be used to determine whether the emission source passes the given level of screening (i.e., all four tests should be used). For views both inside and outside the Class I area, calculations are performed for two assumed plume-viewing backgrounds: the horizon sky and a dark terrain object. VISCREEN assumes that the terrain object is black and located adjacent to the plume on the side of the centerline opposite the observer. In the example shown in Figure 10, the plume from the power plant fails all four screening tests.

After the display of the screening test summary, VISCREEN will ask the analyst whether the calculated results for lines of sight (plume parcels) with maximum predicted visual impact should be displayed. If selected, VISCREEN displays a summary similar to that shown in Figure 11. This summary shows calculated plume perceptibility (color difference) ΔE parameters for four lines of sight corresponding to plume parcels located inside/outside of the Class I area and in front of sky/terrain viewing

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OVERALL RESULTS OF PLUME VISIBILITY SCREENING

SOURCE:  Public Electric Coal #3
CLASS I AREA:  Longview NP

 INSIDE  class I area --
Plume delta E EXCEEDS screening criterion for SKY background
Plume delta E DOES NOT EXCEED screening criterion for TERRAIN background
Plume contrast DOES NOT EXCEED screening criterion for SKY background
Plume contrast DOES NOT EXCEED screening criterion for TERRAIN background

 OUTSIDE class I area --
Plume delta E EXCEEDS screening criterion for SKY background
Plume delta E EXCEEDS screening criterion for TERRAIN background
Plume contrast EXCEEDS screening criterion for SKY background
Plume contrast DOES NOT EXCEED screening criterion for TERRAIN background


 SCREENING CRITERIA:        DELTA E =  2.0
                     GREEN CONTRAST =  .050
```

FIGURE 10. Sample VISCREEN screening summary.

VIEW	ANGLES (DEGREES)			DIST (KM)		PLUME PERCEPTIBILITY	DELTA E(L*A*B*)
no	phi	alpha	psi	x	rp	forward	backward
Line of sight with maximum perceptibility for plume viewed against a SKY background INSIDE class I area.							
33	84.4	84.4	1.39	80.0	15.7	4.7 *	2.4 *
Line of sight with maximum perceptibility for plume viewed against a TERRAIN background INSIDE class I area.							
33	84.4	84.4	1.39	80.0	15.7	1.5	.6
Line of sight with maximum perceptibility for plume viewed against a SKY background OUTSIDE class I area.							
7	35.0	133.8	.96	63.5	21.6	5.7 *	2.7 *
Line of sight with maximum perceptibility for plume viewed against a TERRAIN background OUTSIDE class I area.							
1	5.0	163.8	.29	24.9	55.8	3.4 *	1.2

* Exceeds screening criteria

FIGURE 11. Sample VISCREEN summary for lines of sight with maximum plume perceptibility.

backgrounds. These four lines of sight were selected by VISCREEN (from as many as 37 lines of sight for which plume contrast calculations were made) as the plume parcels with maximum predicted visual impact (i.e., the largest ratio of the calculated plume ΔE parameter or contrast to the screening criterion).* The lines of sight (LOS's) are described by a view number. The plume is viewed in 5° increments of azimuth (see Figure 8) starting from the emission source. Thus, view No. 1 would be the plume parcel 5° to the right (or left) of the emission source. The last three views or lines of sight are for plume parcels 1 kilometer downwind from the source and at the nearest and most distant Class I area boundaries. These are included to describe the plume appearance for LOS's nearly across the source, and at the points of plume entry and exit from the Class I area. In addition to view number, the lines of sight are described by three angles (see Figure 12):

ϕ (phi), which is the azimuthal angle (in degrees) between the line connecting the source and observer and the line of sight;

α (alpha), the angle (in degrees) between the line of sight and the plume centerline; and

ψ (psi), the vertical angle (in degrees) subtended by the plume (see Figure 3).

In addition, two distances relevant to the given plume parcel are provided that are critical to the identification of perceptibility. The plume parcel's downwind distance (x) and the distance between the observer and the plume (r_p) are provided (in kilometers). A third distance is that from the observer to terrain background (r_o).

Results are provided for two assumed worst-case sun angles. The "forward scatter" case refers to a situation in which the sun is in front of the observer such that the scattering angle (θ) is 10°. Such a sun angle will tend to maximize the light scattered by plume particulates and maximize the brightness of the plume. (In reality, such a sun angle may or may not occur during worst-case conditions for the given line of sight). The "backward scatter" case refers to a situation in which the sun is behind the observer such that the scattering angle is 140°. A plume is likely to appear the darkest with such a sun angle. Asterisks denote values that exceed the screening criteria.

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* The largest ratio, rather than the largest ΔE and contrast values, is used because a broad or narrow plume may have large ΔE or contrast and yet be imperceptible (see Figure 6).

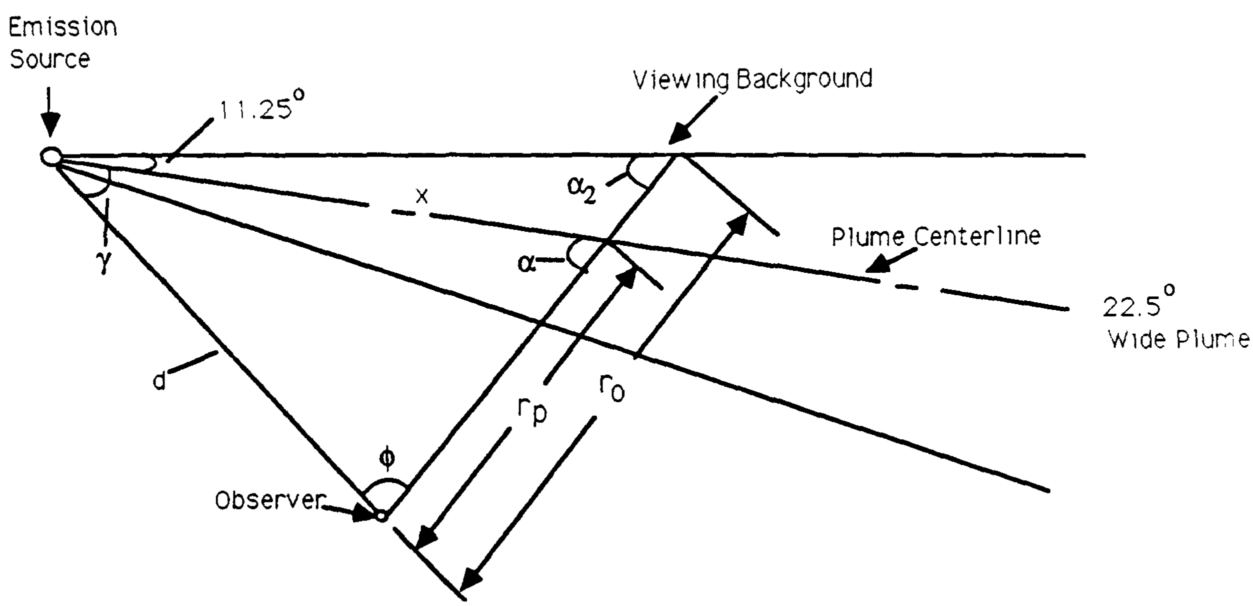

FIGURE 12. Distances and angles that specify a given line of sight.

After displaying the summary of lines of sight with maximum calculated plume visual impact, VISCREEN asks whether ΔE's for lines of sight are to be displayed. If this option is selected, VISCREEN will show all the lines of sight analyzed in the screening procedure. These results are displayed in order of view number, first for the sky background cases and second for the terrain background cases. Several screens of output are necessary to show all the lines of sight (as many as eight screens, four for each of the two viewing backgrounds). Figure 13 is a sample of such output.

After viewing the ΔE summaries and output, the analyst is given the option of viewing plume contrast values at 0.55 μm. Plume contrasts at three wavelengths of light are calculated by VISCREEN, and are written to the results file. These may be useful in characterizing the relative brightness and color of the plume compared to its viewing background. A summary of lines of sight with maximum negative or positive green contrast is provided (see example in Figure 14). Since maximum plume perceptibility may occur for lines of sight different from those of maximum plume contrast, the lines of sight summarized here may be different from those in the ΔE summary. As for the ΔE summary, asterisks denote contrasts whose absolute values exceed the screening criterion. In a fashion similar to that for the ΔE summary, VISCREEN gives the analyst the option of viewing the green plume contrast values for all lines of sight (Figure 15). In some cases, because VISCREEN calculates results for lines of sight every 5 degrees, one or several of the lines of sight may be physically unrealistic. The analyst should review each line of sight, paying particular attention to those for which screening criteria are exceeded, to verify that screening decisions are not based on unrealistic geometries. For example, in Figure 13, view number 2 corresponds to a 10° line of sight (ϕ). If the view is toward the north then this worst-case impact should be eliminated because it is associated with an unrealistic geometry. The 10 degree forward scatter scenarios are only possible for views to the east (mornings), south (high latitudes and winter periods), and west (evenings). Screening decisions should be based on the worst case impacts associated with realistic geometries.

After these VISCREEN outputs are displayed, the analyst is asked whether additional calculations are to be made with changed emissions, distances, and so on. Unless the analyst is interested in evaluating the effect of alternative emissions or siting distances, additional VISCREEN analyses will not be needed for Level-1 screening.

The summary and results files, with filenames as entered by the user when VISCREEN was invoked, are written to the disk as the program executes. If multiple runs of VISCREEN are carried out (e.g., with changed emissions), results for these runs are appended to the end of the files. The summary

PLUME DELTA E AGAINST A SKY BACKGROUND

VIEW	ANGLES (DEGREES)			DIST (KM)		PLUME PERCEPTIBILITY	DELTA E(L*A*B*)
no	phi	alpha	psi	x	rp	forward	backward
1	5.0	163.8	.29	24.9	55.8	2.3 *	1.4
2	10.0	158.8	.42	38.3	43.1	3.7 *	1.6
3	15.0	153.8	.55	46.8	35.3	4.8 *	2.0
4	20.0	148.8	.66	52.7	30.1	5.3 *	2.3 *
5	25.0	143.8	.77	57.2	26.4	5.5 *	2.5 *
6	30.0	138.8	.87	60.7	23.7	5.7 *	2.6 *
7	35.0	133.8	.96	63.5	21.6	5.7 *	2.7 *
8	40.0	128.8	1.04	65.9	20.0	5.6 *	2.7 *
9	45.0	123.8	1.12	68.0	18.8	5.5 *	2.7 *
10	50.0	118.8	1.19	69.9	17.8	5.4 *	2.7 *
11	55.0	113.8	1.25	71.6	17.1	5.3 *	2.6 *
12	60.0	108.8	1.30	73.2	16.5	5.2 *	2.6 *
13	65.0	103.8	1.34	74.6	16.1	5.1 *	2.5 *
14	70.0	98.8	1.37	76.1	15.8	5.0 *	2.5 *
15	75.0	93.8	1.38	77.4	15.6	4.9 *	2.5 *
16	80.0	88.8	1.39	78.8	15.6	4.8 *	2.4 *
17	85.0	83.8	1.39	80.2	15.7	4.7 *	2.4 *
18	90.0	78.8	1.37	81.6	15.9	4.6 *	2.3 *

Please press [ENTER] for more, Q to quit

FIGURE 13. Sample VISCREEN ΔE output.

-GREEN PLUME CONTRAST-

VIEW no	ANGLES phi	alpha	DISTANCES (KM) x	rp	ro	forward contrast	backward contrast	screening criterion
Line of sight with maximum contrast for plume viewed against a SKY background INSIDE class I area.								
33	84.4	84.4	80.0	15.7	32.0	-.004	-.033	.05
Line of sight with maximum contrast for plume viewed against a TERRAIN background INSIDE class I area.								
33	84.4	84.4	80.0	15.7	32.0	.020	.011	.05
Line of sight with maximum contrast for plume viewed against a SKY background OUTSIDE class I area.								
2	10.0	158.8	38.3	43.1	57.0	-.008	-.064 *	.05
Line of sight with maximum contrast for plume viewed against a TERRAIN background OUTSIDE class I area.								
2	10.0	158.8	38.3	43.1	57.0	.044	.038	.05

* Absolute value exceeds screening criteria

FIGURE 14. Sample VISCREEN summary for lines of sight with maximum plume contrast.

PLUME CONTRAST AGAINST A SKY BACKGROUND

VIEW no	ANGLES phi	alpha	DISTANCES (KM) x	rp	ro	-GREEN PLUME CONTRAST- forward contrast	backward contrast	screening criterion
19	95.0	73.8	83.0	16.3	34.5	-.004	-.032	.05
20	100.0	68.8	84.5	16.7	36.3	-.004	-.032	.05
21	105.0	63.8	86.2	17.4	38.6	-.004	-.032	.05
22	110.0	58.8	87.9	18.3	41.5	-.004	-.031	.05
23	115.0	53.8	89.9	19.4	45.3	-.004	-.031	.05
24	120.0	48.8	92.1	20.8	50.3	-.004	-.031	.05
25	125.0	43.8	94.8	22.6	57.0	-.004	-.030	.05
26	130.0	38.8	97.9	24.9	66.3	-.003	-.029	.05
27	135.0	33.8	101.8	28.1	80.0	-.003	-.028	.05
28	140.0	28.8	106.9	32.4	101.8	-.003	-.026	.05
29	145.0	23.8	113.9	38.8	141.4	-.003	-.023	.05
30	150.0	18.8	124.4	48.6	234.5	-.002	-.018	.05
31	155.0	13.8	142.2	65.7	701.9	-.001	-.011	.05
32	.1	168.6	1.0	79.0	79.5	.051	-.037	.11
33	84.4	84.4	80.0	15.7	32.0	-.004	-.033	.05
34	148.2	20.6	120.0	44.4	156.9	-.002	-.020	.05

When you're ready, please press [ENTER] for
more lines of sight (Q to quit)

FIGURE 15. Sample VISCREEN summary for all lines of sight.

file is designed for inclusion in a report (e.g., a PSD permit application) describing the results of the analysis. It contains all information needed for a reviewing agency to duplicate the VISCREEN results, including emissions, particle characteristics, meteorology, and geometry. Obviously, reports prepared by the users of VISCREEN should include the rationale for selecting these inputs, especially if non-default values are chosen. The summary report automatically identifies Level-1 analyses by their use of default values. Figure 16 shows an example of a Level-1 summary report.

The results file is not designed for inclusion in reports, but rather to facilitate the user's preparation of additional graphics displays. Such displays can be created by commercially available "spreadsheet" programs and graphics packages, or by user-developed programs. For example, this file can be used to plot plume ΔE as a function of viewing azimuth. As described more fully in Appendix B, the results file includes all user inputs, as well as VISCREEN-calculated values for plume-observer geometry variables (e.g., downwind distance and plume thickness) and all optical parameters for each line of sight. Optical parameters include contrast values at three wavelengths (red, green, and blue), ΔE, and the applicable screening criterion for each combination of line-of-sight, scattering angle, and viewing background. The file is formatted with spaces separating variables, allowing it to be read into commercially available "spreadsheet" programs. It also includes an entry showing the number of lines-of-sight for which results are presented.* This entry can be read as an index limit by programs written in FORTRAN or other languages.

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* This is necessary for scenarios in which the user specifies a relatively large observer-source-terrain angle, causing VISCREEN to calculate results for fewer than the normal 34 lines-of-sight.

Visual Effects Screening Analysis for
Source: Public Electric Coal #3
Class I Area: Longview NP

*** Level-1 Screening ***

Input Emissions for

Particulates	10.00	G	/S
NOx (as NO2)	120.00	G	/S
Primary NO2	.00	G	/S
Soot	.00	G	/S
Primary SO4	.00	G	/S

**** Default Particle Characteristics Assumed ***

Transport Scenario Specifications:

Background Ozone:	.04 ppm
Background Visual Range:	110.00 km
Source-Observer Distance:	80.00 km
Min. Source-Class I Distance:	80.00 km
Max. Source-Class I Distance:	120.00 km
Plume-Source-Observer Angle:	11.25 degrees
Stability: 6	
Wind Speed: 1.00 m/s	

R E S U L T S

Asterisks (*) indicate plume impacts that exceed screening criteria

Maximum Visual Impacts INSIDE Class I Area
Screening Criteria ARE Exceeded

					Delta E		Contrast	
Backgrnd	Theta	Azi	Distance	Alpha	Crit	Plume	Crit	Plume
SKY	10.	84.	80.0	84.	2.00	4.743*	.05	-.004
SKY	140.	84.	80.0	84.	2.00	2.369*	.05	-.033
TERRAIN	10.	84.	80.0	84.	2.00	1.495	.05	.020
TERRAIN	140.	84.	80.0	84.	2.00	.593	.05	.011

Maximum Visual Impacts OUTSIDE Class I Area
Screening Criteria ARE Exceeded

					Delta E		Contrast	
Backgrnd	Theta	Azi	Distance	Alpha	Crit	Plume	Crit	Plume
SKY	10.	35.	63.5	134.	2.00	5.657*	.05	-.006
SKY	140.	35.	63.5	134.	2.00	2.662*	.05	-.048
TERRAIN	10.	5.	24.9	164.	2.00	3.406*	.05	.043
TERRAIN	140.	5.	24.9	164.	2.00	1.197	.05	.040

FIGURE 16. Sample Level-1 summary report.

4 LEVEL-2 SCREENING

As shown in Figure 1, Level-2 plume visual impact screening is done if the Level-1 results exceed the screening criteria. The objective of Level-2 screening is identical to that of Level-1--the estimation of worst-day plume visual impacts--but in Level-2 screening more realistic (less conservative) input, representative of the given source and the Class I area, is provided. This situation-specific input may include particle size distributions for plume and background that are different from those used in the default Level-1 analysis. Median background visual range based on on-site measurements rather than the map shown in Figure 9 might be used. However, the most important potential difference in input between Level-1 and Level-2 analysis centers on meteorology and plume transport and dispersion patterns. While the Level-1 analysis assumes F stability, a 1 m/s wind speed, and a wind direction that would carry plume material very close to the observer, in the Level-2 analysis, meteorological data and the topography representative of the source area and the Class I area may suggest that worst-case plume dispersion conditions are different.

SELECTING PARTICLE SIZE DISTRIBUTIONS

If the Level-1 default parameters are selected, VISCREEN assigns best estimates of particle size and density for the emitted and background atmosphere particulate (see Table 2). However, some situations may not be adequately characterized by the default particle size and density parameters. In such cases, Level-2 screening should be carried out with different parameters.

For example, the Level-1 screening default for background fine particles assumes a mass median diameter of 0.3 μm; however, in certain humid areas, the background fine particulate mode may be larger (0.5 μm), and in certain dry desert areas, such as the southwestern United States, the fine mode may be smaller (0.2 μm). If the analyst has measurements of background particle size distributions and densities that are different from default parameters, these site-specific values should be used and documented.

TABLE 2. Default particle size and density specifications. (Source: Seigneur et al., 1983)

Particle Type	Mass Median Diameter (μm)	Density (g/cm^3)
Background fine	0.3	1.5
Background coarse	6	2.5
Plume particulate	2	2.5
Plume soot	0.1	2
Plume primary sulfate	0.5	1.5

Also, if information regarding the size distribution of emitted particulate is available, this data should be used to specify emitted particulate sizes and densities. In many cases, particulate emission rate estimates for a source will be calculated from emission factors that do not specifically identify the expected size distribution. In such cases the default primary particle size distribution should be used. If more detailed information on actual size distributions is available, appropriate non-default values should be used in Level-2 analyses. In general, larger particles (greater than 10 μm in diameter) have relatively small effects. Thus, if both PM-10 and TSP emission rates are available, it will usually be appropriate to use the PM-10 rate for primary particle emissions. However, if the TSP emission rate is substantially higher than that for PM-10, the large particle effects may be appreciable. In this case the TSP rate should be used, along with appropriate size distribution parameters.

Another alternative exists if there are two distinct processes contributing to primary particle emissions (e.g., fuel combustion emissions from a boiler and fugitive dust from materials handling), and if there are no primary sulfate emissions from the source. In such cases the primary sulfate emission input can be used for one of the processes, with appropriate modification to particle density and size distribution inputs. If this approach is used, the data and rationale for each input to the Level-2 analysis should be thoroughly documented by the analyst, and reviewed with the permitting agency and Federal Land Manager.

DETERMINING WORST-CASE PLUME DISPERSION CONDITIONS

Probably the most important input specification for Level-2 screening analysis is for meteorological conditions: the worst-case wind direction and speed and atmospheric stability. Therefore, the joint frequency distribution of these parameters as measured at or near the location of the emission source or the Class I area is important input for Level-2 plume visual impact screening.

It is essential to consider the persistence as well as the frequency of occurrence of these conditions. For example, plume discoloration will generally be most intense during light-wind, stable conditions. However, the transport time to a Class I area increases as the wind speed decreases. As the transport time approaches 24 hours, it is increasingly probable that the plume will be broken up by convective mixing and by changes in wind direction and speed; thus it will not be visible as a plume or a discolored layer.

Ideally, one would prefer to have a meteorological data base with detailed spatial and temporal coverage. However, this is rarely possible because of cost considerations. Several alternative approaches can be used to fill in missing data, but they all involve making assumptions. For example, if a complete meteorological data base is available only at the site of the proposed emissions source, one might assume that conditions at the site are representative of conditions at other locations in the region. However, in regions of complex terrain, this assumption may not be appropriate. Often, data collected at ground level are assumed to represent conditions at the effective stack height, which is a poor assumption when the plume is several hundred meters above ground or the site is located in complex terrain.

Any assessment of plume visual impacts is limited by the availability, representativeness, and quality of meteorological data. The Level-1 screening analysis discussed in the previous section does not require the user to input any meteorological data; rather, conservative assumptions are made regarding worst-case stability, wind speed, and wind direction. The Level-2 screening analysis assumes that the analyst has at least one year of meteorological data from the site of the proposed emissions source, a nearby site within the region, or the Class I area(s) potentially affected by emissions. For a detailed discussion of the meteorological data input requirements, refer to the EPA Guidelines on Air Quality Models (Revised) (1986) and Supplement A (1987) [EPA 450/2-78-027R].

The meteorological data base discussed previously should be used to prepare tables of joint frequency of occurrence of wind speed, wind direction, and stability class similar to those shown in Figure 17. These tables should be stratified by time of day. If meteorological data are available at hourly intervals, it is suggested that these tables be stratified as follows: 0001-0600, 0601-1200, 1201-1800, and 1801-2400. If data are available twice daily, morning and afternoon data should be tabulated separately. With this stratification, diurnal variation in winds and stability is more easily discernible. If meteorological data are not available, the assumptions regarding meteorology used in the Level-1 analysis are used to assess impact.

On the basis of maps showing the source, observer location, and topography, the analyst should select the wind direction sector that would transport emissions closest to a given class I area observer point so that the frequency of occurrence of impact can be assessed as discussed below. For example, in the schematic diagram shown in Figure 18, west winds would transport emissions closest to observer A, whereas either west-southwest or west winds would transport emissions closest to observer B. Observer C would be affected by emissions transported by west-northwest and northwest winds, but primarily by west-northwest winds.

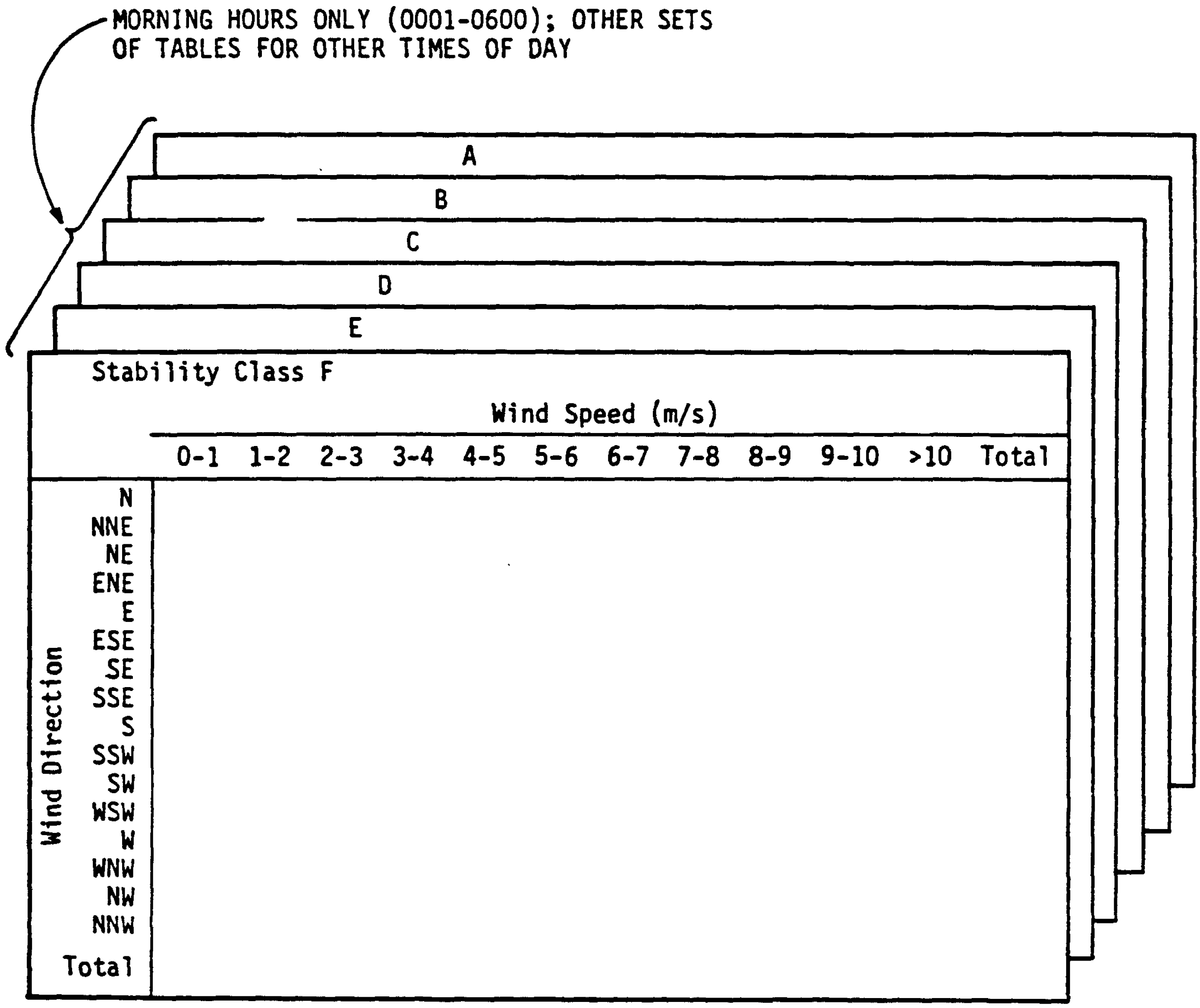

FIGURE 17. Joint frequency distribution tables required to estimate worst-case meteorological conditions for plume visual impact.

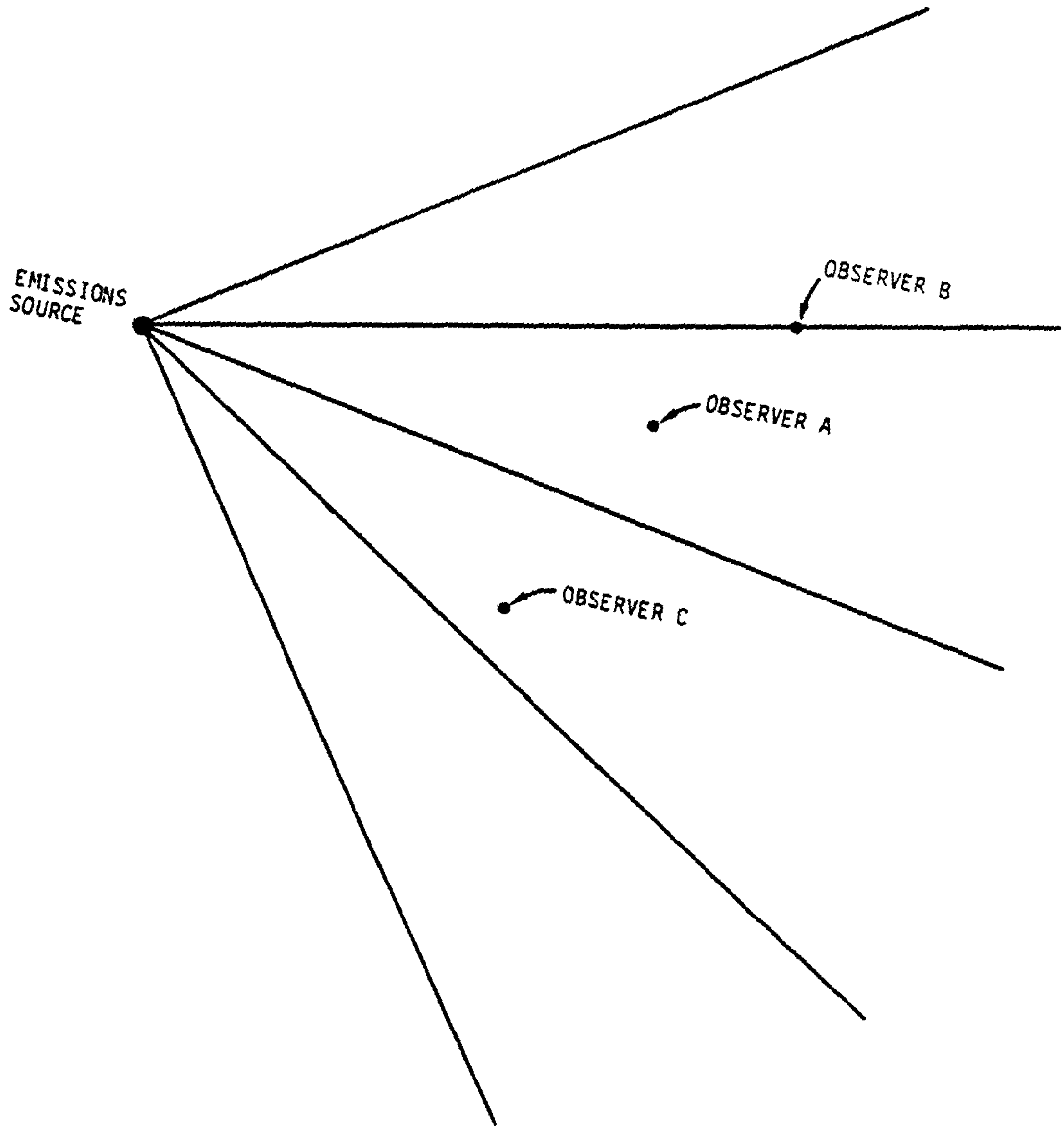

FIGURE 18. Schematic diagram showing emissions source, observer locations, and wind direction sectors.

For situations influenced by complex terrain, determination of this worst-case wind direction and its frequency of occurrence is much more difficult. The analyst should use professional judgment in this determination. In such situations, determination of the worst-case wind direction and its frequency of occurrence should be made on the basis of the following factors:

Location(s) for which meteorological data were collected relative to terrain features, emissions source, and potentially affected class I areas.

Likely plume trajectories for each wind direction (and possibly wind speed and stability) based on either data or professional judgment. For example, potential channeling, convergence, and divergence of flows should be assessed (see Figure 19).

The next step is to construct a table (see the example in Table 3) that shows worst-case dispersion conditions ranked in order of decreasing severity and the frequency of occurrence of these conditions associated with the wind direction that could transport emissions toward the class I area. Dispersion conditions are ranked by evaluating the product $\sigma_y \sigma_z u$, where σ_y and σ_z are the Pasquill-Gifford horizontal and vertical diffusion coefficients for the given stability class and downwind distance x along the stable plume trajectory identified earlier, and u is the maximum wind speed for the given wind speed category in the joint frequency table. Equations that approximately fit the Pasquill-Gifford curves are presented in Appendix E. The method presented in Appendix E should be used to calculate σ_y and σ_z. The analysis should be conducted for the following meteorological conditions:

Pasquill-Gifford Stability Class	Wind Speed (m/s)
F	1,2,3
E	1,2,3,4,5
D	1,2,3,4,5,6,7,8

The dispersion conditions are then ranked in ascending order of the value $\sigma_y \sigma_z u$. This is illustrated in Table 3. The downwind distance in this hypothetical case is assumed to be 100 km. Note that F,1 (stability class F associated with wind speed class 0-1 m/s) is the worst dispersion condition, since it has the smallest value of $\sigma_y \sigma_z u$ (1.89×10^5 m^3/s). The second worst diffusion condition in this example is F,2, followed by F,3, E,1, and so on.

The next column in Table 3 shows the transport time along the minimum trajectory distance from the emissions source to the Class I area, based on the midpoint value of wind speed for

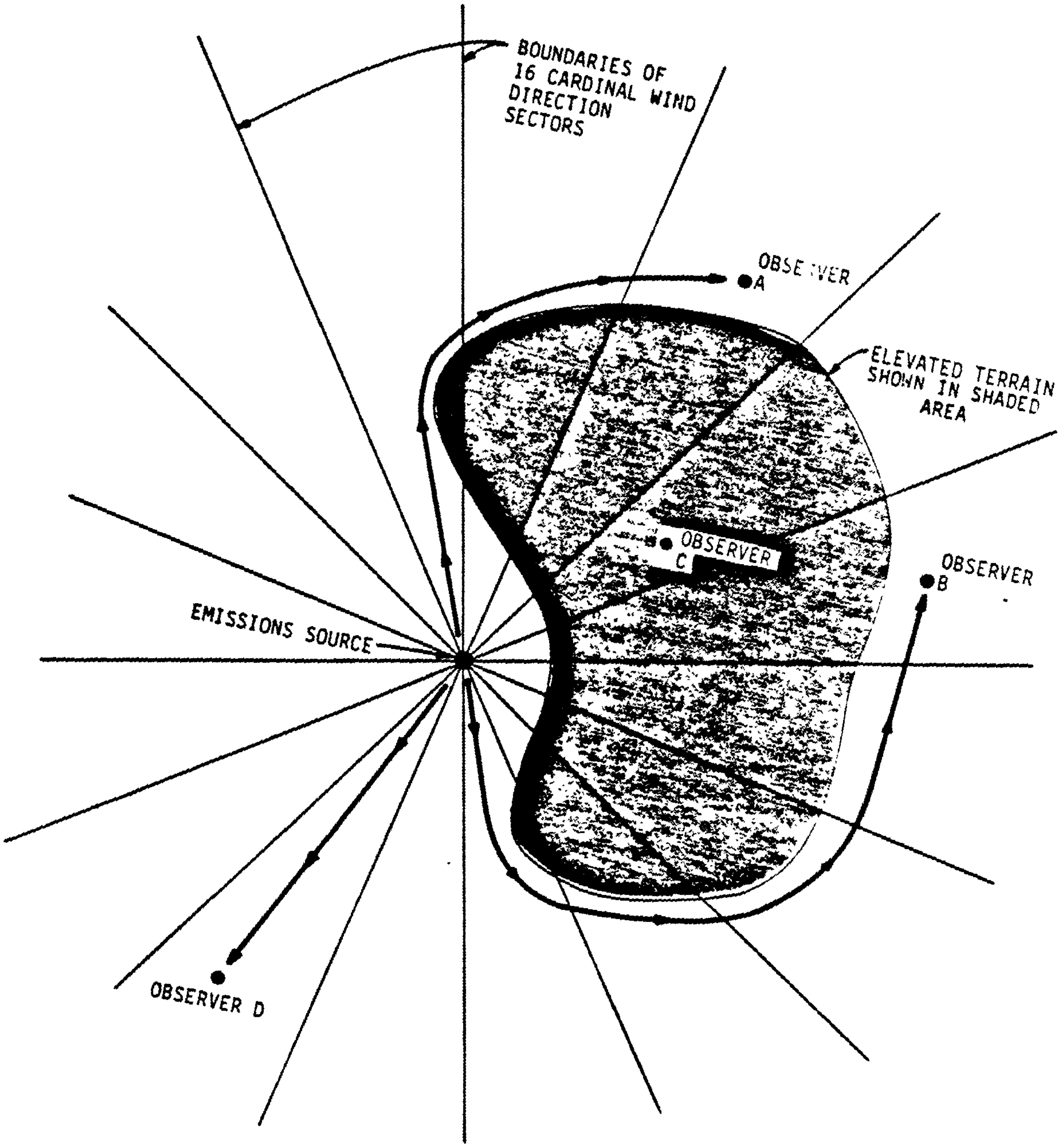

FIGURE 19. Example of map showing emissions source, elevated areas, and stable plume trajectories.

TABLE 3. Example table showing worst-case meteorological conditions for plume visual impact calculations

Dispersion Condition (stability, wind speed)	$\sigma_y \sigma_z u$ (m^3/s)	Transport Time (hours)	Frequency (f) and Cumulative Frequency (cf) of Occurrence† of Given Dispersion Condition Associated with Worst-Case Wind Direction‡ for Given Time of Day (percent) 0-6 f	0-6 cf	6-12 f	6-12 cf	12-18 f	12-18 cf	18-24 f	18-24 cf
F,1	1.89×10^5	56★	0.2	0.0	0.1	0.0	0.0	0.0	0.2	0.0
F,2	3.78×10^5	19★	0.2	0.0	0.1	0.0	0.0	0.0	0.2	0.0
F,3	5.66×10^5	11	0.2	0.2	0.2	0.2	0.0	0.0	0.2	0.2
E,1	5.67×10^5	56★	0.3	0.2	0.2	0.2	0.1	0.0	0.2	0.2
E,2	1.13×10^6	19★	0.4	0.2	0.3	0.2	0.0	0.0	0.2	0.2
E,3	1.70×10^6	11	0.3	0.5	0.1	0.3	0.0	0.0	0.1	0.3
D,1	1.89×10^6	56★	0.0	0.5	0.2	0.3	0.5	0.0	0.1	0.3
E,4	2.27×10^6	8	0.6	1.1	0.3	0.6	0.1	0.1	0.3	0.6
E,5	2.84×10^6	6	0.2	1.2	0.4	1.0	0.5	0.6	0.2	0.8
D,2	3.78×10^6	19★	0.1	1.2	0.2	1.0	0.0	0.6	0.3	0.8
D,3	5.68×10^6	11	0.3	1.5	0.1	1.1	0.4	1.0	0.2	1.0
D,4	7.57×10^6	8	0.2	1.7	0.1	1.2	0.3	1.3	0.1	1.1

★ Transport times to Class I area during these conditions are longer than 12 hours, so they are not added to the cumulative frequency summation.

† The joint frequency and cumulative frequency of wind direction, wind speed, and stability are determined separately for each of the four time periods (0-6, 6-12, 12-18, 18-24). For a given time period, e.g. 0-6, the sum of all frequencies for all dispersion conditions adds up to 100 percent.

‡ For a given Class I area.

Note: Distance downwind, values of σ_y, σ_z, and transport times are based on a distance of 100 km.

the given wind speed category. For example, for the wind speed category, 0-1 m/s, a wind speed of 0.5 m/s should be used to evaluate transport time; for 1-2 m/s, 1.5 m/s; and so on. The times necessary for a plume parcel to be transported 100 km are 56, 19, 11, 8, and 6 hours for wind speeds of 0.5, 1.5, 2.5, 3.5, and 4.5 m/s, respectively.

For the Level-2 screening analysis, we assume it is unlikely that steady-state plume conditions will persist for more than 12 hours. Thus, if a transit time of more than 12 hours is required to transport a plume parcel from the emissions source to a Class I area for a given dispersion condition, we assume that plume material is more dispersed than a standard Gaussian plume model would predict. This enhanced dilution would result from daytime convective mixing and wind direction and speed changes.

To obtain the worst-case meteorological conditions, it is necessary to determine the dispersion condition (a given wind speed and stability class associated with the wind direction that would transport emissions toward the Class I area) that has a $\sigma_y \sigma_z u$ product with a cumulative probability of 1 percent. In other words, the dispersion condition is selected such that the sum of all frequencies of occurrence of conditions worse than this condition totals 1 percent (i.e., about four days per year). The 1-percentile meteorology is assumed to be indicative of worst-day plume visual impacts when the probability of worst-case meteorological conditions is coupled with the probability of other factors being ideal for maximizing plume visual impacts. Dispersion conditions associated with transport times of more than 12 hours are not considered in this cumulative frequency for the reasons stated above.

This process is illustrated by the example shown in Table 3, which indicates that the first two dispersion conditions would cause maximum plume visual impacts because the $\sigma_y \sigma_z u$ products are lowest for these three conditions. However, the transport time from the emissions source to the Class I area associated with each of these dispersion conditions is greater than 12 hours. With the third dispersion condition (F,3), emissions could be transported in less than 12 hours. The frequency of occurrence (f) of this condition is added to the cumulative frequency summation (cf). For this hypothetical example, the meteorological data are stratified into four time-of-day categories. The joint frequency distributions of wind direction, wind speed and stability are determined separately for each of the four time periods. Each time period's frequency distribution is calculated such that the sum of the frequencies for all dispersion conditions adds up to 100 percent. For each time period, the one percentile meteorology would be determined, solely on the cumulative frequencies for that time period. Then, the most restrictive of the one-percentile dispersion conditions determined for the 4 time periods would be used as a basis for the Level II analysis. The rationale for stratifying the joint frequencies in this way is to provide conservatism in the calculation and also to provide information on the time of day that worst-case plume visual impacts are likely to occur. By determining worst-case dispersion in this way, one knows the dispersion conditions for each time period that would be expected to be worse one percent of the hours during that time-of-day period.

Note that the worst-case, stable, light-wind dispersion conditions occur more frequently during the nighttime hours.* In our example, the following additional worst-case dispersion conditions add to the cumulative frequency: F,3; E,3; E,4; E,5; D,3; and D,4. Dispersion conditions with wind speeds less than or equal to 2 m/s (F,1; F,2; E,1; E,2; D,1; and D,2) were not considered to cause an impact because of the long transit times to the Class I area in this example. Thus, their frequencies of occurrence were not added to the cumulative frequency summation. The result of this example analysis is that dispersion condition E,4 is associated with a cumulative frequency greater than or equal to 1 percent and the most restrictive, so we would use this dispersion condition to evaluate worst-case visual impacts for the Level-2 screening analysis for this example case.

It should also be noted that if the location of the observer in the Class I area is at or near the boundary of one of the 16 cardinal wind direction sectors, it may be appropriate to interpolate the joint frequencies of wind speed, wind direction, and stability class from the two wind direction sectors, on the basis of the azimuth orientation of the observer relative to the center of the wind direction sectors.

ACCOUNTING FOR COMPLEX TERRAIN

If the observer is located on elevated terrain or if elevated terrain is between the emissions source and the observer, dispersion patterns may be significantly different from those obtained from the procedures outlined above. For such situations, adjustments to the worst-case meteorological conditions determined by these procedures may be necessary.

For example, consider the elevated terrain feature illustrated by the shaded area in Figure 19. It is unlikely that a stable plume parcel would remain intact after transport to either Observer A or B. Either the stable plume would be transported around the elevated terrain feature, resulting in a longer plume transport distance, or the plume would be broken up by turbulence

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* Although plume visual impact is usually not an issue at night, nighttime dispersion conditions need to be considered because maximum plume visual impacts are often observed in the morning after a period of nighttime transport. For these situations, the nighttime meteorological conditions are most indicative of plume dispersion when the plume is viewed at sunrise. In cooler seasons, stable stagnant conditions may persist during daytime hours also.

encountered during the straight-line transport up and over the terrain feature. Also, stable plume transport in the direction of Observer C would be blocked by elevated terrain. On the other hand, Observer D would be in a position where straight-line stable transport is not only possible but very likely in the drainage flow off the elevated terrain feature.

Accounting for elevated terrain can be a detailed and time-consuming process, requiring complex-terrain windfield models and other sophisticated tools. Although such analytical options are encouraged, we suggest a simpler screening approach based on assumed enhancements to dispersion caused by elevated terrain.

If the observer is located on terrain at least 500 meters above the effective stack height for stable conditions (Observer C in Figure 19) or such elevated terrain separates the emission source and the observer (Observers A and B in Figure 19), the worst-case stability class should be shifted one category less stable.

EXERCISING VISCREEN

The plume visual impact screening model VISCREEN can be run as described previously for the Level-1 analysis. However, for Level-2 analysis, the default parameters are not selected. The analyst selects particle size distribution and density parameters suitable for the source and region in question (although default particle sizes and densities can still be used if desired). Meteorological conditions (stability, wind speed, and plume offset angle) appropriate for the worst-case analysis are used. If available, visual range and ambient ozone data from locations near the source area and Class I area can be used instead of Level-1 default values. Median values of both should be used, if available.

ALTERNATIVE USE OF PLUME VISIBILITY MODELS

As an alternative to the use of the screening model VISCREEN, the analyst may wish to apply plume visibility models [refer to EPA Guideline on Air Quality Models (Revised) EPA 450/2-78-027R, Supplement A, and any future supplements]. Although model input requirements are more extensive for these more sophisticated models, the models are expected to be more realistic (less conservative) than VISCREEN. Several alternative plume and sun positions should be tested to assure that realistic worst-case scattering angles are analyzed (VISCREEN analyses only worst-case scattering angles).

5 LEVEL-3 ANALYSIS

In Level-3 analysis, the objective is broadened from conservative analysis of worst-case conditions to a realistic analysis of all conditions that would be expected to occur in a typical year in the region that includes both the emission source and the observer. Level-3 analysis is no longer considered screening because it is a comprehensive analysis of the magnitude and frequency of occurrence of plume visual impacts as observed at a sensitive Class I area vista.

It is important to determine the frequency of occurrence of visual impact because the adversity or significance of impact is dependent on how frequently an impact of a given magnitude occurs. For example, if a plume is perceptible from a Class I area a third of the time, the impact would be considered much more significant than if it were perceptible only one day per year. The assessment of frequency of occurrence of impact should be an integral part of Level-3 visual impact analysis.

OBJECTIVES OF LEVEL-3 ANALYSIS

In this section we discuss how one can determine both the magnitude and frequency of occurrence of plume visual impact. This procedure entails making several runs with a plume visibility model for different values of the following important input parameters that are likely to vary over the course of a typical year:

- Emission rates (if variable)
- Wind speed
- Wind direction
- Atmospheric stability
- Mixing depth
- Background ozone concentration
- Background visual range
- Time of day and season
- Orientation of observer, plume, and sun

Viewing background (whether it is sky, cloud, or snow-covered, sunlit, or shaded terrain).

Because of the large number of variables important to a visual impact calculation, several model calculations are needed to assess the magnitude and frequency of occurrence of visual impact. It would be ideal to calculate hourly impacts over the course of a year or more using hourly values of the above variables. However, such an extensive data base is rarely available for use. Even if it were available, the computing costs involved would be prohibitive. It is therefore preferable to select a few representative, discrete values for each of these variables to represent the range (i.e., the magnitude and frequency of occurrence) of visual impact over a given period of time, such as a season or year.

It is possible to imagine a worst-case impact condition that would never occur in the real atmosphere; this condition could be represented on a cumulative frequency plot, such as that of Figure 20, as point A. The impact is great, but it almost never occurs. If another worse-case situation less extreme than point A were selected, the magnitude of impact would be less, but it might occur with some nonzero frequency, about one day per year, for example (the reasonable worst-case impacts for Level-1 and Level-2 analyses). It is possible to select various values of all the important input variables and to assess the frequency with which those conditions resulting in impacts worse than a given impact would occur. By this process, several points necessary to specify the frequency distribution could be obtained (for example, points B, C, and D in Figure 20). With average (50-percentile) conditions, a negligible impact, as shown at point E in Figure 20, might be found. In Figure 20, the ordinate could be any of the parameters used to characterize visibility impairment, such as visual range reduction, plume contrast, blue-red ratio, or ΔE, and the abscissa could represent cumulative frequency over a season or a year.

In a visual impact assessment, it is recommended that one select various combinations of upper-air wind speed, wind direction, and atmospheric stability; background ozone concentration; and background visual range to specify the frequency distribution of plume visual impact as shown in Figure 20. If one has a large, concurrent data base of all five of these variables, it would be desirable to calculate a five-way joint-probability distribution matrix and to use these joint probabilities to calculate frequency of occurrence of impact. However, in most situations, such a data base is not available, and one must treat the various worst-case events as independent probabilities. With this assumption, the probability of worst-case impacts can be roughly estimated by multiplying the independent probabilities. This can be represented as follows:

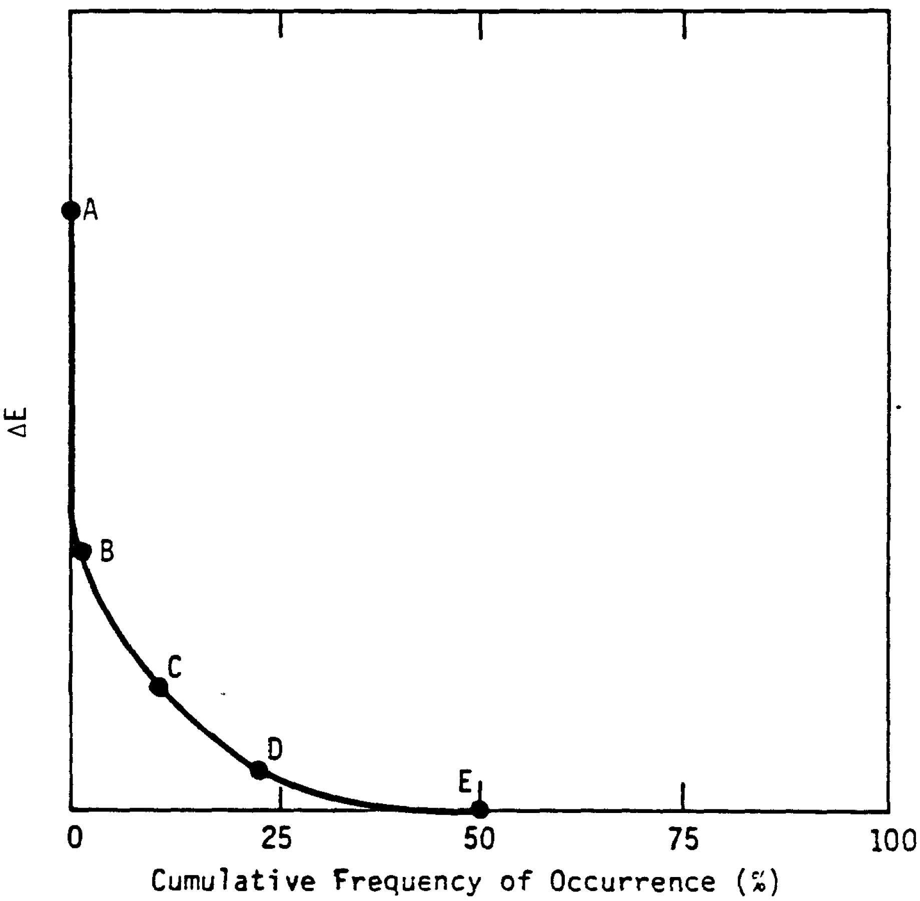

FIGURE 20. Example of a frequency distribution of plume visual impact.

$$f(y > y') = \prod_i f(x_i > x_i') \quad , \qquad (10)$$

where $f(y > y')$ is the cumulative frequency of impact y greater than y', and $f(x_i > x_i')$ is the cumulative frequency of variable x_i having values that would cause greater impact than the value x_i'.

In such an application, one might obtain an estimate of cumulative frequency by using the joint frequency distribution of upper-air wind speed and wind direction and the separate frequency distributions of upper-air stability and other parameters critical to plume visual impact. For example, a cumulative frequency distribution of the plume perceptibility parameter ΔE can be estimated as follows:

$$f(\Delta E > \Delta E') = f(u < u', WD < WD') \cdot f(s > s') \cdot f\,(\text{other factors}) \qquad (11)$$

where

$f(\Delta E > \Delta E')$ = the frequency of occurrence of ΔE values greater than ΔE'. ΔE' is calculated on the basis of a wind speed u', wind direction WD', stability s', ozone concentration $[O_3]'$, and visual range r_v'.

$f(u < u', WD < WD')$ = the frequency of occurrence of wind speeds less than u' for wind directions within a specified value (WD') of the worst-case wind direction.

$f(s > s')$ = the frequency of occurrence of stabilities greater than s'.

f(other factors) = the frequency of occurrence of background ozone concentrations greater than $[O_3]'$ (that would cause higher plume NO_2 concentrations), background visual range values greater than r_v', and plume dimensions (σ_y, σ_z) worse than assumed values (Pasquill-Gifford).

Note that this equation assumes the statistical independence of winds, stability, and other factors. If enough data are available, joint frequency distributions should be used. This is especially important if there are known conditions that contradict the assumption of independence (e.g., terrain-induced stable drainage that flows). Each of the input parameters that are important to the visibility model calculation varies significantly over the period of a year.

SUGGESTIONS FOR LEVEL-3 ANALYSIS

The most exacting way to obtain plume visual impact cumulative frequency distributions would be to apply a plume visibility model for every time period (e.g., every daylight hour or 3-hour period) with the appropriate emissions, wind speed, wind direction, stability, background ozone, background visual range, sun angle, and viewing background. Thus, one would have a calculation for every daytime period in the course of a year. If done every 3 hours, this would be approximately 1460 model applications (365 days/yr X 12 hr/day of daylight/3 hr = 1460 time periods). Such a method is not practical with current plume visual impact analysis hardware and software.

Thus, the analyst needs to estimate the plume visual impact cumulative frequency distribution using a limited set of plume visibility model runs and appropriate assumptions. There is no simple procedure that can be recommended for all Level-3 analyses. Limited comparisons of Level-3 predictions with measurements suggest that magnitudes and frequencies of plume visual impact are reasonably well estimated by the following suggested procedures. It is recommended, however, that any chosen procedures for performing a given Level-3 analysis be reviewed by the permitting authority and the Federal Land Manager of the affected Class I area before analysis commences.

Frequency Distribution of Dispersion Conditions

A joint frequency distribution of wind speed, wind direction, and stability should be prepared separately for the following times of day: midnight to 0600, 0600 to noon, noon to 1800, and 1800 to midnight. This breakdown is necessary to identify the time of day of impacts. These distributions should be compiled for the entire year (or if possible, two or more years) and for each of the four seasons. Seasonal analysis of plume visual impact may be important for the Federal Land Manager and state to assess the number of visitors potentially impacted by a given plume. If worst-case plume visual impacts occur under stable transport conditions, they will most likely occur during the early morning hours. In such cases, it is recommended that the midnight to 0600 frequency distributions be given the primary attention in Level-3 analysis. However, for completeness, the 0600 to noon and noon to 1800 distributions should be used to characterize the frequency of midday and afternoon plume visual impacts.

Calculating Plume Visual Impacts

Plume visual impacts should be calculated for a representative sample (or possibly each) of the categories of stability, wind speed, and wind direction in the joint frequency distribution. Since the objective is to estimate the cumulative frequency curve (similar to that shown in Figure 20), plume visual impact should be calculated for the most distant plume position (from the observer) within the given wind direction and the highest wind speed appropriate for a given category of the distribution. For example, for the frequency distribution cell representing F, 0-1 m/s, plume calculations should be made for 1 m/s, not a lower value, and for the most distant plume position (11.25° offset is recommended for the worst-case wind direction sector). This approach is necessary because the abscissa of the cumulative frequency plot is the frequency of conditions that produce impacts larger than the ordinate value of plume visual impact magnitude (ΔE). Plume visual impact should be calculated for a number of the cells of the frequency distribution (perhaps 20 or more). The largest impact magnitudes are likely to occur for wind directions that would carry the plume closest to the observer, light wind speeds, and stable conditions. To fill in conditions causing lower magnitudes (but higher cumulative frequencies), the analyst should identify a sample of wind directions, wind speeds, and stabilities that represent typical conditions. For example, all the 72 combinations of 8 plume positions or wind directions (e.g., worst case and three adjacent 22.5° sectors to the left and right, representing plume offset angles of 11.25, 33.75, 56.25, and 78.75°, 3 wind speeds (e.g., 0-2, 2-5, and 5-10 m/s), and 3 stabilities (e.g., F, E, and D) could be used as the input for 72 plume visibility model runs. These runs would be made using median background ozone concentration and visual range values. Sun angles would be specified by the date and time of the simulation. The worst-case sun angles should be determined by sensitivity analysis for one of the worst-case combinations of meteorological conditions before the full complement of model runs (72 in our example above) is made. Since worst-case meteorological conditions generally occur in the morning, it is suggested that simulation date/times of an hour after sunrise and an hour before sunset on 21 March, 21 June, 21 September, and 21 December be analyzed in the sensitivity test, and the worst-case date/time be used for all subsequent model runs. Model runs should be made for the appropriate viewing backgrounds for each line of sight and each plume position. If terrain is found to be the plume's viewing background, the appropriate distance between the observer and the terrain feature should be provided as part of the model input.

Coupling Magnitude and Frequency

Each of the (for example, 72) model calculations should be evaluated to select the two maximum plume ΔE's for conditions when the plume parcel is inside and outside the Class I area's boundary, respectively. (If discussions with the Federal Land Manager of the given Class I area suggest that only within-area plume parcels are of concern, only the former ΔE need be compiled.) The inside and outside ΔE's separately should be put in descending order of magnitude and coupled with the corresponding frequency of dispersion conditions. Cumulative frequencies should be added by summing the individual frequencies (see Table 3). If a wind direction, stability, or wind speed class was skipped in the sampling of the cells in the frequency distribution, the frequencies for all conditions expected to cause greater plume visual impact should be added and coupled with the given plume visual impact ΔE. Separate magnitude/frequency tables should be compiled for inside/outside views, each time of day, and each season.

Interpreting the Cumulative Frequency Curve

Cumulative frequency distribution curves of plume visual impacts prepared using the procedures described in the preceding paragraphs should be interpreted in light of the assumptions and simplifications underlying the various steps. Several factors that can be particularly significant include the use of median values for visual range and background ozone concentration; the persistence of stable conditions for long transport distances; and the use of Pasquill-Gifford coefficients as the sole determinant of plume dispersion. For specific cases, the combined effect of such assumptions can be that estimated frequencies of a specific level of effects (say, ΔE greater than 5) may be higher or lower than would actually occur.

Cumulative frequency curves based solely on the joint frequency of wind speed, wind direction, and atmospheric stability ignore the probability of occurrence of other factors that affect plume visual impacts. This probability appears as "f(other factors)" in Equation 11. In our experience, wind speed, direction and stability are the principal determinants of plume visual impacts. In some cases, however, these "other factors" could be significant. Obviously, if data and resources allow, analyses can be expanded to incorporate joint frequency distributions for all key parameters. However, the number of model simulations required will increase geometrically with the addition of each new dimension. For example, treating three visual ranges (e.g., 50th, 75th, and 90th percentiles) triples the number of simulations. Further, the data required to develop such joint frequency distributions are not available for many areas.

No explicit formal guidance can be provided at this time for interpreting cumulative frequency curves. The analyst should, however, identify which transport scenarios have both high visual effects and high frequencies of occurrence. Similarly, the analyst should verify that the transport scenarios modeled include those under which visual impacts will be greatest. If it is likely that simplifying assumptions may have led to bias in the cumulative frequency curves, then the factors leading to this conclusion should be described for consideration by the permitting agency, the Federal Land Manager, and other reviewers.

Summarizing Results

Cumulative frequency plots similar to Figure 20 should be made for each season, time of day, and inside/outside combination. In addition, the number of mornings and afternoons in each season that ΔE's are greater than 2 should be tabulated.

RECOMMENDED MODEL FOR LEVEL-3 ANALYSIS

Plume Visibility Model (PLUVUE II)

The recommended model for a Level-3 analysis is the PLUVUE II model (EPA, 1986). The PLUVUE II (Seigneur et al., 1984) model uses a Gaussian formulation for transport and dispersion. The spectral radiance $I(\lambda)$ at 39 visible wavelengths ($0.36 < \lambda < 0.75$ µm) is calculated for views with and without the plume; the changes in the spectrum are used to calculate various parameters that predict the perceptibility of the plume and contrast reduction caused by the plume. PLUVUE II is designed to perform plume optics calculations in two modes. In the plume-based mode, the visual effects are calculated for a variety of lines of sight and observer locations relative to the plume parcel; in the observer-based mode, the observer position is fixed and visual effects are calculated for the specific geometry defined by the position of the observer, plume, and sun. For either mode, the model requires the user to select up to 16 different locations downwind of the emission source. These distances determine the locations of the optics calculations along the plume trajectory. For further information regarding the application of the PLUVUE II model, the updated, abridged version of the PLUVUE II User's Guide (EPA, 1992) should be reviewed.

Optional Use of VISCREEN

As a low-cost, easy-to-apply, but more conservative estimate of plume visual impact, the analyst may wish to use VISCREEN as the model for generating plume visual impact magnitudes in the Level-3 analysis. VISCREEN could be used either in place of, or in addition to, a plume visibility model. VISCREEN can also be used to choose meteorological scenarios to be further analyzed with a plume visibility model.

REFERENCES

Blackwell, H. R. 1946: Contrast thresholds of the human eye. *J. Optical Society of America*, **36**:624643.

Booker, R. L., and C. A. Douglas. 1977: Visual Range Concepts in Instrumental Determination and Aviation Application. NBS monograph 159, U.S. Department of Commerce.

Cornsweet, T. 1970: *Visual Perception.* Academic Press, New York.

EPA 1986: Guideline on Air Quality Models (Revised) and Supplement A. EPA-450/2-78-027R. Research Triangle Park, NC.

EPA 1992: Updated User's Guide for the Plume Visibility Model (PLUVUE II). Research Triangle Park, NC.

Faugeras, O. D. 1979: Digital color image processing within the framework of a human visual model. *IEEE Trans. Acoust., Speech Sig. Process*, **Vol. ASSP-27**, pp. 380-393.

Gordon, J. I. 1979: Daytime Visibility: A Conceptual Review. Scripps Institution of Oceanography, Visibility Laboratory, La Jolla, California.

Hall, C. F., and E. L. Hall. 1977: A nonlinear model for the spatial characteristics of the human visual system. *IEEE Trans. Syst., Man, Cybern.*, SMC-7, pp. 161-170.

Helson, H. 1938: Fundamental principles of color vision. I. The principle governing changes in hue, saturation, and lightness of non-selective samples in chromatic illumination. *J. Exp. Psychol.*, **23**:439-471.

Henry, R. C. 1979: The Human Observer and Visibility--Modern Psychophysics Applied to Visibility Degradation. View on Visibility--Regulatory and Scientific. Air Pollution Control Association, Pittsburgh, Pennsylvania.

Henry, R. C., and J. F. Collins. 1982: Visibility Indices: A Critical Review and New Directions. Prepared for Western Energy Supply and Transmission Associates. Environmental Research & Technology, Inc., Westlake Village, California (ERT Document P-A771).

Howell, E. R., and R. F. Hess. 1978: The functional area for summation to threshold for sinusoidal gratings. *Vision Res.*, **18**:369-374.

Jaeckel, S. M. 1973: Utility of color-difference formulas for match acceptability decisions. *Appl. Optics*, **12**:1299-1316.

Johnson, R. W. 1981: Daytime visibility and nephelometer measurements related to its determination. *Atmos. Environ.*, **16**:1835-1846.

Judd, D.B. 1940: Hue saturation and lightness of surface colors with chromatic illumination. *J. Opt. Soc. Am.*, 30:2-32.

Judd, D. B., and G. Wyszecki. 1975: *Color in Business, Science, and Industry*. John Wiley & Sons, New York.

Koenig, A., and E. Brodhun. 1888, 1889: Experimentelle Untersuchungen uber die psychophysische Fundamentalformel in Bezug auf den Gesichtssinn. *Sitzungssberichte preussischen Akademie der Wissenschaften*, **26**:917-931; 27:641-644.

Latimer, D. A., and R. G. Ireson. 1980: *Workbook for Estimating Visibility Impairment.* U.S. Environmental Protection Agency, Research Triangle Park, North Carolina (EPA-450/4-80-031).

Latimer, D. A., R. W. Bergstrom, S. R. Hayes, M. K. Liu, J. H. Seinfeld, G. Z. Whitten, M. A. Wojcik, and M. J. Hillyer. 1978: The Development of Mathematical Models for the Prediction of Anthropogenic Visibility Impairment. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina (EPA-4503-78-110a,b,c).

Loomis, R. J., M. J. Kiphart, D. B. Garnand, W. C. Malm, and J. V. Molenar. 1985: Human Perception of Visibility Impairment. Paper presented at the Annual Meeting of the Air Pollution Control Association, Detroit, Michigan, June 1985.

Lowry, E. M. 1931: The photometric sensibility of the eye and the precision of photometric observations. *J. Optical Society of America*, **21**:132.

Lowry, E. M. 1951: The luminance discrimination of the human eye. *Journal of the Society of Motion Picture and Television Engineers*, **57**:87.

Malm, W., M. Kleine, and K. Kelley. 1980: Human Perception of Visual Air Quality (Layered Haze). Paper presented at the 1980 Conference on Visibility at the Grand Canyon.

Malm, W. C., D. M. Ross, R. Loomis, J. Molenar, and H. Iyer. 1986: An Examination of the Ability of Various Physical Indicators to Predict Perception Thresholds of Plumes as a Function of Their Size and Shape. Paper presented at the Air Pollution Control Association International Specialty Conference on Visibility, Grand Teton National Park, September 7-10, 1986.

Mathai, C. V., and I. H. Tombach. 1985: Assessment of the technical basis regarding regional haze and visibility impairment. AeroVironment Inc., Monrovia, California (AV-FR-84/520).

Middleton, W.E.K. 1952: *Vision Through the Atmosphere.* University of Toronto Press, Toronto, Canada.

Optical Society of America, Committee on Colorimetry. 1963: The Science of Color. Optical Society of America, Washington, D.C.

Seigneur, C. et al. 1984: User's Manual for the Plume Visibility Model (PLUVUE II). Systems Applications, Inc., San Rafael, California. NTIS PB84-158302.

Stevens, R. K., T. G. Dzubay, C. W. Lewis, and R. W. Shaw. 1984: Source apportionment methods applied to the determination of the origin of ambient aerosols that affect visibility in forested areas. *Atmos. Environ.*, **18**:261-272.

Systems Applications, Inc. 1985: Modeling Regional Haze in the Southwest: A Preliminary Assessment of Source Contribution. Systems Applications, Inc., San Rafael, California (SYSAPP-85/038).

Tombach, I., and D. Allard. 1980: Intercomparison of visibility measurement methods. *J. Air Pollut. Control Assoc.*, **30**:134-142.

Tombach, I., and D. Allard. 1983: Comparison of Visibility Measurement Techniques: Eastern United States. Electric Power Research Institute, Palo Alto, California (EPRI EA-3292).

Appendix A

PERCEPTIBILITY THRESHOLDS AND RECOMMENDED SCREENING ANALYSIS CRITERIA FOR PLUMES AND HAZE LAYERS

Appendix A

PERCEPTIBILITY THRESHOLDS AND RECOMMENDED SCREENING ANALYSIS CRITERIA FOR PLUMES AND HAZE LAYERS

INTRODUCTION

The plume from an emissions source is visible to an observer if the constituents of the plume, such as particulates and nitrogen dioxide, scatter or absorb enough light out of or into the observer's line of sight so that the plume contrasts with its viewing background. If this plume contrast is sufficiently large (either positively, signifying a bright plume, or negatively, signifying a dark plume), the plume becomes perceptible. Thus, the objective of plume visibility impact analysis is first to determine the plume contrast and second to determine whether that contrast will be perceptible. Some plumes are not visible because the concentration of optically active species in the plume (i.e., those that scatter or absorb light) is low. In addition, other factors, such as the position of the plume relative to the observer and the nature of the haze through which the plume is viewed, can affect plume visibility.

The objective of this appendix is to review the literature regarding perceptibility thresholds in order to recommend criteria for use in plume visibility impact screening and analysis. A perceptibility threshold would be a suitable criterion for visibility impact analysis if the policy objective were to be very strict (i.e., to prevent any visible plumes in a given location). A perceptibility threshold also may help to define the lower bound for less strict criteria (that would prevent significant plume impacts but allow a few days of marginally perceptible plumes).

PERCEPTIBILITY PARAMETERS

Contrast is the parameter most commonly used in the published literature to describe the sensitivity of the human eye-brain system. Contrast is also the most easily calculated plume visibility parameter, since it can be based on a single wavelength of light and does not require calculations at other wavelengths in the visible spectrum as do more sophisticated parameters.

Contrast is the relative difference in light intensity (radiance) of two viewed objects and can be calculated as follows:

$$C = \frac{I_1 - I_2}{I_2}$$

where I_1 and I_2 are the light intensities at a given wavelength for objects 1 and 2 (e.g., a plume and its viewing background).

Another parameter commonly used in plume visual impact analysis is ΔE. ΔE is perhaps the best currently available plume perceptibility parameter because it is based on the human eye/brain system's relative sensitivity to all wavelengths in the visible spectrum. It is proportional to the perceptibility of color differences and is essentially identical to just noticeable differences (jnd). A ΔE value of 1 is commonly taken to be 1 jnd.

OVERVIEW OF THRESHOLD RESEARCH

The issue of defining the conditions under which a plume or haze layer will be visible is part of the scientific field known as psychophysics. Psychophysics is the branch of psychology that is concerned with subjective measurement. It relates physical stimuli to psychological response. In the current context, we are interested in the effect that differences in radiant energy (light) directed toward a human observer (the physical stimulus) have on the psychological response of the eye/brain system of the observer.

One of the oldest psychophysical determinations is the minimum physical stimulus increment that the observer can just barely perceive. This increment is called the just noticeable difference, differential threshold, or difference limen. A just noticeable contrast is also called a liminal contrast, and contrasts greater or less than this contrast are called supraliminal and subliminal. The difference limen is never a sharply defined value. Since an observer's sensitivity and attention vary from moment to moment, it is common to define the limen as a statistical measure. For example, the limen might be defined as that stimulus that could be distinguished 50, 70, or 90 percent of the time. The difference limen is often set at a value of 70 percent probability of distinguishing two stimuli. One of the oldest laws of psychophysics is Weber's Law, which states that the difference limen is a constant fraction of the stimulus. Since contrast is defined as the relative difference in light intensities of two objects and is itself a ratio, Weber's Law could be stated as follows: the liminal contrast is a constant (regardless of the light intensity). Later research has shown that Weber's Law is only approximate.

The famous Koschmieder equation that inversely relates the visual range to the light extinction coefficient was based on the assumption that the liminal contrast for relatively large, sharp-edged objects observed in daylight is 0.02, or 2 percent. Although there were no scientific data to support this assumption made by Koschmieder in 1924, this contrast value is widely used in visibility work for uniformity in discussion.

One of the largest research studies of liminal contrast was carried out by Blackwell (1946). In this study, 19 young female observers made more than 2,000,000 observations, of which 450,000 were suitable for statistical analysis (Middleton, 1952). Circular stimuli of various sizes ranging from 0.6 to 360 minutes of arc were presented to the observers. These studies indicated that for a typical daytime luminance of 100 candle/m^2, the liminal, or threshold, contrast ranges from a low of 0.003 (or 0.3 percent) for stimuli subtending 121 minutes of arc (2°) viewed for unlimited times to contrasts as high as 0.02 (or 2 percent) for stimuli subtending 10 minutes of arc viewed for limited periods. Thus, Blackwell's data suggest that the human observer is more sensitive than Koschmieder assumed him to be, at least under laboratory conditions.

The data of Koenig and Brodhun (1888, 1889) suggest that for typical daylight luminances, the liminal contrast is independent of the wavelength of light over the range tested (0.43 to 0.67 μm) and is on the order of 0.01, or 1 percent. For luminances greater than about 100 candles/m^2, Lowry (1931, 1951) reported a liminal contrast of 0.014, or 1.4 percent.

Recent psychophysical research (Cornsweet, 1970; Hall and Hall, 1977; Faugeras, 1979; Howell and Hess, 1978; Malm et al., 1986) has documented the fact that the response of the human eye/brain system to brightness contrast is a strong function of the spatial frequency of the contrast. Spatial frequency is defined as the reciprocal of the distance between sine-wave crests (or troughs) measured in degrees of angular subtense of a sine-wave grating. Thus, spatial frequency has units of cycles/degree (cpd). Any pattern of light intensities, whether it is a sine-wave, square-wave, step-function or any other pattern, can be resolved by Fourier analysis into a sum of sine-wave curves of different magnitude and frequency. To a first approximation, the spatial frequencies (f) corresponding to a Gaussian plume of width (w) are within the order of magnitude centered on $f = 1/w$. The human eye/brain system is most sensitive to spatial frequencies of approximately 3 cycles/degree (cpd). Thus, we might expect that plumes of width 0.33° (inverse of 3 cpd) to be the most easily perceptible. Figure A-1 summarizes the research of Howell and Hess

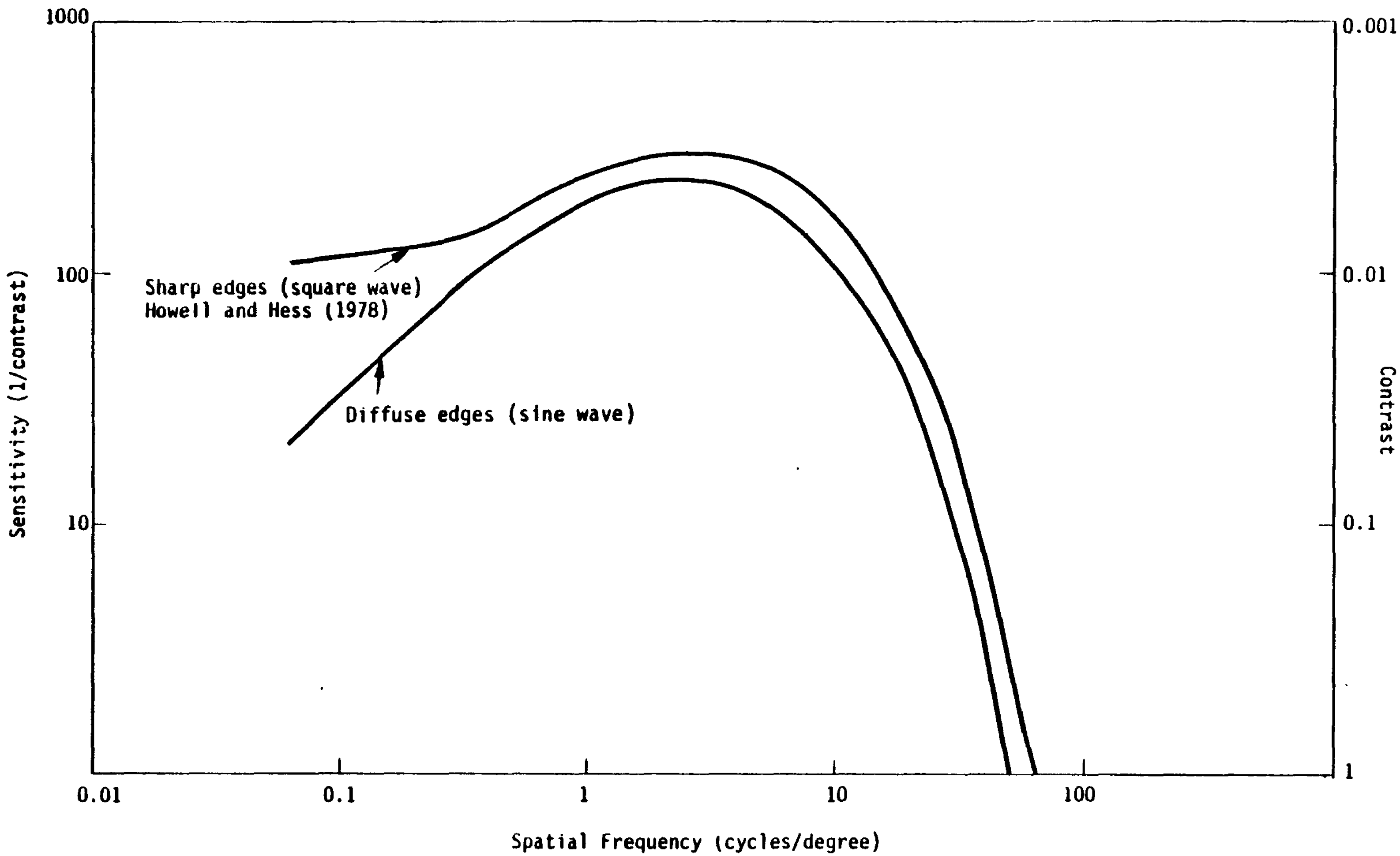

FIGURE A-1. Contrast sensitivity curves as a function of spatial frequency.

(1978). The sensitivity of the human eye-brain system drops off significantly at high spatial frequency (due to visual acuity) and also to a less extent at low spatial frequency (i.e., broad, diffus objects). The human visual system is much more sensitive to images with sharp, distinct edges (e.g., square waves) than to images with diffuse, indistinct edges (e.g., sine waves or Gaussian plumes). At 3 cpd the human visual system has a sensitivity* to square waves of 300 (corresponding to a threshold contrast of 2/300, or 0.0066) and to sine waves of 230 (contrast of 0.0086). Thus, at this most sensitive frequency, the eye/brain system is 1.3 times more sensitive to square waves than to sine waves. At lower spatial frequencies, the difference in sensitivities increases significantly (see Figure A-1). The fall-off in sensitivity at high spatial frequencies is consistent with the data of Blackwell (1946) and with the known responses of lens systems such as the human eye (Cornsweet, 1970).

To this point, we have discussed perception threshold research that is based on the use of contrast as the quantitative parameter. Before proceeding to the research of Malm and co-workers that specifically addresses the perception thresholds of plumes and haze layers, we discuss the limited work that has been performed using the ΔE parameter. The ΔE parameter is designed to be proportional to the perceptibility of differences in brightness and color (Judd and Wyszecki, 1975). It is generally accepted that a ΔE of 1 corresponds to 1 just-noticeable difference (jnd). Thus, a ΔE of 1 is roughly the liminal, or threshold, color difference. Applying the ΔE formulas to a 2 percent contrast, Latimer et al. (1978) calculated a ΔE of 0.78 and concluded that "ΔE's less than 1 would be imperceptible." Jaeckel (1973) presented data on the probability that observers would accept given color differences as a match. He found that approximately 30 percent of observers could distinguish a ΔE of about 1, 50 percent could distinguish a ΔE of 2, and more than 90 percent could distinguish a ΔE of 4.

Essentially all of the work specifically addressed to the perception threshold of plumes and layered haze has been carried out by Malm and co-workers at Colorado State University. Their laboratory studies were based on actual or computer-generated color slides of plumes and layered haze.

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* Howell and Hess (1978) define sensitivity as the inverse of modulation contrast which is $(I_1 - I_2)/(I_1 + I_2)$. This definition of contrast is approximately half the contrast defined earlier $(I_1 - I_2)/I_2$. Thus, we multiply modulation contrast by two to obtain contrasts used for visibility.

Malm, Kleine, and Kelley (1980) studied the perception threshold for computer-generated white and NO_2 Gaussian plumes. The response to white and NO_2 plumes resulted in essentially identical contrasts. Fifty percent of the observers were able to identify a plume with a contrast of 0.014 and ΔE of 2.3, 75 percent a contrast of 0.020 and ΔE of 3.3, and 90 percent a contrast of 0.025 and ΔE of 4.1.

The most detailed study to date of plume perceptibility thresholds is the work of Malm et al. (1986). In this study sharp-edged (square wave) plumes were generated by computer and overlaid on color slides of a natural scene. Plumes of various contrasts and sizes (ranging from 0.1 to 3° wide) were shown to observers. These researchers found that the detection thresholds for such computer-generated square-wave plumes were a relatively strong function of the vertical plume width. The highest visual sensitivity was found for 0.36° plumes, which is consistent with the previously noted maximum sensitivity at a spatial frequency of 3 cycles /degree. Maximum sensitivity was 200 (corresponding to a contrast of 0.005) for the 0.36° plume, and sensitivities for all size plumes were approximately 100 or greater (contrasts of 0.01 or smaller). These thresholds were defined at the 70 percent probability of detection point. This threshold contrast of 0.005 is consistent with the threshold contrast of 0.007 of Howell and Hess (1978).

Table A-1 summarizes the research described previously. Under laboratory conditions in which observers are attentive and trained, the detection threshold (for 50 percent detection) for objects of optimum size with distinct edges is in the range 0.003-0.007. For conditions in which the stimulus has a diffuse edge (such as would be the case with a Gaussian plume) or is different from the optimum-sensitivity size, threshold contrasts appear to be higher, approximately 0.009. The evidence for ΔE thresholds is not as clear-cut. The data of Jaeckel (1973) and Malm, Kleine, and Kelley (1980) support 70 percent detection thresholds for ΔE of 3, while the estimates of Latimer et al. (1978) and the more recent data of Malm et al. (1986) suggest a ΔE threshold of less than one.

It is instructive to consider the relationship between contrast (which has been used in most perception research) and ΔE. For monochromatic contrasts (those involving brightness change (ΔL^*), but not color change):

$$\Delta a^* = \Delta b^* = 0$$

thus

$$\Delta E(L^*a^*b^*) = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} = \Delta L^*$$

TABLE A-1. Summary of contrast and color change threshold data.

Contrast	Delta E	Percent Detection	Edge	Reference
0.003*	--	50	Sharp	Blackwell (1946)
0.014	--	?	Sharp	Lowry (1931, 1951)
0.007‡	--	?	Sharp	Howell and Hess (1978)
0.009‡	--	?	Diffuse	
0.016§	--	?	Sharp	
--	1	30	Sharp	Jaeckel (1973)
--	2	50	Sharp	
--	3	70	Sharp	
--	4	90	Sharp	
0.006	1.0	10	Diffuse	(Malm, Kleine, Kelley (1980)
0.009	1.5	25	Diffuse	
0.014	2.3	50	Diffuse	
0.020	3.3	75	Diffuse	
0.025	4.2	90	Diffuse	
0.01	--	90	Sharp	Loomis et al. (1985)
0.005**	--	70	Sharp	Malm et al. (1986)
0.010♯	--	70	Sharp	
--	1.2	100	Sharp	

* The most sensitive contrast reported for largest size of stimulus and largest luminance and longest response time evaluated (probably the minimum possible threshold).

‡ The most sensitive contrast reported at a spatial frequency of 3 cycles/degree.

§ Threshold contrast for sharp objects at low spatial frequencies.

** Minimum threshold for 0.36° wide plumes.

♯ Maximum threshold for all size plumes tested.

since

$$L^* = 116 \left(\frac{Y}{Y_o}\right)^{1/3} - 16 \quad , \text{ and}$$

$$\Delta L^* = 116 \left[\left(\frac{Y'}{Y_o}\right)^{1/3} - \left(\frac{Y}{Y_o}\right)^{1/3}\right] .$$

If $Y' = (1 + C)Y$,

$$\Delta L^* = 116\left(\frac{Y}{Y_o}\right)^{1/3} [(1 + C)^{1/3} - 1]$$

where

$\Delta E(L^*a^*b^*)$ = color difference parameter

ΔL^* = change in perceived brightness

Y', Y, Y_o = Y tristimulus values for an object (e.g., a plume), a viewing background, and a white reference, respectively

C = contrast between observed object (e.g., a plume) and its viewing background

For bright viewing backgrounds (Y = 100), this formula yields the following approximate formula;*

$$\Delta E = 38\ C$$

Thus, the laboratory-derived threshold contrast of 0.009 for diffuse-edged objects is the equivalent ΔE of 0.34. The "traditional" (Koschmieder) threshold contrast of 0.02 is the equivalent ΔE of 0.76. Conversely, the "traditional" just-noticeable-difference ΔE of 1 is the same as a contrast of 0.026.

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* This relationship assumes a bright viewing background and object. A smaller ΔE would result for darker viewed objects. This finding is consistent with the psychophysical experimental evidence that suggests that higher contrasts are required between two dark objects for them to be discerned.

RECOMMENDATIONS FOR PLUME SCREENING CRITERIA

The concept underlying the use of screening analyses, such as Level-1 and Level-2, is that for some facilities whose emission rates are sufficiently low, or that are located far enough away from sensitive areas, it may be possible to use relatively simple calculations to determine that plume visual effects will be negligible. In this way, complex and costly analytical approaches will only be required for those cases in which they are needed to determine whether visual impacts are unacceptable. Perceptibility thresholds establish a lower bound for Level-1 and Level-2 screening criteria. If, under transport and viewing conditions that conservatively describe "reasonable worst case" scenarios, it can be shown that a plume's visual effects are below the threshold of perceptibility, there is clearly no need to conduct more sophisticated analyses.

As noted in the preceding paragraphs, the perceptibility of an object (e.g., a plume) may depend on both the observer and the viewing conditions. Under controlled conditions, trained observers looking for specific objects having sharp edges may have ˉower perception thresholds than do casual observers in natural conditions.

The literature suggests that the perceptibility threshold for trained and attentive observers in a laboratory environment is on the order of 0.3-0.7 percent contrast and a ΔE of 0.1-0.3. In the natural environment, the observer is likely to be much less sensitive to contrast and color differences because he or she is not specifically "looking for plumes and haze layers." Thus, the use of laboratory-derived estimates of perceptibility thresholds as screening criteria would be unnecessarily conservative.

Henry (Henry, 1979; Henry and Collins, 1982; Henry, private communication, 1987) suggests that the field threshold may be 2 to 4 times greater than the laboratory threshold. Although this speculation is not based on empirical evidence, it is consistent with our experience with "prevailing visibility" measurements. For example, airport visibility observations appear to correlate best with light extinction measurements when a contrast threshold of 5 percent is assumed in the Koschmieder equation (Gordon, 1979; Tombach and Allard, 1983). In their review of regional haze, Mathai and Tombach (1985) make the following observation:

> Laboratory and field experiments of the same sort gave similar results, but most field data suggest a higher contrast threshold than do laboratory data, most probably because the attention and target search conditions differ. Field experiments during World War II have suggested a threshold contrast of about 0.05 to be more appropriate for ordinary viewing, and additional recent research (Booker and Douglass, 1977;

> Johnson, 1981; Tombach and Allard, 1980 and 1983; Stevens et al., 1984) further support[s] the conclusion that a value near 0.05 is more representative of normal viewing than the traditional 0.02 [contrast threshold used in the Koschmieder equation]. Simply explained, for normal casual viewing of nonspecific scenic features, the perception threshold is greater than it is when a specific target is being sought in earnest with a relatively long time or a known distinctive form available to identify it.

Laboratory thresholds appear to underestimate actual thresholds for the casual observer (e.g., a visitor to a national park or wilderness area who is not specifically searching for plumes or haze layers). The above-suggested threshold contrast of 0.05 is an order-of-magnitude larger than the laboratory-derived threshold contrast of 0.005. For bright viewing objects, a contrast of 0.05 translates to a ΔE of approximately 2.

On the other hand, if we use the factor of 4 recommended by Henry (Henry and Collins, 1982; Henry, personal communication, 1987) to relate laboratory conditions to field conditions, the above-mentioned thresholds derived for the laboratory convert to the following values for field observation: a contrast of ~ 0.02 and a ΔE of ~ 0.8. These values may be construed as the approximate "best estimate" thresholds of perceptibility. We emphasize that these values are estimates of the perceptibility threshold for the casual observer in the field; a sensitive observer may be able to detect plumes having much lower contrasts (0.003-0.007) and lower ΔE (0.1-0.3).

In summary, we suggest that the following values characterize our current understanding of perceptibility:

	Contrast	ΔE
Lower-bound threshold (sensitive observer in laboratory)	0.005	0.2
Best-estimate threshold (sensitive observer in field)	0.02	0.8
Upper-bound threshold (casual observer in field)	0.05	2

Figure A-2 synthesizes the results of this review of perceptibility thresholds. The abscissa (x-axis) shows the vertical width (angular subtense) of a plume. The ordinate (y-axis) is the just-perceptible contrast. The

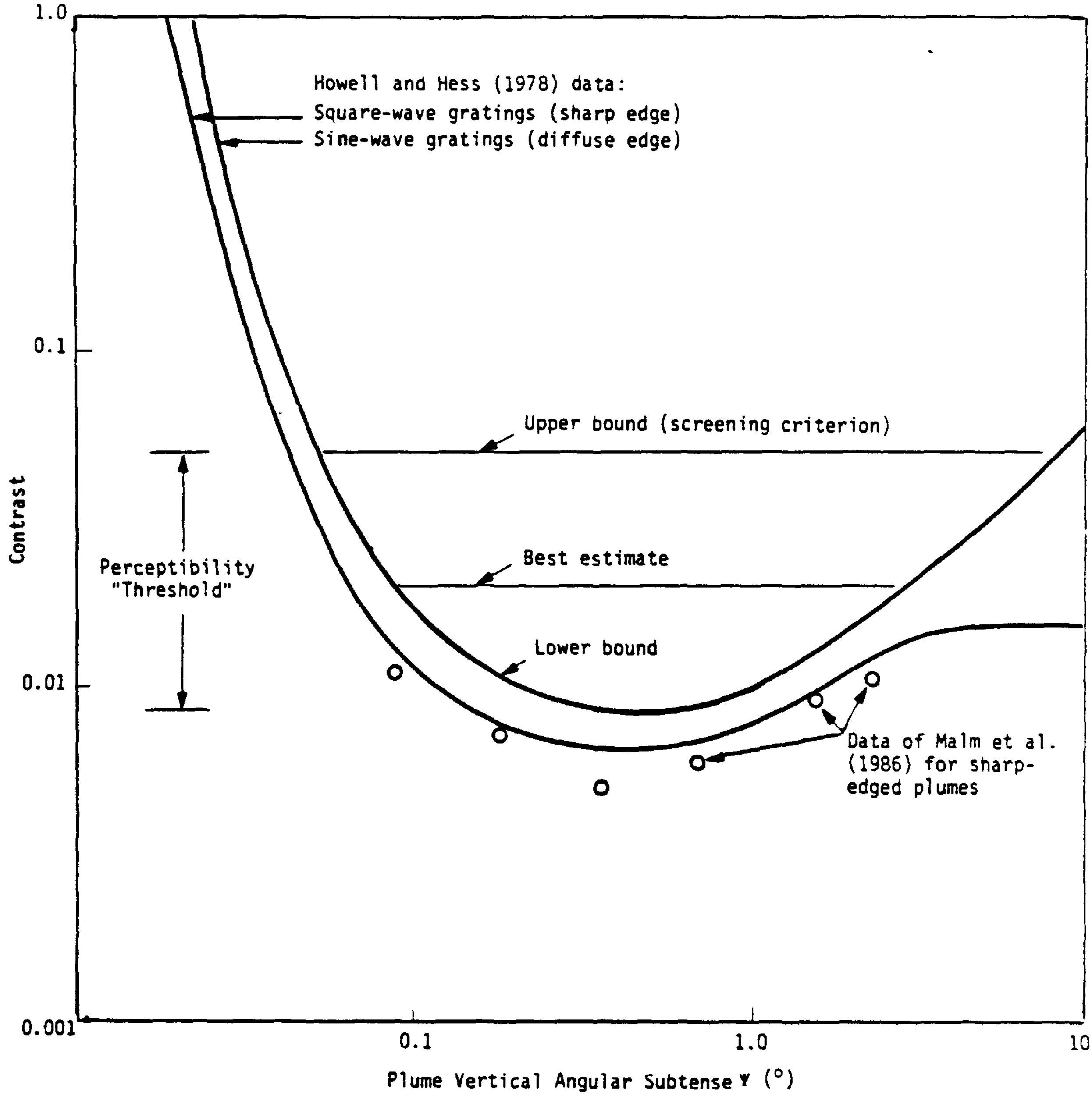

FIGURE A-2. Plume perceptibility threshold as a function of plume thickness (Ψ). See definition of Ψ in the Glossary in the front of this workbook and in Figure 3.

two curves show the data of Howell and Hess (1978) for sharp and diffuse edged objects, and the circles show the data of Malm et al. (1986) for sharp-edged plumes. These two separate and independent experiments are remarkably consistent, indicating that plumes of approximately 0.3-0.5 degree vertical angular width are most easily perceptible. Diffuse-edged objects have larger perceptibility thresholds than sharp-edged objects. The diffuse-edged curve derived from Howell and Hess (1978) data is taken to be the lower bound of perceptibility for plumes. The "best estimate" and "upper bound" are also shown for comparison. For very thin plumes (< 0.1° width) and very wide plumes (> 5° width) the Howell and Hess (1978) data are assumed to define the threshold.

For Levels 1 and 2 plume visual impact screening, we recommend that the higher set of threshold values (contrast of 0.05; ΔE of 2) be used as the criteria for screening. For very wide or narrow plumes the Howell and Hess (1978) diffuse-edge thresholds should be taken as the criteria for screening (see Figure A-2).

Appendix B

THE PLUME VISUAL IMPACT SCREENING MODEL (VISCREEN)

Appendix B

THE PLUME VISUAL IMPACT SCREENING MODEL (VISCREEN)*

The plume visual impact screening model (VISCREEN) was designed to provide the user with a simple, easy-to-use analytical tool for performing Level-1 and -2 screening calculations of potential plume visual impacts, especially in PSD Class I areas where visibility is a protected value. VISCREEN is a simple plume visibility model. The objective of the model is to calculate the contrast and the color difference of a plume and its viewing background. Because VISCREEN is to be used for screening calculations, it was designed to be conservative (i.e., to overpredict potential plume visual impacts). Therefore, VISCREEN calculates larger plume visual impacts, for the same input specifications, than do more sophisticated models such as PLUVUE and PLUVUE II.

VISCREEN is designed to operate on the simplest and most modestly equipped IBM PC or compatible. It will operate with 256K memory. It will utilize a math coprocessor, if installed, with substantial improvement in execution speed. VISCREEN is coded in FORTRAN 77. A listing of the source code is presented in Appendix D. Figure B-1 schematically illustrates the logic flow of VISCREEN. Each of the major calculation steps in VISCREEN is described, in succession, in the following sections.

INPUT

Because VISCREEN is designed to be straightforward, the input requirements have been scaled down to the minimum necessary to describe the variety of emissions, meteorological and background conditions, and the plume/observer geometries an analyst is likely to encounter in Level-1 and -2 plume visual impact screening. Input is requested by screen prompts.

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* See Latimer et al. (1978) and Latimer and Ireson (1980) for derivations of many of the VISCREEN descriptions and algorithms.

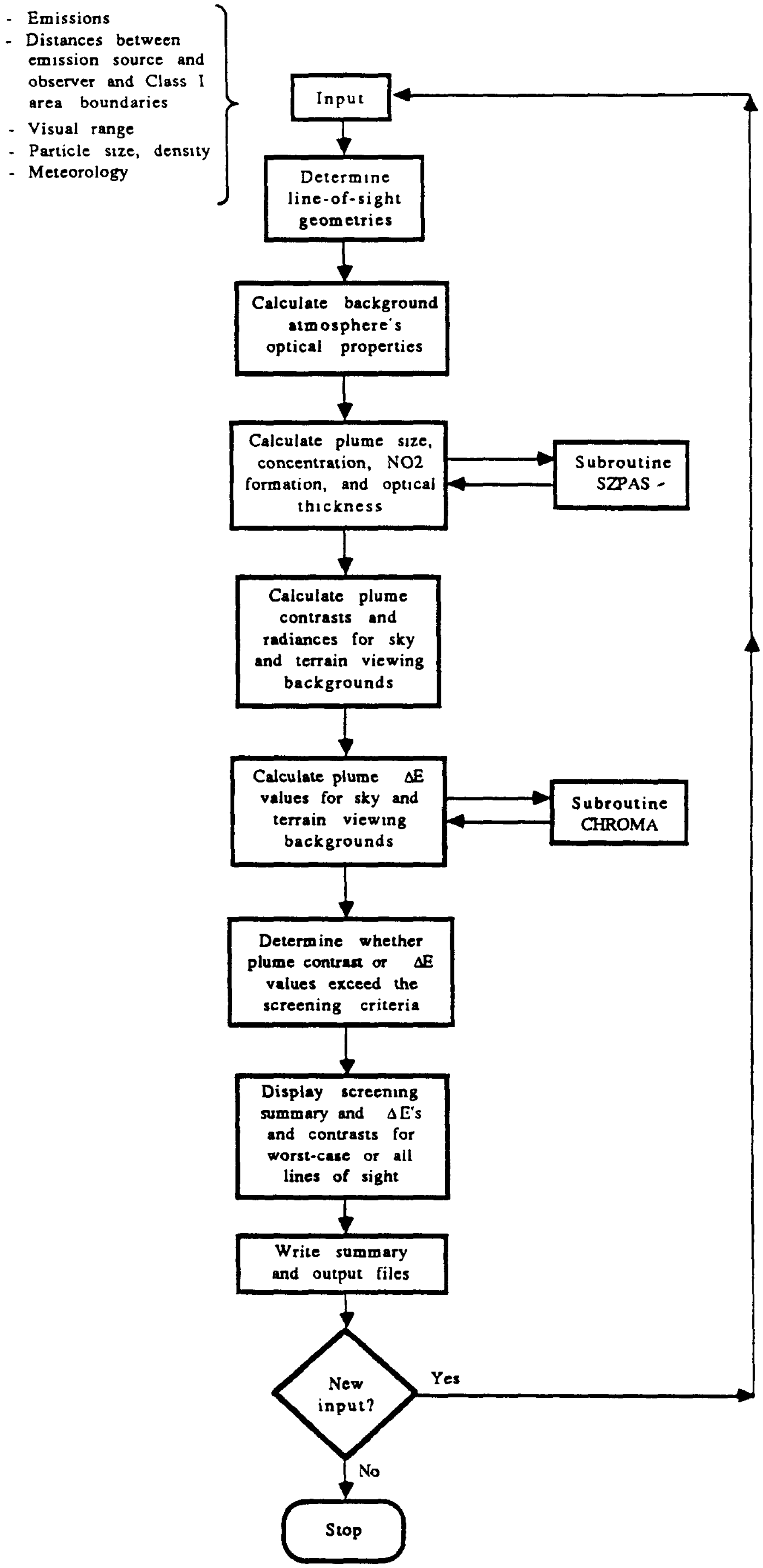


FIGURE B-1. Logic flow diagram of the plume visual impact screening model (VISCREEN).

VISCREEN first requests names for two disk files that will be created. The summary file presents an abbreviated summary of inputs and screening results. The results file contains all inputs used in the analysis, as well as geometry, ΔE, and contrast calculations for each line of sight and wavelength. This file is designed to allow its use as input to user-developed graphics routines or commercially available spreadsheet programs.

The second set of inputs describes the emissions. The user is given a choice of units to input mass emission rates of various species that are likely to cause visual effects. The units of these emission rates are mass per unit time. Mass can be specified in metric units (grams, kilograms, metric tonnes) or in English units (pounds or tons). Time can be specified in seconds, minutes, hours, days, or years. The emission rate, whatever the units used, should be the maximum short-term (i.e., hour) emission rate likely to occur in the course of operation of the emission source. The emissions that almost all analyses will consider are particulates and nitrogen oxides (NO_x); however, VISCREEN will also allow the user to input such species as (1) primary nitrogen dioxide (NO_2) if this species is directly emitted by the given chemical process, (2) primary sulfate ($SO_4^=$) if this species is directly emitted or if a second particle size mode needs to be specified, and (3) elemental carbon (soot) if the emission source is a diesel engine or other source with incomplete combustion. However, for the vast majority of commonly encountered emission sources involving either fugitive emissions or combustion emissions, the analyst would only have to input particulate and NO_x emissions.

The third set of inputs contains the distances that characterize the viewing situation. The first is the distance between the emission source and the observer. The next two are the distances along the plume centerline from the emission source to the closest and most distant Class I area boundaries. Finally, the background visual range distance is specified.

The next set of inputs is requested only if the user indicates that the default specifications built into VISCREEN (see Table B-1) are not acceptable for a given screening analysis. These include the particle size and density for the emitted particulate and primary sulfate and for background fine and coarse particulate, the background ozone concentration (used to calculate NO to NO_2 conversion in the plume), wind speed, atmospheric stability class, and the offset angle between the plume centerline and the line between the emission source and the observer. For Level-1 analyses, the default parameters would be used, and none of the above inputs would need to be specified. In most Level-2 analyses the default particle size and density specifications would be acceptable; only the meteorological input specifications would have to be changed from the Level-1 default values.

TABLE B-1. Default specification for VISCREEN.

Particle Specifications		
Type	Mass Median Diameter D (μm)	Density ρ(g/cm^3)
Background fine	0.3	1.5
Background coarse	6	2.5
Plume particulate	2	2.5
Plume sulfate	0.5	1.5
Plume soot	0.1	2

Wind speed = 1 m/s

Stability = F

Background [O_3] = 0.04 ppm

Plume offset angle γ = 11.25°

VISCREEN summarizes the inputs after specification and allows the user to correct mistakes before proceeding. If necessary, emission rates are converted to grams per second.

GEOMETRY OF PLUME, OBSERVER, CLASS I AREA, VIEWING BACKGROUND, AND LINES OF SIGHT

The next section of VISCREEN computes the angles and distances that describe a variety of lines of sight relevant to the given situation. Figure 7 (in the main text) illustrates the set of lines of sight and geometries for a typical Level-1 and -2 screening calculation. Figure B-2 summarizes the angles and distances that describe a single line of sight. The plume is always assumed to be 22.5° wide, and the viewing background is always assumed to be adjacent to the plume on the side of the plume centerline opposite the observer. VISCREEN computes plume visual impacts for lines of sight at 5° increments for the azimuthal angle ϕ and for lines of sight corresponding to distance x (along the plume centerline) of 1 kilometer, and x_{min} and x_{max} (the distances along the plume centerline from the emission source to the closest and most distant Class I area boundaries). The angle α and the distances r_p and r_o are needed for all subsequent plume visual impact calculations. These parameters can be solved for by noting the following relationships that hold for all triangles: (1) the sum of the three interior angles equals 180° and (2) the ratio of the length of a triangle leg to the sine of the opposite angle is equal for all three legs of the triangle.

For the lines of sight where ϕ is known, angle α can be solved directly as follows:

$$\alpha = 180^{\circ} - \gamma - \phi \quad .$$

Since

$$\frac{d}{\sin \alpha} = \frac{x}{\sin \phi} = \frac{r_p}{\sin \gamma} \quad ,$$

$$x = \left(\frac{\sin \phi}{\sin \alpha}\right) d$$

$$r_p = \left(\frac{\sin \gamma}{\sin \alpha}\right) d$$

For lines of sight where x is known, angle ϕ must be calculated as follows:

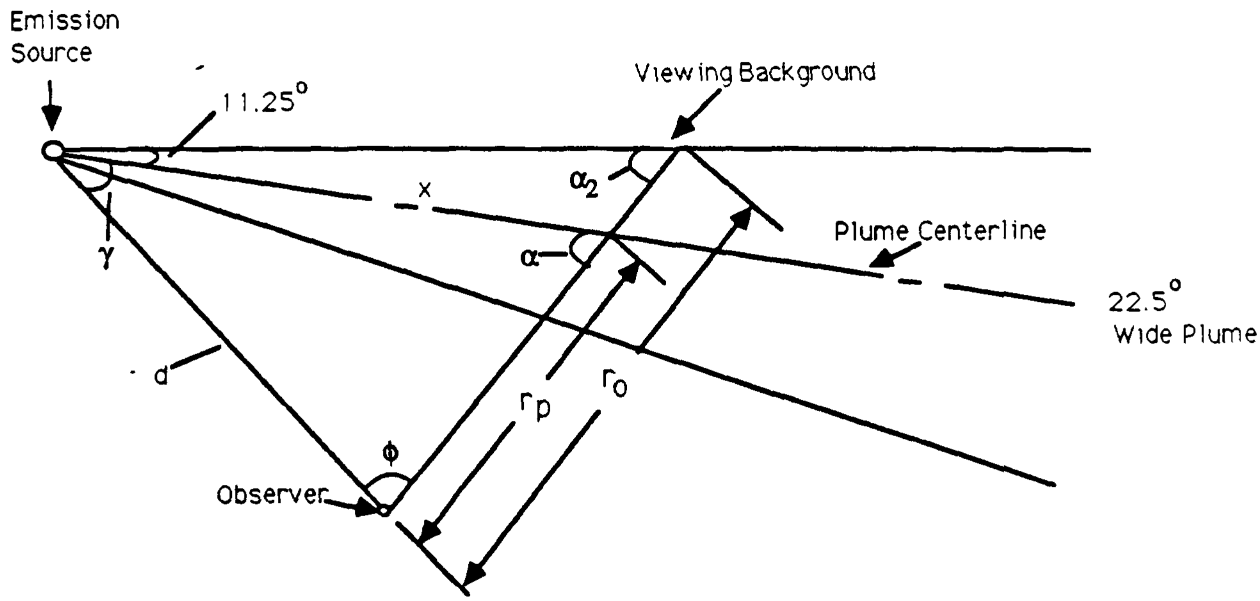


FIGURE B-2. Distances and angles that specify a given line of sight.

$$\phi = \tan^{-1} \frac{x \sin \gamma}{d - x \cos \gamma}$$

Similar calculations are used to determine the distance r_0.

The plume offset angle γ is set to be equal to 11.25° for all Level-1 screening calculations, and most Level-2 screening analyses will be performed for such a plume offset. VISCREEN can be run for any arbitrary offset angle between 0 and 180°; however, angles less than 11.25° and greater than 168.75° are not recommended because these plume positions, which are extremely rare, result in lines of sight along the plume axis that are not calculated with precision using the assumptions coded in VISCREEN.

OPTICAL PROPERTIES OF THE BACKGROUND ATMOSPHERE

The optical properties of the background atmosphere are then calculated for each of the three wavelengths used in VISCREEN: 0.45, 0.55, and 0.65 μm. These optical properties include the extinction coefficient and the phase function for the forward and backward scatter sun angles assumed in the screening process. Sun angles are defined by the scattering angle θ, which is the angle between the line of sight and the direct solar beam. VISCREEN uses two scattering angles--10 and 140°--to calculate potential plume visual impacts for cases where plumes are likely to be brightest (θ = 10°) and darkest (θ = 140°). Figure B-3 and Table B-2 show typical phase functions for these two worst-case sun angles for typical size distributions. The differences between phase functions for given particle size distributions and pure air (Rayleigh scattering) are greatest in forward scatter (10° is a reasonable estimate of a worst-case bright plume situation) and in back scatter (140° is a reasonable estimate of a worst-case dark plume situation).

The scattering coefficient caused by particles is determined by subtracting the Rayleigh scattering coefficient:

$$b_{sp}(\lambda = 0.55\ \mu m) = b_{scat}(\lambda = 0.55) - b_R(\lambda = 0.55) \quad ,$$

where $b_R(\lambda = 0.55\ \mu m) = 11.62 \times 10^{-6} m^{-1}$.

On the basis of the data of Whitby and Sverdrup (1978) and calculations of Latimer et al. (1978), the fraction of b_{sp} caused by coarse particles is assumed to be 0.33. Thus, we have

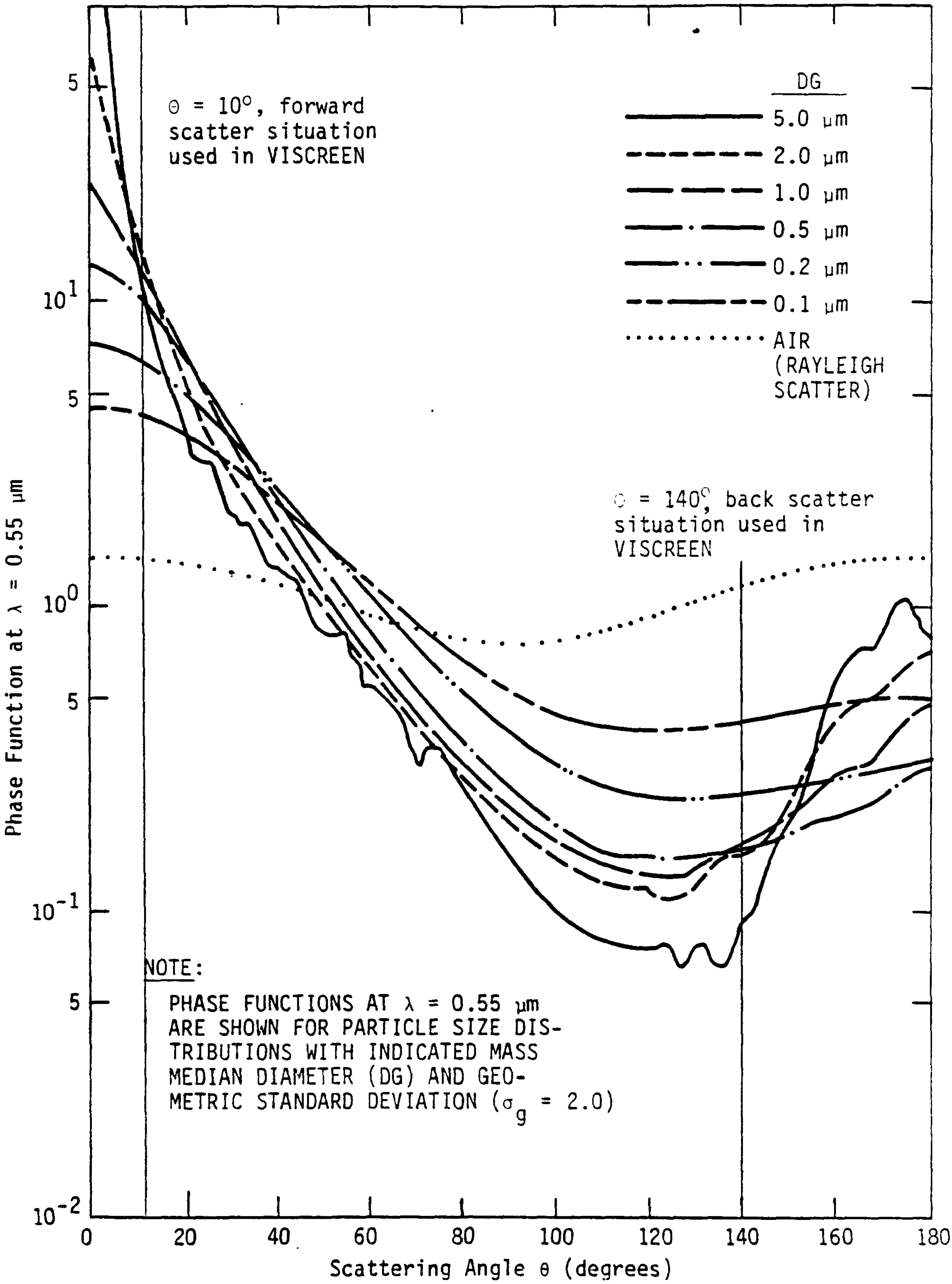


FIGURE B-3. Phase functions for various particle size distributions.

TABLE B-2. Atmospheric optical parameters for various particle size distributions used in VISCREEN.

Particle Size Index	Mass Median Diameter D(μm)	n	b_{scat}/V (m^2/cm^3)	Phase Functions $p(\theta,\lambda)$: Blue (λ = 0.4 μm)		Green (λ = 0.55 μm)		Red (λ = 0.7 μm)	
				θ = 10°	θ = 140°	θ = 10°	θ = 140°	θ = 10°	θ = 140°
1	0.1	2.8	1.7	5.17	0.330	4.24	0.429	3.64	0.517
2	0.2	2.1	4.5	7.76	0.199	0.49	0.247	5.62	0.296
3	0.3	1.6	6.0	9.61	0.172	8.11	0.193	7.14	0.219
4	0.5	1.0	6.7	11.94	0.169	10.33	0.165	9.27	0.175
5	1.0	0.2	5.0	15.09	0.174	13.64	0.166	12.54	0.170
6	2.0	0	2.6	15.84	0.143	16.07	0.156	15.47	0.170
7	5.0	0	0.9	10.98	0.082	13.64	0.094	14.83	0.136
8	6.0	0	0.8	8.39	0.064	11.67	0.085	12.83	0.106
9	10.0	0	0.4	7.28	0.046	9.23	0.055	10.55	0.075

$$b_{sp\text{-}submicron} = 0.67\ b_{sp} \quad ,$$

$$b_{sp\text{-}coarse} = 0.33\ b_{sp} \quad .$$

The phase function for each of the scattering components can now be determined. Phase functions for the submicron and coarse background aerosols are specified in Table B-2.

The Rayleigh scattering phase function (for air) is a function of the scattering angle θ, but it is independent of wavelength λ and can be approximated quite well by the following relationship:

$$p(\theta) = 0.75\ [1 + (\cos\theta)^2] \quad .$$

The scattering coefficients at different wavelengths (i.e., $\lambda = 0.45$ and $0.65\ \mu m$) can be determined from the relationship:

$$b_{sp}(\lambda) = b_{sp}(\lambda = 0.55\ \mu m) \left(\frac{\lambda}{0.55\ \mu m}\right)^{-n} \quad ,$$

where values of n are given in Table B-2 for various particle size distributions and $n = 4.1$ for Rayleigh scatter.

The average background atmosphere phase functions are calculated for each wavelength λ and scattering angle θ as follows:

$$p(\lambda,\theta)\Big|_{background} = \frac{\sum b_{sp}(\lambda)\ p(\lambda,\theta)}{\sum b_{sp}(\lambda)} \quad .$$

PLUME DISPERSION, NO_2 FORMATION, AND OPTICAL CONDITIONS

The plume is treated as a Gaussian distribution in the vertical and a uniform distribution in the horizontal over the width of the 22.5° sector. The line of sight is always assumed to be horizontal in VISCREEN; thus, optical thickness is calculated as follows:

$$\tau_{plume} = \frac{\sum_i Q_i \left(\frac{b_{ext}}{V}\right)_i \rho_i + Q_{NO_2}\ \frac{b_{ext}}{M}}{(2\pi)^{1/2}\ \sigma_z\ u \sin\alpha}$$

where the summation is over all particles (particulate, $SO_4^=$, and soot), b_{ext}/V is the light extinction efficiency per unit aerosol volume, and b_{ext}/M is the light extinction efficiency per unit mass of NO_2.

The amount of NO_2 in the plume is calculated by assuming that 10 percent of initial NO is converted to NO_2 via the reaction with O_2 and the rest is titrated with ambient O_3. For conservatism, the solar photodissociation of NO_2 and the further reaction of NO_2 to form HNO_3 (realistic assumptions for stable plume conditions near sunrise) are ignored. In this conversion the plume concentration of NO_x is calculated as follows:

$$[NO_x] = \frac{Q_{NO_x}}{(2\pi)^{1/2}\,\sigma_z u \left[2 \tan\left(\frac{22.5}{2}\right) x\right]} \quad .$$

NO_2 concentrations in the plume are calculated as follows:

$$[NO_2] = \begin{cases} h + [NO_2]_P \quad , & \text{if } [NO_x] \geq h \\ [NO_x] + [NO_2]_P \quad , & \text{if } [NO_x] < h \end{cases} \quad ,$$

where

$[NO_2]$ = plume centerline NO_2 concentration,
h = $0.1\ [NO_x] + [O_3]$,
$[NO_2P]$ = primary (directly emitted) NO_2
$[O_3]$ = background ozone concentration

The scattering efficiency for each particle size mode is taken from the b_{scat}/V shown in Table B-2. Scattering at different wavelengths is scaled using the parameter n (also shown in Table B-2) as follows:

$$\frac{b_{scat}}{V}(\lambda) = \frac{b_{scat}}{V}\ (\lambda = 0.55\ \mu m) \left(\frac{\lambda}{0.55}\right)^{-n}$$

The light absorption efficiency for NO_2 was taken by averaging efficiencies centered on the three wavelengths (λ = 0.45, 0.55, 0.65 μm) to obtain the following light absorption efficiencies: 0.691, 0.144, and 0.015 m^2/g. The light absorption efficiency of soot was assumed to be 10 m^2/g for all wavelengths.

To avoid gross overestimates of plume optical thickness (and potential division by zero) for small α's, the minimum α is assumed to be 5°. The effect of limited persistence of worst-case stable meteorological conditions is treated in VISCREEN by assuming that input stable dispersion conditions (with stability categories of E and F) persist for a maximum of 12 hours. For plume parcels located in positions that would require longer transport times, additional dispersion is assumed by increasing the wind speed for the given plume parcel so that the transport time exactly equals 12 hours. This is a crude way of accounting for stable plume breakup after long transport times. Plumes with stability classes of A, B, C, or D are assumed to persist for all transport times including those greater than 12 hours.

PLUME CONTRAST

The contrast of the plume against sky and black terrain viewing backgrounds is calculated conservatively by considering single scattering and ignoring multiple scattering (Latimer and Ireson, 1980) as follows:

Plume Contrast

$$C_{plume} = \left[\frac{(\bar{p}\bar{\omega})_{plume}}{(\bar{p}\bar{\omega})_{background}} - 1\right]\left[1 - \exp(-\tau_{plume})\right]\left[\exp(-b_{ext}r_p)\right] \quad .$$

Reduction in Sky/Terrain Contrast Caused by Plume

$$\Delta C_r = \exp(-b_{ext}r_o)\left[1 - \left(\frac{1}{C_{plume} + 1}\right)\exp(\tau_{plume})\right] \quad ,$$

where

$\bar{p}_{plume}$, $\bar{p}_{background}$ $\equiv$ average phase functions for plume and background atmosphere, respectively. $\bar{p}$ is a function of λ and Θ,

$\bar{\omega}_{plume}$ = ratio of light scattering to light extinction in plume

$\bar{\omega}_{background}$ = 1 (assuming no absorption)

These contrast values are calculated for each wavelength (λ = 0.45, 0.55, and 0.65 μm) and each scattering angle (θ = 10 and 140°).

Light intensities for later use in calculating the color difference parameter ΔE are calculated from the contrast values as follows:

The sky background light intensity for each scattering angle (θ) and wavelength of light (λ) is calculated as follows:

$$I_{sky} = \frac{F_s(\lambda)\ p(\lambda,\ \theta)}{4\pi}$$

where $F_s(\lambda)$ is the radiant flux from the sun (see Glossary in front of Workbook).

Similarly, a white reference is

$$I_o = \frac{F_s(\lambda)}{2\pi} \quad .$$

The light intensity of the plume against the sky is (Latimer et al., 1978):

$$I_{plume-sky} = (1 + C_{plume})\ I_{sky} \quad .$$

The light intensity of the terrain background (assumed to be black) viewed at distance r_o is

$$I_{terrain} = (1 - \exp(-b_{ext}\ r_o)\ \ I_{sky} \quad .$$

The light intensity of the plume viewed against the dark terrain viewing background is then

$$I_{plume\ terrain} = I_{terrain} + \Delta C_r\ I_{sky} \quad .$$

PLUME ΔE VALUES

The color difference parameter ΔE is calculated from the three light intensities using the following equation:

$$\Delta E(L^*a^*b^*) = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^{*2}]^{1/2}$$

where

$$L^* = 116\ (Y/Y_O)^{1/3} - 16\ ,$$

$$a^* = 500 \left[\left(\frac{X}{X_O} \right)^{1/3} - \left(\frac{Y}{Y_O} \right)^{1/3} \right] ,$$

$$b^* = 200 \left[\left(\frac{Y}{Y_O} \right)^{1/3} - \left(\frac{Z}{Z_O} \right)^{1/3} \right] ,$$

$$X_O = \sum_{i=1}^{3} I_O(\lambda_i)\ \bar{x}_i\ ,$$

$$Y_O = \sum_{i=1}^{3} I_O(\lambda_i)\ \bar{y}_i\ ,$$

$$Z_O = \sum_{i=1}^{3} I_O(\lambda_i)\ \bar{z}_i\ ,$$

$$X = \sum_{i=1}^{3} I(\lambda_i)\ \bar{x}_i\ ,$$

$$Y = \sum_{i=1}^{3} I(\lambda_i)\ \bar{y}_i\ ,$$

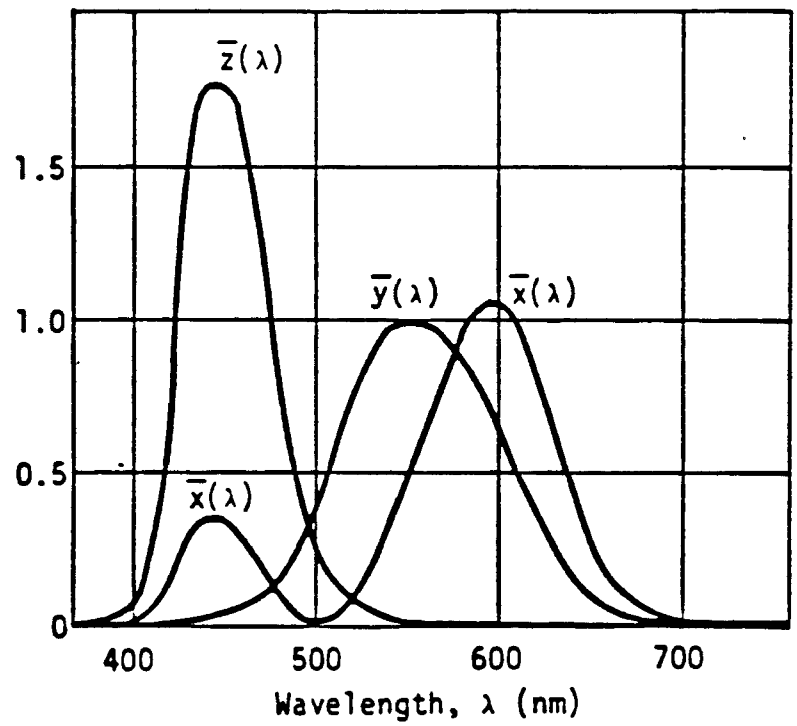
$$Z = \sum_{i=1}^{3} I(\lambda_i)\ \bar{z}_i\ .$$

In these equations, the tristimulus values X_O, Y_O, Z_O define the color of the nominally white object-color stimulus from a perfectly diffuse reflector normal to the direct solar beam (I_o defined above). Calculations are normalized such that Y_o equals a typical midday illumination of 100 candle/m^2 and $X_o \approx Z_o \approx 100$ candle/m^2. The ΔL*, Δa*, and Δb* refer to the difference in these three functions between the plume and its viewing background (either sky or terrain).

The three chromaticity tristimulus weighting functions $\bar{x}\ \bar{y}\ \bar{z}$ were determined for each of the wavelengths by averaging the values shown in Figure B-4 over the wavelengths centered on λ = 0.45, 0.55, and 0.65 µm. These average weighting factors and other parameters used in VISCREEN are summarized in Table B-3.

COMPARISON OF CALCULATIONS WITH SCREENING CRITERIA

The calculated contrast and ΔE values are compared to the default screening criteria described in Appendix A (i.e., ΔE = 2, contrast = 0.05, and the Howell and Hess curve for diffuse-edge objects) or to user-specified criteria. The vertical plume dimension for each line of sight is calculated using the following formula:



Source: Judd and Wyszecki (1975).

FIGURE B-4. Weighting values $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$.

TABLE B-3. Average chromaticity tristimulus weighting functions, NO_2 light absorption efficiency, and solar flux used in VISCREEN.

Parameter	Wavelength λ		
	Blue, 0.45 μm (0.36-0.50 μm)	Green, 0.55 μm (0.51-0.60 μm)	Red, 0.65 μm (0.61-0.74 μm)
$\bar{x}$	0.1196	0.6317	0.1838
$\bar{y}$	0.0935	0.8229	0.0753
$\bar{z}$	0.7012	0.0159	0.0000
b_{abs_2} - NO_2/M (m^2/g)	0.691	0.144	0.015
F_s (watt m^{-2} sr^{-1})	1712	1730	1414

$$\psi = \tan^{-1} \frac{4.3\ \sigma_z}{r_p}$$

This plume width is used with the diffuse-edge curve in Figure A-2 to determine the minimum perceptible contrast. The green (λ = 0.55 μm) plume contrast for each scattering angle and viewing background is then compared to this minimum perceptible contrast and the screening contrast threshold of 0.05. A secondary test is made by comparing the plume ΔE with the minimum perceptible ΔE and the screening ΔE of 2. If the plume contrast is greater than both contrast values, or the plume ΔE is greater than both ΔE thresholds, the given line of sight fails the screening test. To find the minimum perceptible ΔE, the equivalent ΔE is calculated for an object having the minimum perceptible (Howell and Hess) contrast from the sky and the terrain viewing backgrounds (see Appendix A). This approach is believed to provide a conservative underestimate of threshold ΔE, especially for dark terrain viewing backgrounds for which higher contrasts may be needed to distinguish a plume.

OUTPUT

VISCREEN generates a summary file and a results file in addition to the screen display during a user's sessions. The files store the inputs and results to provide the user with a record of a run. The user is queried by VISCREEN for the names of the files.

The summary file (see Figure 16) is designed to provide a concise, single-page summary of the inputs and the results of a run. Only the user-supplied inputs are provided; defaults are not printed to save space. The results included in the summary file display maximum visual impacts inside and outside of the Class I area, with any screening criteria exceedances indicated. Format of the summary file is self-explanatory.

The results file contains all inputs and results that may be used for other analyses. The format of the results file is designed to allow the file to be imported into commercially available spreadsheet programs. In this way, users can design their own tabular and graphical displays of VISCREEN results. The content and output formats for the results file are provided in Table B-4. There are three sections to the file. The first section (records 1 through 11) contains the inputs for the run. Section two (records 12 and 13+) contains the number of lines of sight (record 12, included so that a user-developed program can know how many records of information to read), followed by one record for each line of sight (LOS). These LOS records include LOS geometry information, screening threshold, and ΔE values. The final section is similar to the second, in that it

Table B-4. Output format for the VISCREEN results file

Record No.	Contents	Format
1	Source name	A
2	Class I area name	A
3	Mass unit	I5
	= 1 grams	
	= 2 kilograms	
	= 3 metric tonnes	
	= 4 pounds	
	= 5 tons	
	Time flag	I5
	= 1 seconds	
	= 2 minutes	
	= 3 hours	
	= 4 days	
	= 5 years	
4	Particulate emission rate	F10.3
	NOx emission rate	F10.3
	NO_2 emission rate	F10.3
	Soot emission rate	F10.3
	SO_4 emission rate	F10.3
5	Source-Observer distance	F10.3
	Min. Source-Class I distance	F10.3
	Max. Source-Class I distance	F10.3
	Background visual range	F10.3
6	Default flag	I5
	= 1 used default value	
	= 0 user input value	
	Background Fine Particulate Density (g/cm3)	F10.3
	Background Fine Particulate Size index (um)	I5
	= 1 0.1	
	= 2 0.2	
	= 3 0.3	
	= 4 0.5	
	= 5 1.0	
	= 6 2.0	
	= 7 5.0	
	= 8 6.0	
	= 9 10.0	
7	Default flag	I5
	Background Coarse Particulate density	F10.3
	Background Coarse Particulate size index	I5

Table B-4 (concluded). Output format for the VISCREEN results file

Record No.	Contents	Format
8	Default flag	I5
	Plume Particulate density	F10.3
	Plume Particulate size index	I5
9	Default flag	I5
	Plume Soot density	F10.3
	Plume Soot size index	I5
10	Default flag	I5
	Plume Primary SO_4 density	F10.3
	Plume Primary SO_4 size index	I5
11	Default flag	I5
	Background Ozone (ppm)	F10.3
	Wind speed (m/s)	F10.3
	Stability index	I5
11A	(Record not included in Level-1 runs)	
	Default flag, plume offset angle	I5,F10.3
12	Number of lines of sight	I5
13+	Line of sight (LOS)	1X,I2
	LOS classification	I2
	= 0 outside Class I area	
	= 1 inside Class I area	
	Azimuthal angle	F8.1
	Angle between LOS and plume	F7.1
	Source-observed plume distance	F7.1
	Observer-observed plume distance	F7.1
	Observer-terrain distance behinde plume	F7.1
	PSI	F5.2
	Green Contrast threshold	F7.3
	Screening threshold and delta E for:	
	sky, forward scatter	2F7.2
	sky, backward scatter	2F7.2
	terrain, forward scatter	2F7.2
	terrain, backward scatter	2F7.2
14	Number of lines of sight	I5
15+	Line of sight number	1X,I2
	LOS classification	I2
	Azimuthal angle	F8.3
	Green Contrast threshold	F7.3
	Green contrast for:	
	forward scatter, sky and terrain background	2F7.3
	backward scatter, sky and terrain background	2F7.3
	Blue contrast (as for green)	4F7.3
	Red contrast (as for green)	4F7.3

Note: Records 13+ and 15+ are repeated for each line of sight.

begins with the number of LOS's, and is followed by one record for each LOS. These contain LOS identifiers, the green contrast screening criterion, and green, blue and red contrast values for each line of sight and viewing background. Figure B-5 shows an example of a complete results file.

CONSERVATISM OF VISCREEN

VISCREEN is designed for use in Level-1 and -2 plume visual impact screening calculations. The objective of the screening exercise is to identify emission sources that have the potential to cause adverse visibility impairment. Because these sources can be analyzed further (with more sophisticated models) in a more detailed manner (e.g., using Level-3 analysis), the screening model should yield output that is consistently conservative. That is, it should calculate plume visual impacts that are likely to be greater than those that would actually be encountered and those that would be calculated in Level-3 analysis. This conservatism is necessary to avoid approving an emission source that passes a screening test, but could have problems that would be revealed by a more detailed analysis. It also eliminates the need for facilities with negligible effects to carry out more complicated and costly assessments.

VISCREEN was designed to be conservative by making the following model assumptions:

1. It is assumed that the line of sight is horizontal so that it intersects the most plume material. Nonhorizontal lines of sight intersect less plume material because horizontal dispersion of plumes exceeds vertical dispersion, especially under stable conditions.

2. NO_2 conversion is conservatively treated by assuming the plume is uniformly mixed in the 22.5° sector. This enhanced dispersion mixes the plume with more ambient O_3, resulting in greater conversion. However, the assumed enhanced dispersion does not decrease the line-of-sight integral of plume material for the assumed horizontal viewing conditions. Only the vertical dimensions of the plume determine the magnitude of the plume material that intersects the horizontal line of sight.

3. Worst-case sun (scattering) angles are assumed. The forward scatter case (θ = 10°) yields very bright plumes because the sun is placed nearly directly in front of the observer. This geometry would rarely occur in reality. The backward scatter case (θ = 140°) yields the darkest possible plumes. Thus, the

```
'Public Electric Coal #3 '
'Longview NP             '
    1    1
    10.000    120.000        .000        .000        .000
    80.000     80.000    120.000    110.000
    1      1.500     3
    1      2.500     8
    1      2.500     6
    1      2.000     1
    1      1.500     4
    1       .040      1.000     6
    1     11.250
 34
  1 0     5.0  163.8   24.9   55.8   66.3  .29   .050   2.00   2.29   2.00   1.42   2.00   3.41   2.00   1.20
  2 0    10.0  158.8   38.3   43.1   57.0  .42   .050   2.00   3.70   2.00   1.62   2.00   3.18   2.00   1.03
  3 0    15.0  153.8   46.8   35.3   50.3  .55   .050   2.00   4.78   2.00   1.97   2.00   2.86   2.00    .92
  4 0    20.0  148.8   52.7   30.1   45.3  .66   .050   2.00   5.29   2.00   2.26   2.00   2.55   2.00    .87
  5 0    25.0  143.8   57.2   26.4   41.5  .77   .050   2.00   5.55   2.00   2.47   2.00   2.38   2.00    .87
  6 0    30.0  138.8   60.7   23.7   38.6  .87   .050   2.00   5.65   2.00   2.60   2.00   2.27   2.00    .88
  7 0    35.0  133.8   63.5   21.6   36.3  .96   .050   2.00   5.66   2.00   2.66   2.00   2.18   2.00    .87
  8 0    40.0  128.8   65.9   20.0   34.5 1.04   .050   2.00   5.61   2.00   2.68   2.00   2.11   2.00    .86
  9 0    45.0  123.8   68.0   18.8   33.1 1.12   .050   2.00   5.53   2.00   2.68   2.00   2.04   2.00    .84
 10 0    50.0  118.8   69.9   17.8   32.1 1.19   .050   2.00   5.43   2.00   2.66   2.00   1.98   2.00    .82
 11 0    55.0  113.8   71.6   17.1   31.4 1.25   .050   2.00   5.32   2.00   2.62   2.00   1.91   2.00    .79
 12 0    60.0  108.8   73.2   16.5   30.9 1.30   .050   2.00   5.22   2.00   2.58   2.00   1.84   2.00    .76
 13 0    65.0  103.8   74.6   16.1   30.6 1.34   .050   2.00   5.11   2.00   2.54   2.00   1.78   2.00    .73
 14 0    70.0   98.8   76.1   15.8   30.6 1.37   .050   2.00   5.01   2.00   2.50   2.00   1.71   2.00    .70
 15 0    75.0   93.8   77.4   15.6   30.9 1.38   .050   2.00   4.91   2.00   2.45   2.00   1.64   2.00    .66
 16 0    80.0   88.8   78.8   15.6   31.4 1.39   .050   2.00   4.82   2.00   2.41   2.00   1.56   2.00    .63

 17 1    85.0   83.8   80.2   15.7   32.1 1.39   .050   2.00   4.73   2.00   2.36   2.00   1.48   2.00    .59
 18 1    90.0   78.8   81.6   15.9   33.1 1.37   .050   2.00   4.64   2.00   2.32   2.00   1.40   2.00    .55
 19 1    95.0   73.8   83.0   16.3   34.5 1.35   .050   2.00   4.55   2.00   2.26   2.00   1.32   2.00    .50
 20 1   100.0   68.8   84.5   16.7   36.3 1.32   .050   2.00   4.45   2.00   2.21   2.00   1.22   2.00    .46
```

FIGURE B-5. Example results file.

21	1	105.0	63.8	86.2	17.4	38.6	1.27	.050	2.00	4.35	2.00	2.14	2.00	1.13	2.00	.41
22	1	110.0	58.8	87.9	18.3	41.5	1.22	.050	2.00	4.23	2.00	2.07	2.00	1.02	2.00	.35
23	1	115.0	53.8	89.9	19.4	45.3	1.15	.050	2.00	4.08	2.00	1.98	2.00	.91	2.00	.29
24	1	120.0	48.8	92.1	20.8	50.3	1.08	.050	2.00	3.90	2.00	1.87	2.00	.79	2.00	.23
25	1	125.0	43.8	94.8	22.6	57.0	1.00	.050	2.00	3.67	2.00	1.73	2.00	.67	2.00	.18
26	1	130.0	38.8	97.9	24.9	66.3	.91	.050	2.00	3.38	2.00	1.56	2.00	.53	2.00	.13
27	1	135.0	33.8	101.8	28.1	80.0	.81	.050	2.00	3.00	2.00	1.35	2.00	.38	2.00	.09
28	1	140.0	28.8	106.9	32.4	101.8	.71	.050	2.00	2.51	2.00	1.09	2.00	.22	2.00	.06
29	1	145.0	23.8	113.9	38.8	141.4	.60	.050	2.00	1.91	2.00	.80	2.00	.07	2.00	.02
30	0	150.0	18.8	124.4	48.6	234.5	.49	.050	2.00	1.22	2.00	.50	2.00	.00	2.00	.00
31	0	155.0	13.8	142.2	65.7	701.9	.37	.050	2.00	.55	2.00	.28	2.00	.00	2.00	.00
32	0	.1	168.6	1.0	79.0	79.5	.04	.109	6.13	5.37	2.60	1.33	5.99	5.19	2.56	1.92
33	1	84.4	84.4	80.0	15.7	32.0	1.39	.050	2.00	4.74	2.00	2.37	2.00	1.49	2.00	.59
34	1	148.2	20.6	120.0	44.4	156.9	.53	.050	2.00	1.48	2.00	.60	2.00	.05	2.00	.01

34

1	0	5.000	.050	-.006	.043	-.055	.040	-.026	.021	-.036	.020	.040	.047	-.035	.037
2	0	10.000	.050	-.008	.044	-.064	.038	-.045	.030	-.064	.029	.040	.045	-.035	.031
3	0	15.000	.050	-.008	.042	-.064	.034	-.059	.035	-.084	.035	.036	.041	-.031	.025
4	0	20.000	.050	-.007	.038	-.059	.029	-.065	.037	-.092	.036	.031	.036	-.027	.020
5	0	25.000	.050	-.006	.035	-.054	.025	-.068	.038	-.097	.036	.027	.033	-.024	.017
6	0	30.000	.050	-.006	.033	-.051	.022	-.069	.038	-.098	.036	.024	.031	-.021	.015
7	0	35.000	.050	-.006	.031	-.048	.020	-.069	.038	-.098	.035	.022	.029	-.019	.013
8	0	40.000	.050	-.005	.029	-.045	.018	-.068	.037	-.097	.033	.021	.027	-.018	.012
9	0	45.000	.050	-.005	.028	-.043	.017	-.067	.036	-.096	.032	.019	.026	-.017	.011
10	0	50.000	.050	-.005	.026	-.041	.015	-.066	.034	-.094	.030	.018	.024	-.016	.010
11	0	55.000	.050	-.005	.025	-.039	.014	-.065	.033	-.092	.029	.017	.023	-.015	.010
12	0	60.000	.050	-.004	.024	-.037	.013	-.064	.032	-.090	.028	.016	.022	-.014	.009
13	0	65.000	.050	-.004	.023	-.036	.013	-.062	.031	-.088	.026	.016	.022	-.014	.009
14	0	70.000	.050	-.004	.022	-.035	.012	-.061	.029	-.087	.025	.015	.021	-.013	.008
15	0	75.000	.050	-.004	.021	-.034	.012	-.060	.028	-.085	.024	.015	.020	-.013	.008
16	0	80.000	.050	-.004	.021	-.034	.011	-.059	.027	-.083	.023	.015	.019	-.013	.008
17	1	85.000	.050	-.004	.020	-.033	.011	-.058	.025	-.082	.022	.014	.019	-.013	.007
18	1	90.000	.050	-.004	.019	-.033	.010	-.057	.024	-.080	.020	.014	.018	-.012	.007
19	1	95.000	.050	-.004	.018	-.032	.010	-.056	.022	-.079	.019	.014	.017	-.012	.007
20	1	100.000	.050	-.004	.017	-.032	.010	-.054	.020	-.077	.018	.014	.017	-.012	.007

FIGURE B-5 Continued

21	1	105.000	.050	-.004	.016	-.032	.009	-.053	.018	-.075	.016	.014	.016	-.012	.007
22	1	110.000	.050	-.004	.015	-.031	.009	-.052	.016	-.073	.014	.014	.015	-.012	.006
23	1	115.000	.050	-.004	.013	-.031	.008	-.050	.014	-.071	.012	.014	.014	-.012	.006
24	1	120.000	.050	-.004	.012	-.031	.007	-.048	.011	-.068	.010	.014	.012	-.012	.006
25	1	125.000	.050	-.004	.010	-.030	.006	-.045	.008	-.064	.007	.014	.011	-.012	.005
26	1	130.000	.050	-.003	.007	-.029	.005	-.042	.005	-.059	.005	.014	.009	-.012	.004
27	1	135.000	.050	-.003	.005	-.028	.004	-.037	.003	-.053	.002	.014	.007	-.012	.003
28	1	140.000	.050	-.003	.002	-.026	.002	-.031	.001	-.044	.001	.014	.004	-.012	.002
29	1	145.000	.050	-.003	.001	-.023	.001	-.024	.000	-.034	.000	.013	.001	-.011	.001
30	0	150.000	.050	-.002	.000	-.018	.000	-.015	.000	-.021	.000	.011	.000	-.010	.000
31	0	155.000	.050	-.001	.000	-.011	.000	-.006	.000	-.009	.000	.008	.000	-.007	.000
32	0	.141	.109	.051	.050	-.037	.049	.006	.011	-.010	.011	.101	.102	-.059	.098
33	1	84.375	.050	-.004	.020	-.033	.011	-.058	.026	-.082	.022	.014	.019	-.013	.007
34	1	148.157	.050	-.002	.000	-.020	.000	-.018	.000	-.026	.000	.012	.001	-.010	.001

FIGURE B-5 Concluded

screening calculations are likely to yield the brightest and darkest possible plumes. It is left to more detailed PLUVUE modeling to identify realistic worst-case sun angles that would occur at specific times of interest.

4. Multiple scattering is ignored in VISCREEN. Light scattered into the line of sight from directions other than directly from the sun tend to slightly decrease the plume contrast for the worst-case sun angles assumed.

5. For terrain viewing backgrounds, the terrain is assumed to be black (the darkest possible) and located as close to the observer and the plume as possible. This assumption yields the darkest possible background against which particulate plumes are likely to be most visible. In reality, terrain viewing backgrounds (if indeed terrain is behind the plume) would be less dark and would be located farther from the observer.

6. Meteorological conditions are assumed to persist for at least 12 hours. After 12 hours, some additional dispersion is assumed in VISCREEN (by increased wind speeds), but the plume is still considered to remain intact. More realistic treatment of the persistence of worst-case dispersion conditions would most likely yield lower plume visual impacts.

7. Default meteorological conditions assumed for the most conservative Level-1 screening (F, 1 m/s, γ = 11.25°) are extreme and are expected to be more conservative than worst-case conditions identified in the more realistic Level-2 and -3 analyses.

8. The screening threshold (ΔE = 2; contrast of 0.05) was selected at the upper bound of the perceptibility threshold, representing a reasonable estimate for casual observers in the field.

Appendix C

EXAMPLES OF PLUME VISUAL-IMPACT SCREENING AND ANALYSIS

Appendix C

EXAMPLES OF PLUME VISUAL-IMPACT SCREENING AND ANALYSIS

The objective of this appendix is to assist the reader in understanding how specific screening and analyses might be carried out in different situations and at different levels of analysis. The detailed instructions provided in the text of this document are not repeated here. Rather, the examples are accompanied by limited commentary so that the reader obtains an overview of different plume visibility screening alternatives. Any application of plume visual-impact screening and analysis technology will differ depending on the circumstances of the given scenario.

This appendix provides examples of visibility screening and more detailed analyses for five different scenarios:

LEVEL-1 AND LEVEL-2 SCREENING

1. The first example that was presented in Latimer and Ireson (1980), a coal-fired power plant, for which Level-1 and -2 screening calculations were performed.

2. The second example that was presented in Latimer and Ireson (1980), a cement plant, for which Level-1 and -2 screening calculations were performed.

3. A paper mill located very close to a Class I area for which Level-1 and -2 screening calculations were performed.

LEVEL-3 ANALYSIS

4. A large coal-fired power plant located 90 km from a western national park, for which Level-1, -2, and -3 screening and analyses were carried out.

5. A very small emission source located extremely close to a western Class I area, for which all three levels of screening and analysis were performed.

EXAMPLE 1: COAL-FIRED POWER PLANT (1980 WORKBOOK EXAMPLE 1)

This example is based on a hypothetical coal-fired power plant proposed for a site approximately 70 km from a Class I PSD area in Nevada. The emission rates for this hypothetical power plant are projected to be 25 g/s of particulates, 380 g/s of nitrogen oxides (as NO_2), and 120 g/s of sulfur dioxide. Figure C-1 shows the relative locations of the proposed site and the Class I area. The Federal Land Manager has identified the view toward the mountains to the west.as integral to the visitors' experience of the Class I area.

For conservatism, the observer is placed on the boundary of the Class I area closest to the power plant, which in this case is at the southwestern corner of the Class I area. (Although more visitors would be located at the visitors' center, the Federal Land Manager has stated that all locations in the Class I area are of interest because of widespread visitor use.) From measurements made off of a topographical map (see Figure C-1), the distance from the proposed plant site to this closest corner is 70 km. Since the lines drawn at an 11.25° angle on both sides of the line between the plant site and the nearest corner of the Class I area are outside the Class I area, the closest Class I area boundary is also selected to be 70 km, for conservatism.

Exhibit C-1 shows the results of the VISCREEN analysis for this example. The source fails the Level-1 test with a maximum ΔE of 17.8, nearly nine times the screening threshold. Its maximum contrast of -0.140 (for the backward-scattering scenario) is nearly identical to the 1980 Workbook Level-1 screening calculation of -0.146. The plume is also predicted to be visible against terrain with a contrast of +0.107 (for the forward-scattering scenario), a slightly higher value than the 0.0814 calculated in the 1980 Workbook.

To characterize worst-case meteorological conditions for Level-2 screening, we obtained meteorological data from an airport 100 km west of the proposed power plant. Although the intervening terrain is not flat, we judged that the 850-mb wind and stability data are the best available data source. For the trajectory passing to the northwest of the Class I area,

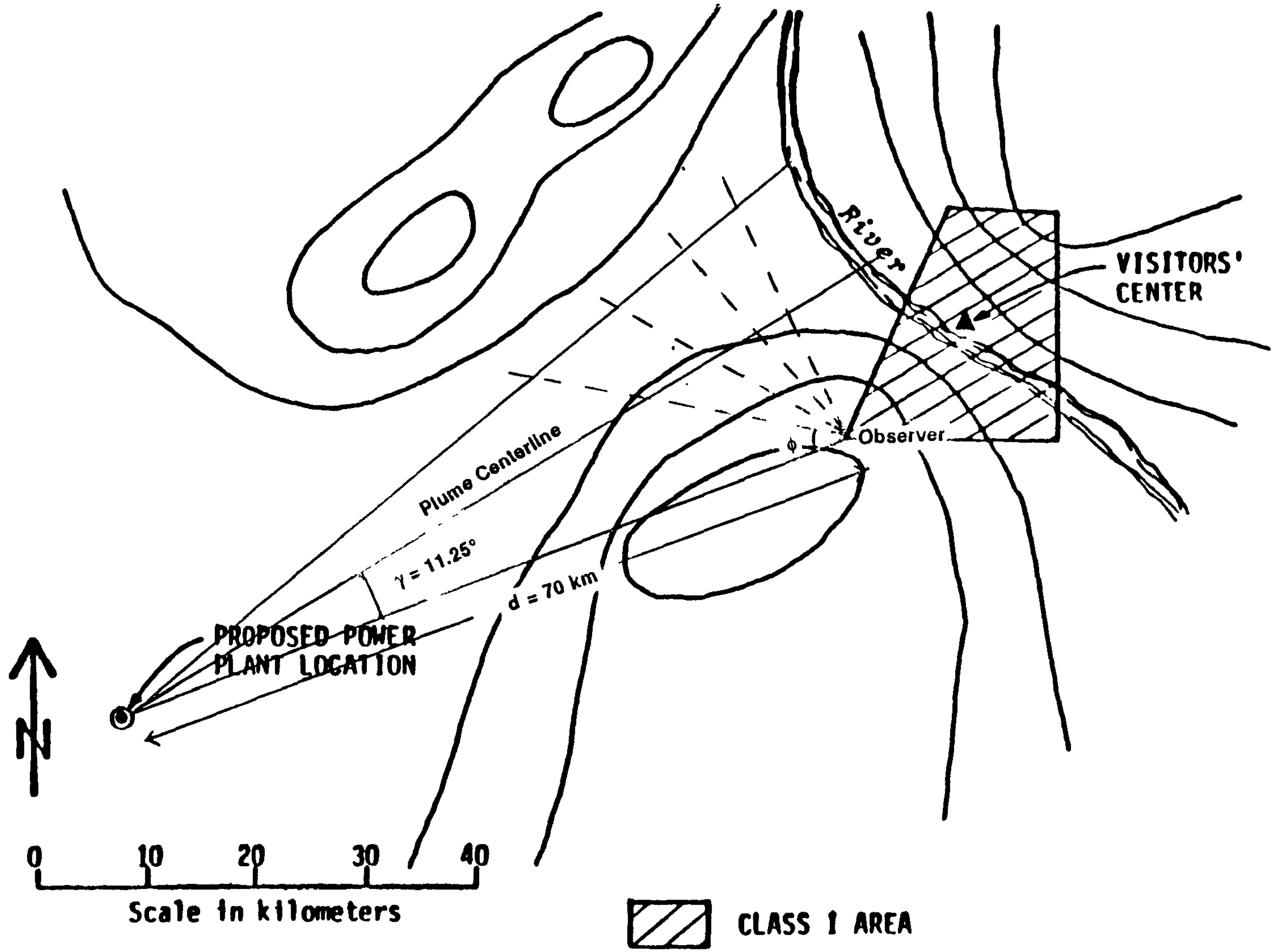


Figure C-1. Relative locations of Example 1 proposed power plant and Class I area for example 1, screening example (where $\gamma = 11.25°$ and ϕ = azimuthal angle of observer line of sight).

*** Level-1 Screening ***

Input Emissions for

Particulates	25.00	G	/S
NOx (as NO2)	380.00	G	/S
Primary NO2	.00	G	/S
Soot	.00	G	/S
Primary SO4	.00	G	/S

**** Default Particle Characteristics Assumed

Transport Scenario Specifications:

Background Ozone:	.04 ppm
Background Visual Range:	170.00 km
Source-Observer Distance:	70.00 km
Min. Source-Class I Distance:	70.00 km
Max. Source-Class I Distance:	90.00 km
Plume-Source-Observer Angle:	11.25 degrees
Stability: 6	
Wind Speed: 1.00 m/s	

R E S U L T S

Asterisks (*) indicate plume impacts that exceed screening criteria

Maximum Visual Impacts INSIDE Class I Area
Screening Criteria ARE Exceeded

					Delta E		Contrast	
Backgrnd	Theta	Azi	Distance	Alpha	Crit	Plume	Crit	Plume
SKY	10.	84.	70.0	84.	2.00	17.807*	.05	-.005
SKY	140.	84.	70.0	84.	2.00	10.828*	.05	-.140*
TERRAIN	10.	84.	70.0	84.	2.00	8.852*	.05	.107*
TERRAIN	140.	84.	70.0	84.	2.00	4.004*	.05	.041

Maximum Visual Impacts OUTSIDE Class I Area
Screening Criteria ARE Exceeded

					Delta E		Contrast	
Backgrnd	Theta	Azi	Distance	Alpha	Crit	Plume	Crit	Plume
SKY	10.	35.	55.6	134.	2.00	20.370*	.05	-.007
SKY	140.	35.	55.6	134.	2.00	11.101*	.05	-.207*
TERRAIN	10.	15.	41.0	154.	2.00	15.827*	.05	.205*
TERRAIN	140.	15.	41.0	154.	2.00	4.791*	.05	.143*

EXHIBIT C-1. Level 1 screening analysis for Example 1.

we tabulated winds from the southwest and west-southwest for both morning and afternoon soundings. From these tabulations, a frequency of occurrence (Table C-1) was developed. The cumulative frequency entries show that on three to four days per year conditions with $\sigma_y \sigma_z u$ values of 7.5×10^5 m^3/s (E stability, 2 m/s) can be expected. Note that the bulk of the contribution to the cumulative frequency (0.9 percent out of 1.0 percent) represents the 1200 GMT E,2 dispersion conditions. This corresponds to approximately 5:00 a.m. LST. Note also that the afternoon sounding frequency of E,2 dispersion conditions was relatively high (0.6 percent, or about two days per year).

Exhibit C-2 summarizes the VISCREEN analysis using the meteorological conditions of E and 2 m/s (less extreme than the Level-1 F and 1 m/s). The maximum plume perceptibility for plume parcels located within the Class I area occurs when the sun is in front of the observer (forward-scatter conditions) and the plume is observed against the sky. For these conditions, the plume ΔE is 8.9, about 4.5 times larger than the screening threshold. Given the geometry shown in Figure C-1, the possibility could not be ruled out that such a forward-scatter situation would occur. Even if such a sun angle were not possible, the second test for a backward scatter sun angle indicates that the plume would be quite visible, exceeding both the ΔE and the green contrast screening thresholds. The even larger impacts calculated for plume parcels outside the Class I area are relevant in this example since they could occur within an identified integral vista. The maximum green contrasts for the plume parcels located outside the Class I area were 0.231 in forward scatter and -0.129 in backward scatter. These values require careful interpretation, however, as they are for the line of sight through a plume parcel only 1 km from the source.

Although not shown here, a Level-3 analysis would be required for this plant because of the failure of both the Level-1 and -2 tests for lines of sight within the Class I area.

EXAMPLE 2: CEMENT PLANT AND RELATED OPERATIONS (1980 WORKBOOK EXAMPLE 2)

A cement plant has been proposed, along with related quarrying, materials handling, and transportation facilities, for a location 20 km from a Class I area. Terrain in the vicinity is relatively flat, and no external vistas from the Class I area (a national park) are considered integral to park visitor experience. Visibility at some locations within the park boundaries is of concern, however.

The point in the Class I area closest to the proposed site is shown in Figure C-2 as Point A. This point is 20 km away from the proposed

TABLE C-1. Frequency of Occurrence of SW and WSW Winds by Dispersion Condition and Time of Day

Dispersion Condition (stability, wind speed)	$\sigma_y \sigma_z u$ (m^3/s)	Transport Time (hours)	Time of Day (percent)[1] 00Z f[2]	00Z cf[3]	12Z f	12Z cf
F,1	$1.29x10^5$	33	0.1	0.0	0.2	0.0
F,2	$2.57x10^5$	11	0.1	0.1	0.0	0.0
E,1	$3.75x10^5$	33	0.2	0.1	0.3	0.0
F,3	$3.86x10^5$	7	0.0	0.1	0.1	0.1
E,2	$7.50x10^5$	11	0.6	0.7	0.9	1.0
E,3	$1.12x10^6$	7	0.6	1.3	1.4	2.4
D,1	$1.16x10^6$	33	0.4	1.3	0.3	2.4
E,4	$1.50x10^6$	5	0.4	1.7	1.2	3.6
E,5	$1.87x10^6$	4	0.2	1.9	1.8	5.4
D,2	$2.32x10^6$	11	1.6	3.5	0.8	6.2
D,3	$3.49x10^6$	7	3.4	6.9	1.2	7.4
D,4	$4.65x10^6$	5	2.4	9.3	1.5	8.9

1. 00Z refers for midnight Greenwich Mean Time (GMT) and 12Z refers to noon GMT.

2. Frequency

3. Cumulative Frequency

4. Persistence of stable meteorological conditions for over 12 hours is not considered likely. Therefore, conditions requiring greater than 12-hour transport time are not included in the cf contribution.

Note: Distance downwind, values of σ_y, σ_z, and transport times are based on a distance of 70 km.

*** User-selected Screening Scenario Results ***

Input Emissions for

Particulates	25.00	G /S
NOx (as NO2)	380.00	G /S
Primary NO2	.00	G /S
Soot	.00	G /S
Primary SO4	.00	G /S

PARTICLE CHARACTERISTICS

	Density	Diameter
Primary Part.	2.5	6
Soot	2.0	1
Sulfate	1.5	4

Transport Scenario Specifications.

Background Ozone:	.04 ppm
Background Visual Range:	170.00 km
Source-Observer Distance:	70.00 km
Min. Source-Class I Distance:	70.00 km
Max. Source-Class I Distance:	90.00 km
Plume-Source-Observer Angle:	11.25 degrees

Stability: 5

Wind Speed: 2.00 m/s

R E S U L T S

Asterisks (*) indicate plume impacts that exceed screening criteria

Maximum Visual Impacts INSIDE Class I Area
Screening Criteria ARE Exceeded

					Delta E		Contrast	
Backgrnd	Theta	Azi	Distance	Alpha	Crit	Plume	Crit	Plume
SKY	10.	120.	80.6	49.	2.00	8.925*	.05	-.002
SKY	140.	120.	80.6	49.	2.00	5.312*	.05	-.070*
TERRAIN	10.	84.	70.0	84.	2.00	4.050*	.05	047
TERRAIN	140.	84.	70.0	84.	2.00	1.763	.05	.017

Maximum Visual Impacts OUTSIDE Class I Area
Screening Criteria ARE Exceeded

					Delta E		Contrast	
Backgrnd	Theta	Azi	Distance	Alpha	Crit	Plume	Crit	Plume
SKY	10.	0.	1.0	169.	2.00	18.948*	.05	.231*
SKY	140.	0.	1.0	169.	2.00	4.808*	.05	-.129*
TERRAIN	10.	0.	1.0	169.	2.00	15.292*	.05	.166*
TERRAIN	140.	0.	1.0	169.	2.00	6.160*	.05	.151*

EXHIBIT C-2. Level 2 screening analysis for Example 1.

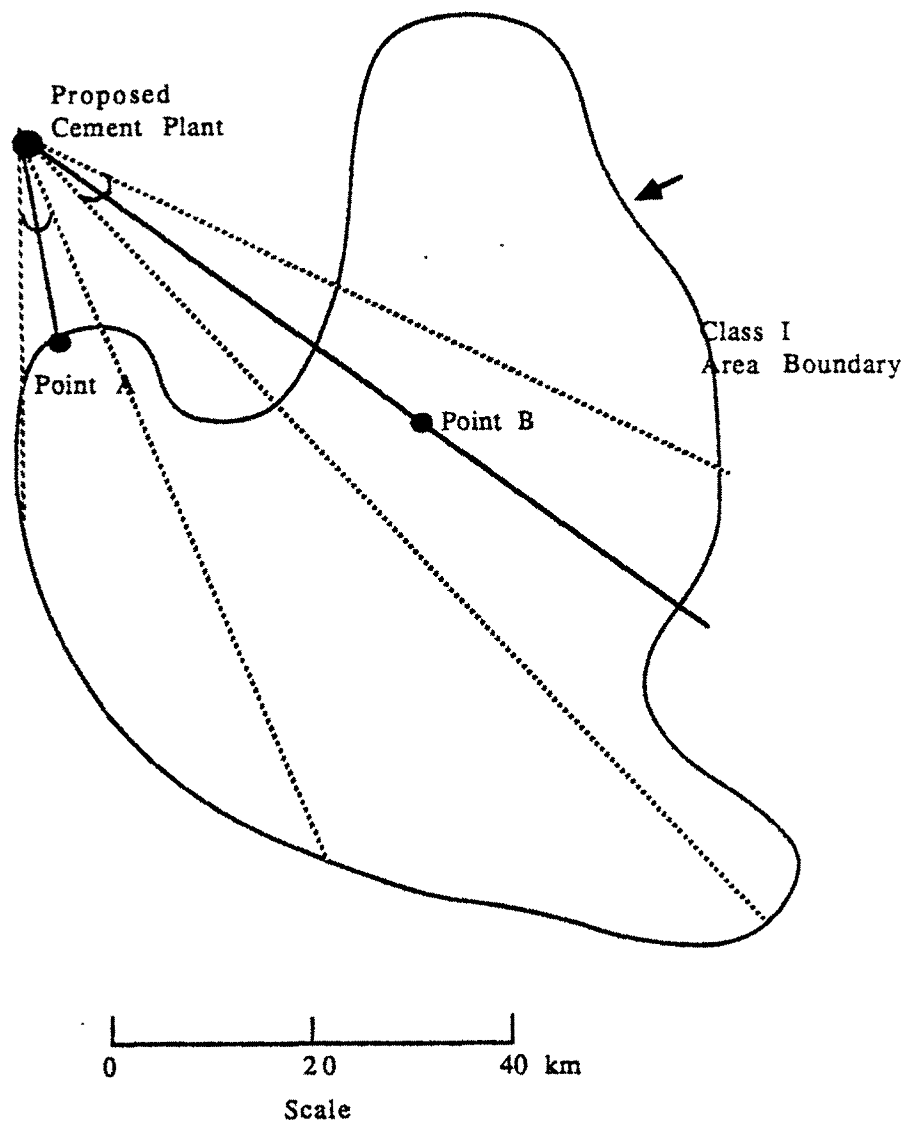


Figure C-2. Relative locations of Example 2 proposed cement plant and Class I area.

plant. Lines drawn 11.25° on either side of the line between the site and Point A intersect the Class I area boundary at distances (for conservatism in Level-1 screening) of 23 and 25 km. Since these distances are greater than the minimum distance, the minimum distance to the Class I area boundary (x_{min}) is set equal to 20 km, as suggested by the Workbook. The most distant Class I area boundary (x_{max}) for analyses on Point A is 80 km away from the cement plant site.

On the basis of discussions with the Federal Land Manager, the closest point that is likely to be visited within the Class I area is 58 km away from the site (Point B). The two dashed lines shown in Figure C-2, which are drawn at 11.25° on opposite sides of the line connecting the plant site and Point B, intersect the closest boundary at 40 and 44 km and the most distant boundary at 117 and 90 km. For conservatism, x_{min} is set at 40 km and x_{max} is set at 117 km. Also for conservatism, Level-1 analysis was performed using Point A, while Point B was used for Level-2 analysis.

The proposed project would cause elevated emissions from numerous process points and ground-level emissions of fugitive dust. (Estimated emissions rates and particle-size distributions are shown in Table C-2.) In the Level-1 and -2 screening, for conservatism, all the elevated and ground-based emissions were lumped together as if they originated from a single source. Thus, the particulate emissions were specified as the sum of the process and fugitive emissions. In the Level-1 analysis, Level-1 default particle specifications were used rather than the known particle size distributions. Exhibit C-3 summarizes the VISCREEN analysis results. Since integral vistas are not protected at this Class I area, only the within-park impacts were relevant. Even so, every case considered--forward and backward scatter as well as sky and terrain viewing backgrounds--showed an impact exceeding the Level-1 screening criteria. Thus, further screening and analysis were warranted.

The Level-2 analysis separately specified the process and fugitive emissions with their known particle-size distributions (while still assuming the two plumes overlapped). This was carried out by letting the primary particulate signify the fugitive emissions and the primary sulfate signify the process emissions. Particle sizes were specified to agree with Table C-2. The less severe worst-case meteorology was found to be D and 1 m/s. Exhibit C-4 shows that VISCREEN calculated impacts were not in excess of the screening criteria. The marked difference in Level-1 and Level-2 results arises in part from the less conservative meteorology and geometry of the Level-2 scenario. A major factor also, however, is the significant change in particle size characteristics used for the fugitive emissions.

*** Level-1 Screening ***

Input Emissions for

Particulates	4.93	MT /DAY
NOx (as NO2)	2.72	MT /DAY
Primary NO2	.00	MT /DAY
Soot	.00	MT /DAY
Primary SO4	.00	MT /DAY

**** Default Particle Characteristics Assumed

Transport Scenario Specifications:

Background Ozone:	.04 ppm
Background Visual Range:	60.00 km
Source-Observer Distance:	20.00 km
Min. Source-Class I Distance:	20.00 km
Max. Source-Class I Distance:	80.00 km
Plume-Source-Observer Angle:	11.25 degrees

Stability: 6

Wind Speed: 1.00 m/s

R E S U L T S

Asterisks (*) indicate plume impacts that exceed screening criteria

Maximum Visual Impacts INSIDE Class I Area
Screening Criteria ARE Exceeded

					Delta E		Contrast	
Backgrnd	Theta	Azi	Distance	Alpha	Crit	Plume	Crit	Plume
SKY	10.	145.	28.5	24.	2.00	18.245*	.05	.287*
SKY	140.	145.	28.5	24.	2.00	4.677*	.05	-.186*
TERRAIN	10.	84.	20.0	84.	2.00	27.724*	.05	.279*
TERRAIN	140.	84.	20.0	84.	2.00	4.859*	.05	.134*

Maximum Visual Impacts OUTSIDE Class I Area
Screening Criteria ARE Exceeded

					Delta E		Contrast	
Backgrnd	Theta	Azi	Distance	Alpha	Crit	Plume	Crit	Plume
SKY	10.	10.	9.6	159.	2.00	22.273*	.05	.346*
SKY	140.	10.	9.6	159.	2.00	5.425*	.05	-.224*
TERRAIN	10.	35.	15.9	134.	2.00	30.404*	.05	.326*
TERRAIN	140.	35.	15.9	134.	2.00	6.276*	.05	.190*

EXHIBIT C-3. Level 1 screening analysis for Example 2.

TABLE C-2. Estimated project emissions.

Emissions	Emissions Rates
Particulate Matter	
Process Sources (effective stack height = 50 m) DG = 1 μm $\sigma_g = 2$ $\rho = 2\ g\ cm^{-3}$	0.395 MT/day
Fugitive Emissions DG = 10 μm $\sigma_g = 2$ $\rho = 2\ g\ cm^{-3}$	4.54 MT/day
Sulfur Oxides (effective stack height = 50 m)	7.26 MT/day
Nitrogen Oxides (effective stack height = 50 m)	2.72 MT/day

*** User-selected Screening Scenario Results ***

Input Emissions for

Particulates	4.54	MT /DAY
NOx (as NO2)	2.72	MT /DAY
Primary NO2	.00	MT /DAY
Soot	.00	MT /DAY
Primary SO4	.40	MT /DAY

PARTICLE CHARACTERISTICS

	Density	Diameter
Primary Part.	2.0	9
Soot	2.0	1
Sulfate	2.0	5

Transport Scenario Specifications:

Background Ozone: .04 ppm
Background Visual Range: 60.00 km
Source-Observer Distance: 58.00 km
Min. Source-Class I Distance: 40.00 km
Max. Source-Class I Distance: 117.00 km
Plume-Source-Observer Angle: 11.25 degrees
Stability: 4
Wind Speed: 1.00 m/s

R E S U L T S

Asterisks (*) indicate plume impacts that exceed screening criteria

Maximum Visual Impacts INSIDE Class I Area
Screening Criteria ARE NOT Exceeded

					Delta E		Contrast	
Backgrnd	Theta	Azi	Distance	Alpha	Crit	Plume	Crit	Plume
SKY	10.	35.	46.1	134.	2.00	.657	.05	.003
SKY	140.	35.	46.1	134.	2.00	.307	.05	-.012
TERRAIN	10.	35.	46.1	134.	2.00	.724	.05	.009
TERRAIN	140.	35.	46.1	134.	2.00	.155	.05	.006

Maximum Visual Impacts OUTSIDE Class I Area
Screening Criteria ARE NOT Exceeded

					Delta E		Contrast	
Backgrnd	Theta	Azi	Distance	Alpha	Crit	Plume	Crit	Plume
SKY	10.	0.	1.0	169.	2.00	.802	.05	.008
SKY	140.	0.	1.0	169.	2.00	.421	.05	-.013
TERRAIN	10.	0.	1.0	169.	2.00	1.988	.05	.018
TERRAIN	140.	0.	1.0	169.	2.00	.636	.05	.018

EXHIBIT C-4. Level 2 screening analysis for Example 2.

EXAMPLE 3: PAPER MILL

A paper mill is proposed near a Class I area (see Figure C-3). Anticipated paper mill emissions are shown in Table C-3.

The closest point in the Class I area is Point A, which is 7.8 km from the mill. However, Point B is the location in the Class I area that is closest to the mill, relatively frequently visited, and unobstructed by tree cover. Point A was used for Level-1 screening and Point B for Level-2 screening.

Although a plume-rise analysis shows that the plume from the largest emission source (the power boiler) would not be at the same elevation as plumes from other sources, and, thus, that plumes would not overlap, for conservatism all emissions are lumped together as a single plume. Exhibit C-5 shows the result of Level-1 VISCREEN calculations for this plume and the closest Class I area boundary. With plume ΔE values ranging from 10.2 to 25.7 for views against the sky (views of distant terrain were not possible at this Class I area), the screening clearly shows the significant potential for adverse plume visual impacts. The plume contrast values indicate that the plume would be bright (positive contrast) in forward scatter (sun in front of observer) and dark (negative contrast) in backward scatter (sun behind observer).

An analysis of on-site data indicated that the worst-case meteorology could be characterized by F and 3 m/s, rather than the F and 1 m/s assumed in Level-1 screening. Exhibit C-6 summarizes VISCREEN results using this meteorology and Point B geometry (see Figure C-3). Although impacts are substantially lower (ranging from ΔE's of 4.0 to 8.6), they are still considerably above the Level-2 screening criteria for both scattering angles assumed. Since the plume-rise analysis indicated that the plume from the largest emitter at the mill would not overlap plumes from other sources, a final analysis was performed with emissions from this single largest emission source--the power boiler. Exhibit C-7 summarizes the VISCREEN results. ΔE's range from 2.2 to 4.7, down considerably from the more conservative Level-1 and -2 analyses, but still considerably in excess of the screening threshold. Thus, a Level-3 analysis would be warranted in this case, and the possibility of adverse plume visual impact could not be ruled out without additional analysis.

EXAMPLE 4: POWER PLANT IN THE WESTERN UNITED STATES

A power plant located in the western United States north of a Class I area was scheduled to be expanded from two to four units of 400 MWe each. Table C-4 summarizes the emissions for the base and expanded scenarios for

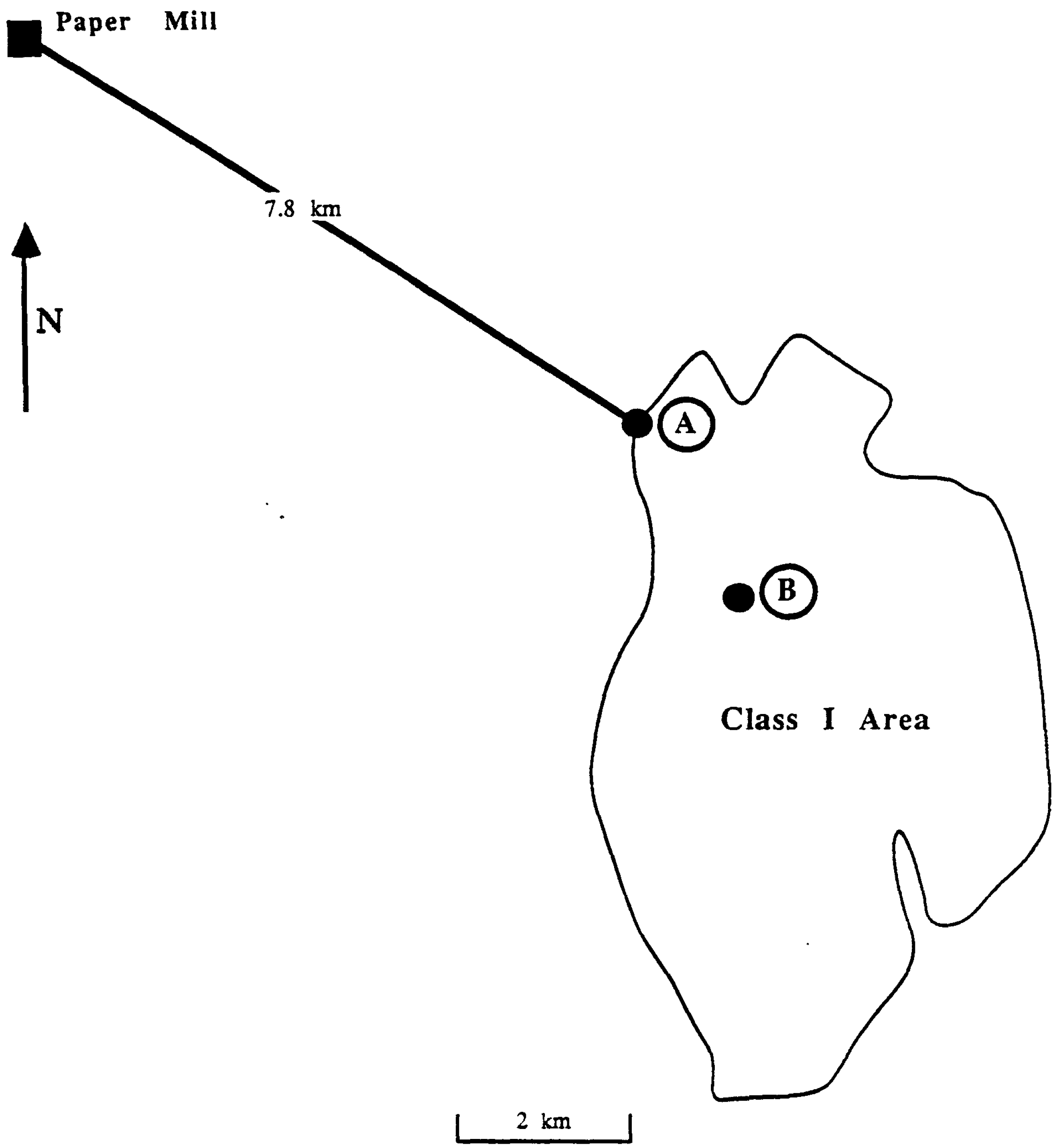


FIGURE C-3. Relative locations of paper mill and Class I area used in example 3.

TABLE C-3. Paper mill stack emissions data.

	Stack Height (Ft)	Stack Diam. (In)	Exit Velocity (Ft/Sec)	Exit Temp. (°F)	Emissions (Metric Tons/Day)		
					PM	SO_2	NO_x
Power Boiler	200	144	25.36	155	1.022	1.756	2.027
Recovery Boiler	275	114	94.06	380	.491	4.069	1.560
Smelt Tank	250	72	23.00	155	.130	.064	--
Lime Kiln	260	50	26.02	160	.087	.091	.454
Total:					1.72	5.97	4.03

*** Level-1 Screening ***

Input Emissions for

Particulates	1.72	MT /DAY
NOx (as NO2)	4.03	MT /DAY
Primary NO2	.00	MT /DAY
Soot	.00	MT /DAY
Primary SO4	.00	MT /DAY

**** Default Particle Characteristics Assumed

Transport Scenario Specifications:

Background Ozone:	.04 ppm
Background Visual Range:	60.00 km
Source-Observer Distance:	7.80 km
Min. Source-Class I Distance:	7.80 km
Max. Source-Class I Distance:	13.00 km
Plume-Source-Observer Angle:	11.25 degrees

Stability: 6

Wind Speed: 1.00 m/s

R E S U L T S

Asterisks (*) indicate plume impacts that exceed screening criteria

Maximum Visual Impacts INSIDE Class I Area
Screening Criteria ARE Exceeded

					Delta E		Contrast	
Backgrnd	Theta	Azi	Distance	Alpha	Crit	Plume	Crit	Plume
SKY	10.	153.	13.0	16.	2.00	25.677*	.05	.201*
SKY	140.	153.	13.0	16.	2.00	10.235*	.05	-.245*
TERRAIN	10.	84.	7.8	84.	2.00	34.701*	.05	.247*
TERRAIN	140.	84.	7.8	84.	2.00	5.013*	.05	.086*

Maximum Visual Impacts OUTSIDE Class I Area
Screening Criteria ARE Exceeded

					Delta E		Contrast	
Backgrnd	Theta	Azi	Distance	Alpha	Crit	Plume	Crit	Plume
SKY	10.	2.	1.0	167.	2.00	31.191*	.05	.577*
SKY	140.	2.	1.0	167.	2.00	8.757*	.05	- 337*
TERRAIN	10.	2.	1.0	167.	2.00	52.827*	.05	.597*
TERRAIN	140.	2.	1.0	167.	2.00	16.779*	.05	.564*

EXHIBIT C-5. Level 1 screening analysis for Example 3.

*** User-selected Screening Scenario Results ***

Input Emissions for

Particulates	1.72	MT /DAY
NOx (as NO2)	4.03	MT /DAY
Primary NO2	.00	MT /DAY
Soot	.00	MT /DAY
Primary SO4	.00	MT /DAY

PARTICLE CHARACTERISTICS

	Density	Diameter
Primary Part.	2.5	6
Soot	2.0	1
Sulfate	1.5	4

Transport Scenario Specifications:

Background Ozone:	.04 ppm
Background Visual Range:	60.00 km
Source-Observer Distance:	9.30 km
Min. Source-Class I Distance:	8.00 km
Max. Source-Class I Distance:	13.00 km
Plume-Source-Observer Angle:	11.25 degrees

Stability: 6

Wind Speed: 3.00 m/s

R E S U L T S

Asterisks (*) indicate plume impacts that exceed screening criteria

Maximum Visual Impacts INSIDE Class I Area
Screening Criteria ARE Exceeded

					Delta E		Contrast	
Backgrnd	Theta	Azi	Distance	Alpha	Crit	Plume	Crit	Plume
SKY	10.	144.	13.0	25.	2.00	8.558*	.05	.062*
SKY	140.	144.	13.0	25.	2.00	3.984*	.05	-.076*
TERRAIN	10.	47.	8.0	122.	2.00	15.596*	.05	.105*
TERRAIN	140.	47.	8.0	122.	2.00	1.948	.05	.034

Maximum Visual Impacts OUTSIDE Class I Area
Screening Criteria ARE Exceeded

					Delta E		Contrast	
Backgrnd	Theta	Azi	Distance	Alpha	Crit	Plume	Crit	Plume
SKY	10.	1.	1.0	167.	2.00	19.745*	.05	.335*
SKY	140.	1.	1.0	167.	2.00	5.156*	.05	-.204*
TERRAIN	10.	1.	1.0	167.	2.00	36.760*	.05	.403*
TERRAIN	140.	1.	1.0	167.	2.00	9.265*	.05	.294*

EXHIBIT C-6. Level 2 screening analysis for Example 3 (all emissions).

Input Emissions for

Particulates	1.02	MT /DAY
NOx (as NO2)	2.03	MT /DAY
Primary NO2	.00	MT /DAY
Soot	.00	MT /DAY
Primary SO4	.00	MT /DAY

PARTICLE CHARACTERISTICS

	Density	Diameter
Primary Part.	2.5	6
Soot	2.0	1
Sulfate	1.5	4

Transport Scenario Specifications:

Background Ozone:	.03 ppm
Background Visual Range:	60.00 km
Source-Observer Distance:	9.30 km
Min. Source-Class I Distance:	8.00 km
Max. Source-Class I Distance:	13.00 km
Plume-Source-Observer Angle:	11.25 degrees

Stability: 6

Wind Speed: 3.00 m/s

R E S U L T S

Asterisks (*) indicate plume impacts that exceed screening criteria

Maximum Visual Impacts INSIDE Class I Area

Screening Criteria ARE Exceeded

					Delta E		Contrast	
Backgrnd	Theta	Azi	Distance	Alpha	Crit	Plume	Crit	Plume
SKY	10.	144.	13.0	25.	2.00	4.724*	.05	.041
SKY	140.	144.	13.0	25.	2.00	2.184*	.05	-.044
TERRAIN	10.	47.	8.0	122.	2.00	10.096*	.05	.064*
TERRAIN	140.	47.	8.0	122.	2.00	1.150	.05	.020

Maximum Visual Impacts OUTSIDE Class I Area

Screening Criteria ARE Exceeded

					Delta E		Contrast	
Backgrnd	Theta	Azi	Distance	Alpha	Crit	Plume	Crit	Plume
SKY	10.	1.	1.0	167.	2.00	14.179*	.05	.236*
SKY	140.	1.	1.0	167.	2.00	3.630*	.05	-.144*
TERRAIN	10.	1.	1.0	167.	2.00	29.335*	.05	.306*
TERRAIN	140.	1.	1.0	167.	2.00	6.406*	.05	.192*

EXHIBIT C-7. Level 2 screening analysis for Example 3 (power boiler emissions).

TABLE C-4. Emissions parameters for Example 4 Power Plant.

Parameter	Emissions per Unit: Unit 1 or 2	Emissions per Unit: Unit 3 or 4
Stack height (ft)	600	600
(m)	183	183
Flue gas flow rate (acfm)	1,555,980	1,555,980
(m^3/sec)	734	734
Flue gas temperature (°F)	138	138
(°K)	332	332
Particulate emissions		
Density (g/cm^3)	2.0	2.0
Mass median diameter (μm)	1.7	1.7
Geometric standard deviation	1.5	1.5
Flue gas concentration (μg/m^3)	25,100	10,100
Flue gas opacity (%)	20	9
Mass emissions rate (g/sec)	18.4	7.4
Nominal control efficiency (%)	99.5	99.8
Sulfur dioxide (SO_2) emissions		
Flue gas concentration (ppm)	93	47
Mass emissions rate (g/sec)	132	66
Nominal control efficiency (%)	80	90
Nitrogen oxide emissions		
Flue gas concentration (ppm)	366	314
Mass emissions rate (as NO_2) (g/sec)	372	319

each boiler unit. Figure C-4 summarizes the geometry of the plant, the Class I area, and typical stable plume trajectories. The Federal Land Manager was concerned about the view from the observer location shown in this figure, because from this vantage point an observer has an unobstructed view north, where a plume from the power plant would probably be transported. Since the vista of concern and the Class I area itself are both elevated relative to the position of stable plumes, it was felt that stable plume transport into the Class I area was unlikely, but that a view of a stable plume, as shown in Figure C-4, would be of concern.

Level-1 and -2 analyses were carried out using VISCREEN. These analyses indicated that adverse visibility impairment could not be ruled out. As a result, a Level-3 analysis was performed. PLUVUE II was run for several plume transport scenarios to characterize the cumulative frequency distribution of plume visual impact for mornings in the four seasons. Since the calculated plume visual impact magnitudes were to be coupled with the cumulative frequency of conditions worse than the indicated impact, plume positions for each wind direction sector modeled were selected so that the plume impact was the minimum for the given sector (see Figure C-5). Plume visual impacts were calculated as a function of azimuth of view. The maximum plume ΔE (over all the possible azimuths) was determined for each plume transport scenario corresponding to given meteorological conditions. The individual scenarios were ordered in descending value of ΔE. The cumulative frequencies for each season were plotted and these results are summarized in Table C-5. For every season except one (Fall, ΔE threshold = 5), the number of mornings which exceed the ΔE threshold are greatest for Units 1 through 4. On average, the largest number of mornings which exceed the threshold ΔE occur in the winter, followed by fall, summer, and spring.

EXAMPLE 5: CONSTRUCTION SITE NEAR A CLASS I AREA

A facility was proposed to be located only 1.9 km from the eastern boundary of a Class I area (see Figure C-6). Three phases of construction or operation were identified. Each of these phases (P1, P2, and P3) has its own set of emissions (see Table C-6). Because diesel engines were used during construction, emissions of NO_x and soot were relatively high. In addition, fugitive dust emissions from the construction vehicles' disruption of the native soil were high. However, these emissions would have relatively high particle sizes.

Level-1 and -2 screening was performed, using VISCREEN, for each of the three phases of construction/operation. For every emissions, sun angle, and viewing background scenario, impacts were calculated to be considerably in excess of the screening thresholds. Thus, a Level-3 analysis was performed. Figure C-7 shows the plume trajectories that were modeled for each of three observer locations. Using the PLUVUE II model, a sensitivity analysis was

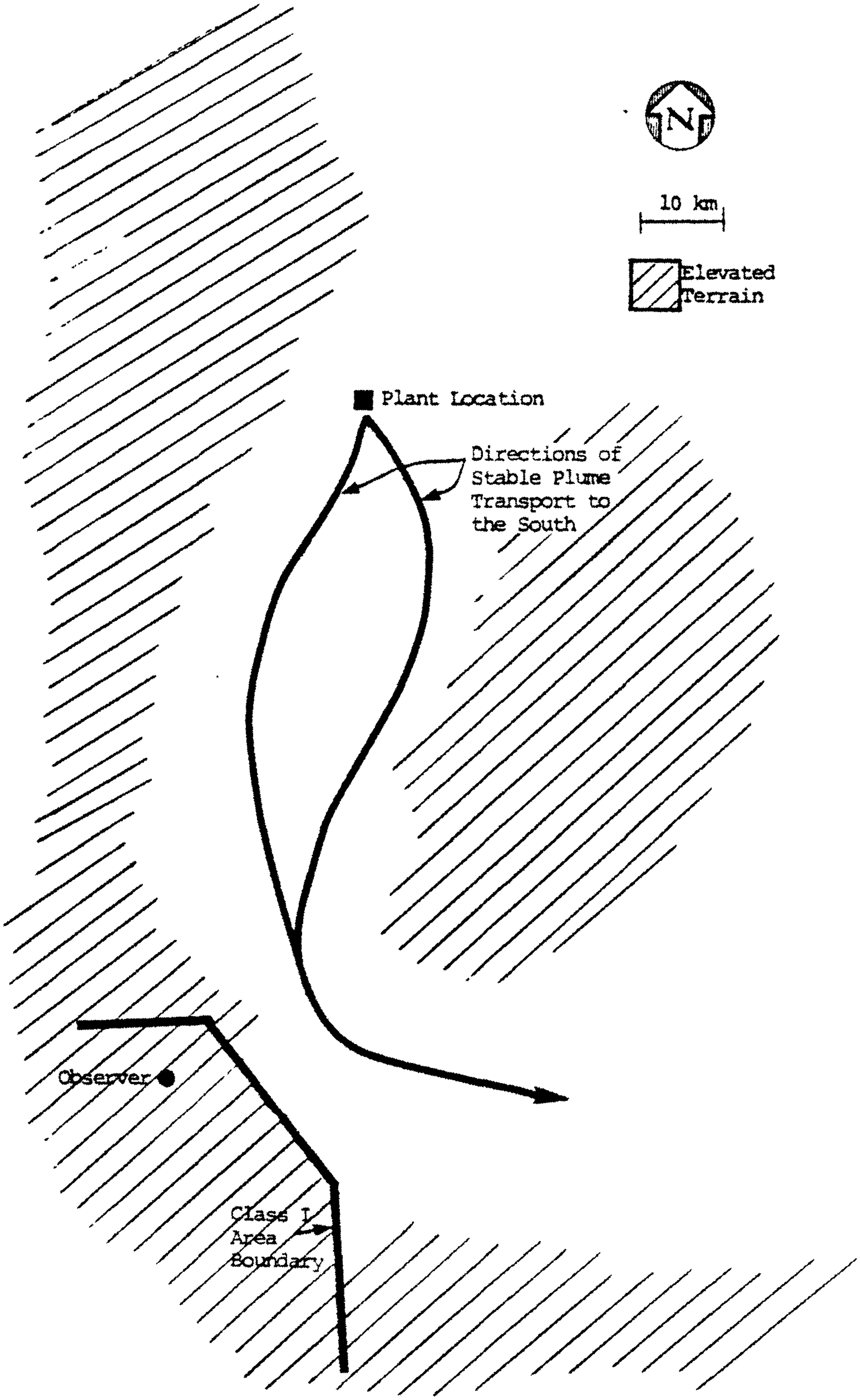


FIGURE C-4. Location of Example 4 power plant relative to Class I area.

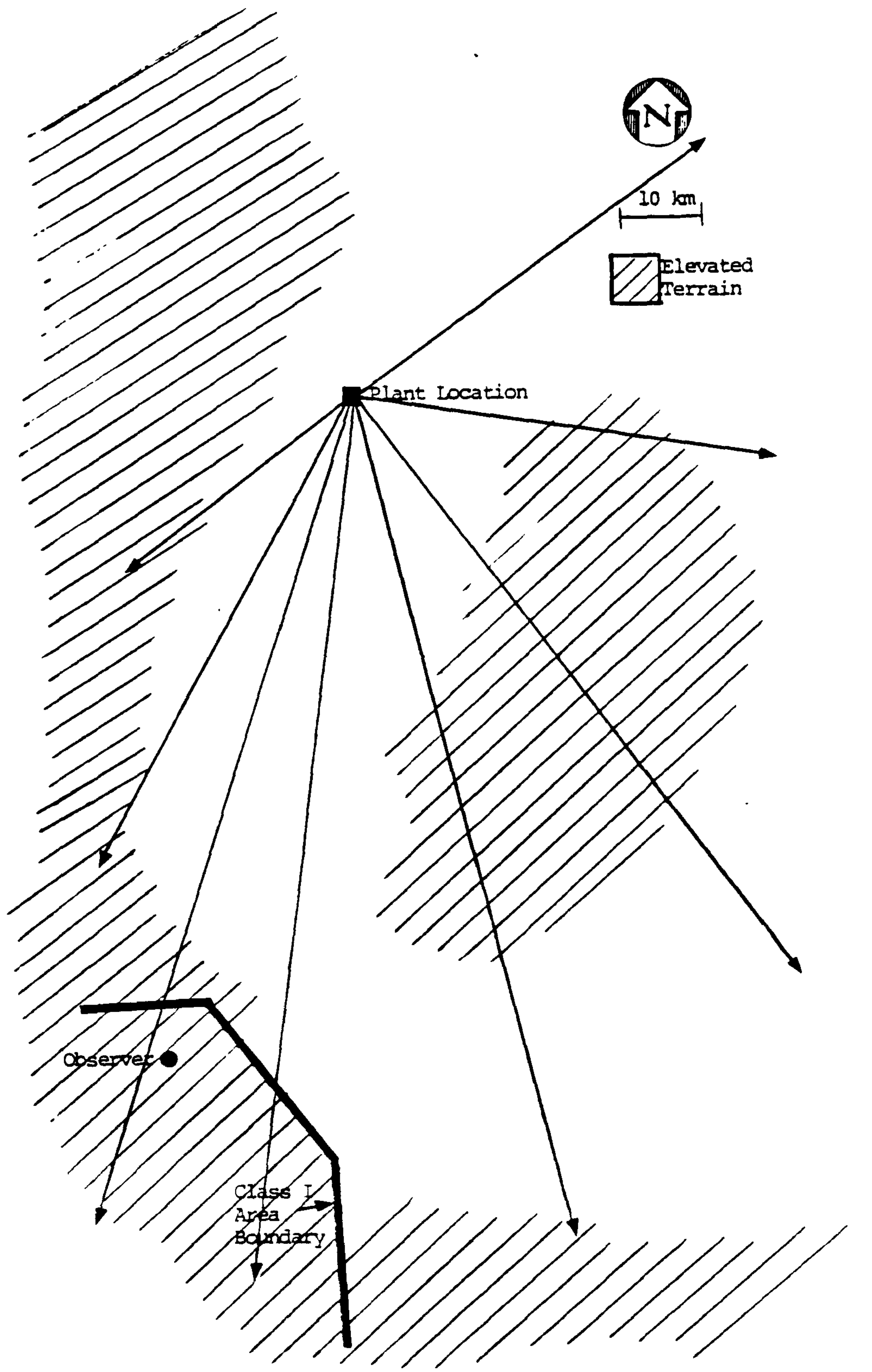


FIGURE C-5. Plume trajectories corresponding to various wind directions used in the visibility impact assessment.

TABLE C-5. Summary of the frequency of occurrence of power plant plume visual impact predicted for Example 4.

	Number of Mornings with ΔE(L*a*b*) Greater than Indicated Value					
	2.5		5		10	
Season	Units 1 and 2	Units 1 through 4	Units 1 and 2	Units 1 through 4	Units 1 and 2	Units 1 through 4
Winter	4	6	2	3	< 1	1
Spring	1	2	< 1	1	0	0
Summer	2	3	1	1	0	0
Fall	3	5	4	2	< 1	< 1
Annual Total	10	16	4	7	1	< 2

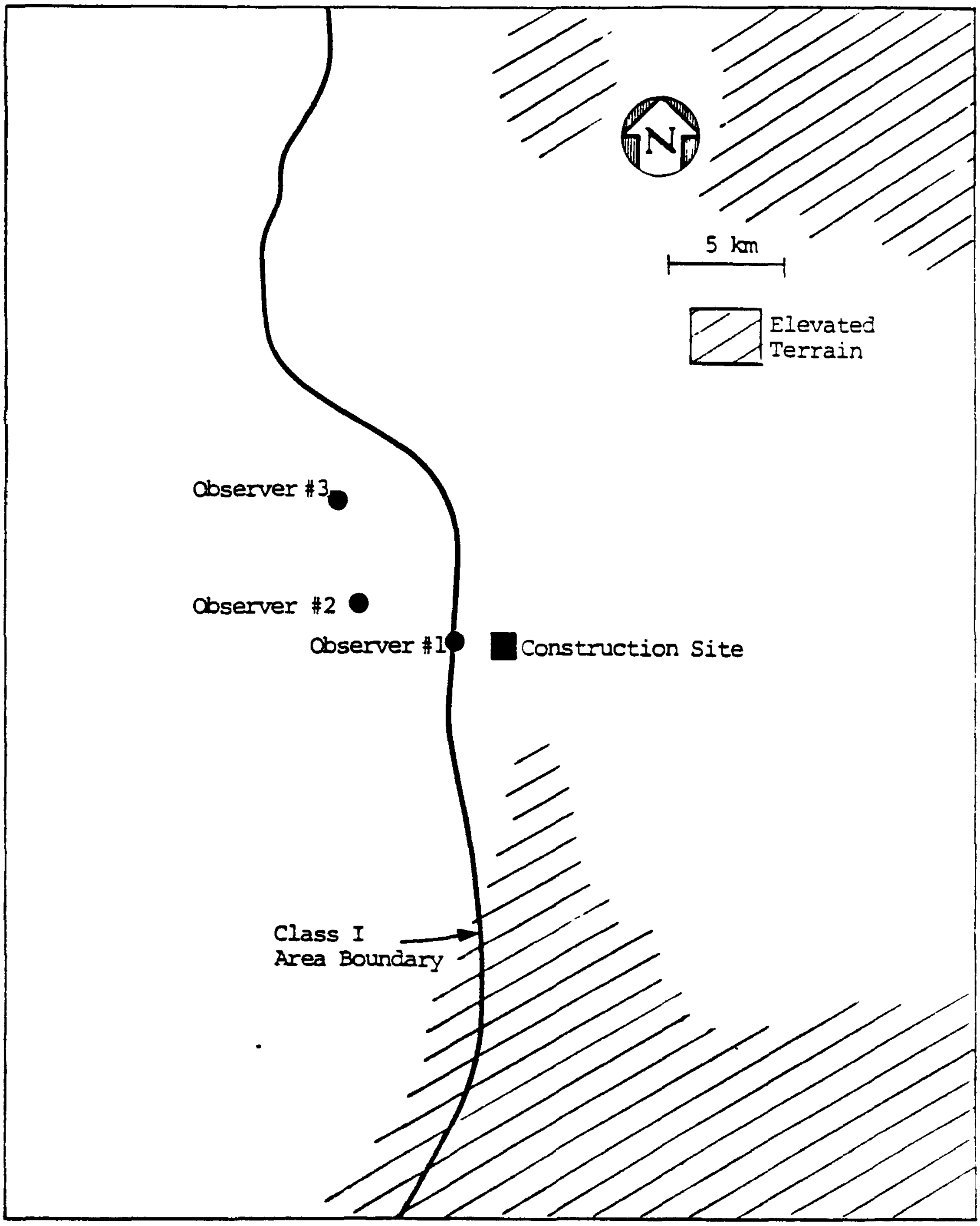


Figure C-6. Source and observer locations for Example 5.

TABLE C-6. Emissions used as PLUVUE-II input for three phases of construction and operation (tons per day).

Phase	NOx	Diesel Exhaust	Fugitive Dust
Phase 1 Construction (P1)	0.86	0.06	0.15
Phase 2 Construction (P2)	2.75	0.28	0.61
Phase 3 Operation (P3)	0.58	0.01	0.24

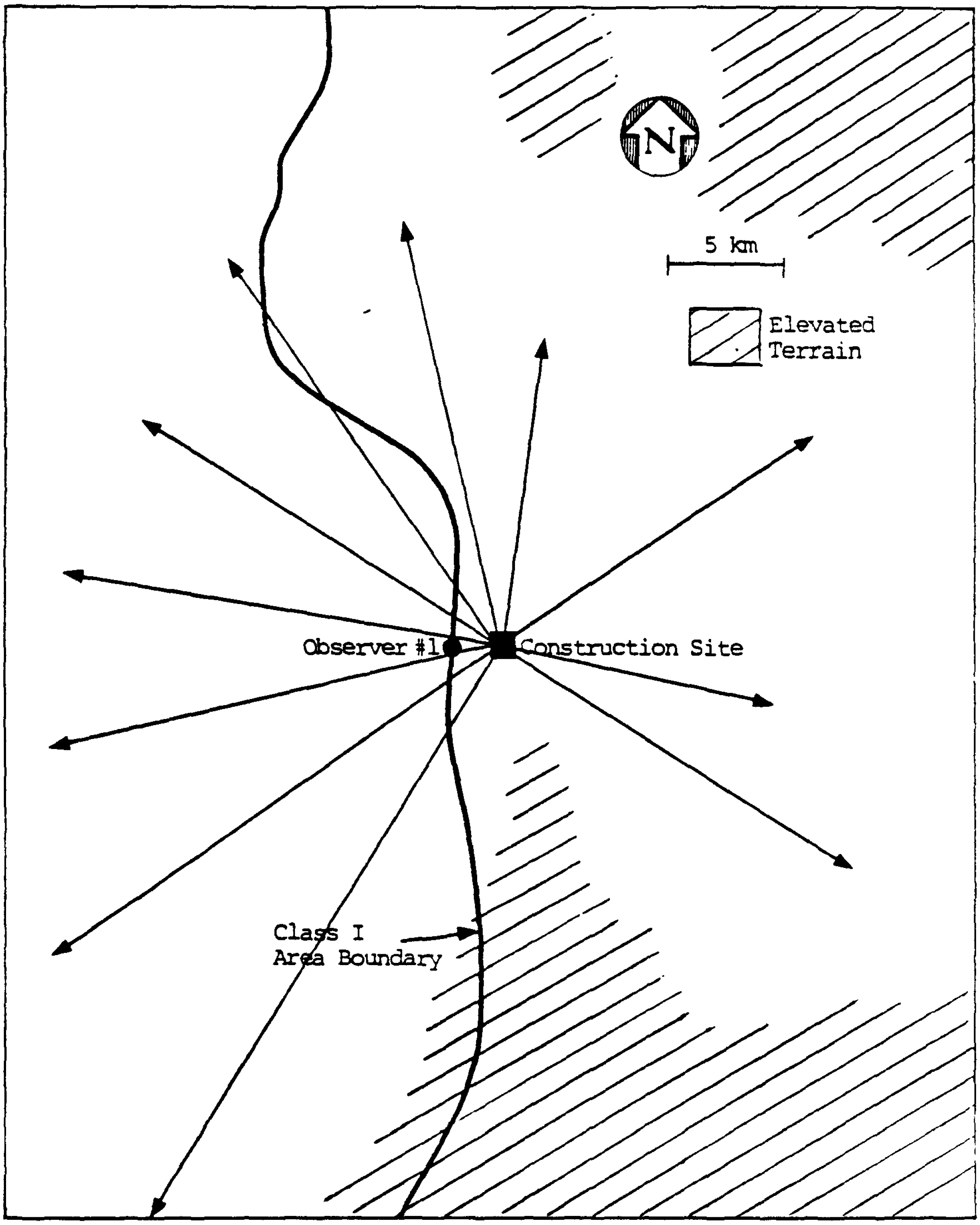


Figure C-7a. Plume orientations for which plume visual impacts were calculated from the perspectives of individual observer--observer No. 1.

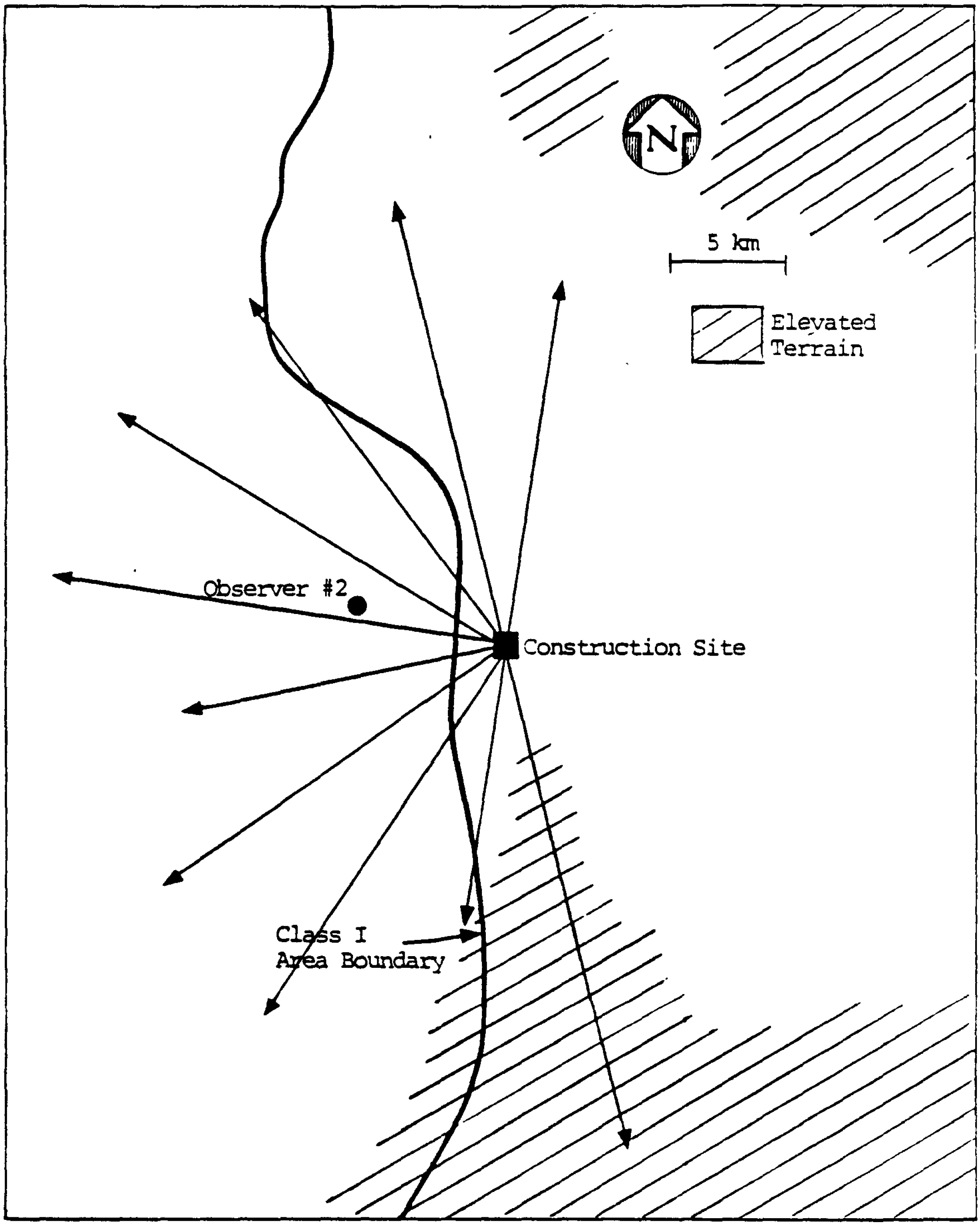


Figure C-7b. Observer No. 2.

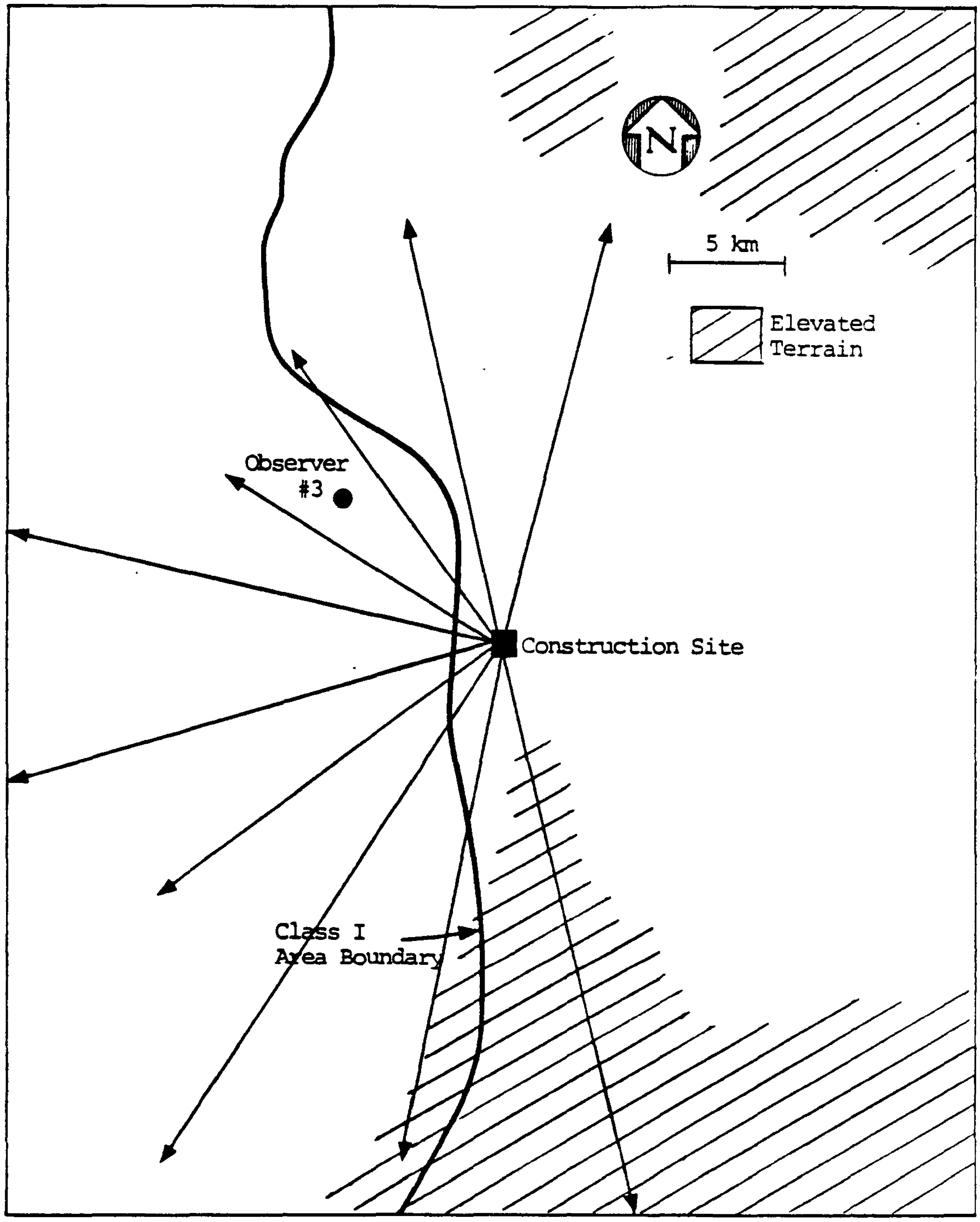


Figure C-7c. Observer No. 3.

carried out to determine the emitted species most responsible for plume visual impacts. As shown in Table C-7, all three species (diesel exhaust or soot, NO_x; and fugitive dust) were important contributors; however, soot and NO_x appeared to be the largest contributors because both species absorb light, which results in dark plumes. Because of the large number of wind speed/wind direction/stability scenarios for which the plume would be visible, over 200 PLUVUE II runs were made. Table C-8 summarizes the output from one of these runs. For the west southwest wind direction, the plume perceptibility threshold (ΔE) is exceeded up to a distance of 5 km, for west winds the ΔE threshold is exceeded up to 7 km, and for east northeast winds the ΔE threshold is never exceeded. The green contrast value never exceeds the .05 threshold.

For each run the maximum ΔE was selected from all the lines of sight that were modeled. Tables C-9 and C-10 summarize these maximum ΔE's. ΔE's were ordered by descending value (see Table C-11) and coupled with frequencies of meteorological conditions (see Table C-12). Plumes were predicted to be visible almost every day from observer location #1. Plumes were also predicted to be visible from observer locations #2 and #3, but at lower frequencies.

TABLE C-7. Sensitivity of plume visual impact to emitted species.

	Visual Range Reduction (%)	Blue-Red Ratio	Plume Contrast	ΔE(L*a*b*)
Base Case	15.2	0.987	-0.016	0.641
Diesel Exhaust Only	9.8	0.988	-0.015	0.586
NO_x Only	5.7	0.998	-0.011	0.497
Fugitive Dust Only	1.7	0.996	-0.005	0.175

Run Description:

Spring 0800 AM

Wind direction = E

Wind speed = 2 m/s

Stability = D

Observer #1

Emissions: Phase Construction (P1)

Downwind distance: 3 km

TABLE C-8. Examples of PLUVUE-II output.

EMISS	OBS	DATE	TIME	STAB	WS (M/S)	WD
	1	12/21	0800	D	2	WSW

DISTANCE (KM)	1.	3.	5.	7.	10.	15.
SKY BACKGROUND REDUCTION OF VISUAL RANGE (%)	.497	.454	.500	.548	.646	.862
BLUE-RED RATIO	.919	.937	.948	.960	.975	.992
PLUME CONTRAST AT 0.55 µm	-.032	-.028	-.026	-.024	-.022	-.018
PLUME PERCEPTIBILITY DELTA E(L*A*B*)	3.110	2.492	2.212	1.873	1.436	.894

WD
W

DISTANCE (KM)	1.	3.	5.	7.	10.	15.
SKY BACKGROUND REDUCTION OF VISUAL RANGE (%)	.550	.541	.595	.642	.736	.938
BLUE-RED RATIO	.918	.935	.945	.957	.972	.989
PLUME CONTRAST AT 0.55 µm	-.030	-.024	-.023	-.021	-.018	-.015
PLUME PERCEPTIBILITY DELTA E(L*A*B*)	3.203	2.629	2.352	2.015	1.574	1.007

WD
ENE

DISTANCE (KM)	1.	3.	5.	7.	10.	15.
SKY BACKGROUND REDUCTION OF VISUAL RANGE (%)	.215	.063	.133	.201	.312	.533
BLUE-RED RATIO	.965	.983	.971	.970	.976	.991
PLUME CONTRAST AT 0.55 µm	-.011	-.007	-.014	-.017	-.019	-.019
PLUME PERCEPTIBILITY DELTA E(L*A*B*)	1.315	.585	1.102	1.243	1.182	.859

TABLE C-9. Summary of maximum ΔE's calculated for each of the PLUVUE II runs for Observer #1.

			Phase 1									Phase 2									Phase 3
			Winter			Spring			Summer			Winter			Spring			Summer			Winter
Stab.	WS,m/s	WD	8 am	noon	4 pm	8 am	noon	4 pm	8 am	noon	4 pm	8 am	noon	4 pm	8 am	noon	4 pm	8 am	noon	4 pm	8 am
D	2	E	1.2	0.9	1.2	1.1	0.9	1.0		0.9	0.9		1.8	2.5	2.1	1.8				1.9	
D	2	WSW	3.1	2.3	3.0	2.7	2.2	2.5		2.1	2.3		4.2	5.7	4.8	4.1	4.8			4.4	
D	2	W	3.2	2.3	3.0		2.2	2.5		2.1	2.3		4.3	5.6		4.1	4.8		4.0	4.4	
D	2	ENE	1.3	0.9	1.2		0.9	1.0			0.9		1.9	2.4		1.8	2.0			1.9	
D	2	WNW	1.1	0.8	1.0		0.8	0.9		0.7	0.8	2.6	1.9	2.4		1.8	2.1		1.8	1.9	0.6
D	1	W	5.0																		
D	3	W	2.4									4.6									1.0
D	5	W	1.6									3.3									0.7
E	1	W	4.9																		
E	2	W	3.0																		
E	3	W	2.3																		
E	5	W	1.6																		
F	2	W	4.0																		
F	3	W	3.0																		
F	5	W	2.1																		
D	1	ENE	2.1																		
D	3	ENE	1.0									2.0									0.4
D	5	ENE	0.7									1.4									0.3
E	1	ENE	1.9																		
E	2	ENE	1.2																		
E	3	ENE	0.9																		
E	5	ENE	0.7																		
F	2	ENE	1.4																		
F	3	ENE	1.1																		
F	5	ENE	0.8																		
D	1	WSW										8.2									2.0
D	1	W										8.4									2.0
D	1	ENE										3.8									0.8
D	1	E										3.6									0.8
D	1	WNW										3.9									0.9
D	2	WSW										5.7									1.3
D	2	W										5.9									1.3
D	2	ENE										2.5									0.5
D	2	E										2.4			2.1						0.5
D	3	WSW										4.5									1.0
D	3	E										1.9									0.4
D	3	WNW										2.0									0.4
D	5	WSW										3.3									0.7
D	5	E										1.3									0.3
D	5	WNW										1.4									0.3

TABLE C-10. - Summary of maximum ΔE's calculated for each of the PLUVUE-II runs for Observers #2 and #3 for each phase.

			Obs.#2			Obs.#3		
Stab.	WS,m/s	WD	P1	P2	P3	P1	P2	RO
D	2	NNW	0.5	1.0		0.5		
D	2	N	0.4			0.4		
D	2	NNE	0.4			0.4		0.2
D	2	NE	0.5			0.4		
D	2	ENE	1.0	2.1	0.5	0.4		
D	2	E				0.7		0.4
D	2	ESE	0.4			4.4	6.6	2.7
D	2	SE	0.2	0.9	0.2	0.5		
D	2	SSE	0.2			0.3		
D	2	S	0.2			0.2		
D	1	NNW	0.7	1.6	0.4			
D	1	NNE	5.4				1.2	
D	1	SE	3.2	17.1	17.3			
D	1	NNE				0.6		0.3
D	1	E				3.3	18.0	18.2
D	1	ESE				10.0	27.3	28.5
D	3	NNW	0.3	1.1	0.7			
D	3	ENE	0.7	1.7	0.5			
D	3	SE	0.2	7.9	0.4			
D	3	NNE				0.3	0.6	0.2
D	3	E				0.5	1.0	0.4
D	3	ESE				3.3	5.3	2.1
D	5	NNW	0.2	0.6	0.4			
D	5	ENE	0.5	2.0	1.6			
D	5	SE	0.1	1.2	1.0			
D	5	NNE				0.2	0.4	0.1
D	5	E				0.4	1.2	1.0
D	5	ESE				2.3	3.9	3.0
D	1	ENE		24.8	25.2			

NOTE: All runs performed with a winter morning (0800) sun angle.

TABLE C-11. Transport scenarios ordered by maximum plume ΔE for each observer location and phase of construction and operation.

TABLE 3-5a

Stab.	WS,m/s	WD	Obs.#1 P1
D	1	W	5.0
E	1	W	4.9
F	2	W	4.0
D	2	W	3.2
D	2	WSW	3.1
F	3	W	3.0
E	2	W	3.0
D	3	W	2.4
E	3	W	2.3
F	5	W	2.1
D	1	ENE	2.1
E	1	ENE	1.9
E	5	W	1.6
D	5	W	1.6
F	2	ENE	1.4
D	2	ENE	1.3
D	2	E	1.2
E	2	ENE	1.2
F	3	ENE	1.1
D	2	WNW	1.1
D	3	ENE	1.0
E	3	ENE	0.9
F	5	ENE	0.8
D	5	ENE	0.7
E	5	ENE	0.7

TABLE 3-5b

Stab.	WS,m/s	WD	Obs.#1 P2
D	1	W	8.4
D	1	WSW	8.2
D	2	W	5.9
D	2	WSW	5.7
D	3	W	4.6
D	3	WSW	4.5
D	1	WNW	3.9
D	1	ENE	3.8
D	1	E	3.6
D	5	W	3.3
D	5	WSW	3.3
D	2	WNW	2.6
D	2	ENE	2.5
D	2	E	2.4
D	3	ENE	2.0
D	3	WNW	2.0
D	3	E	1.9
D	5	ENE	1.4
D	5	WNW	1.4
D	5	E	1.3

TABLE 3-5c

Stab.	WS,m/s	WD	Obs.#1 P3
D	1	WSW	2.0
D	1	W	2.0
D	2	WSW	1.3
D	2	W	1.3
D	3	W	1.0
D	3	WSW	1.0
D	1	WNW	0.9
D	1	E	0.8
D	1	ENE	0.8
D	5	WSW	0.7
D	5	W	0.7
D	2	WNW	0.6
D	2	E	0.5
D	2	ENE	0.5
D	3	WNW	0.4
D	3	E	0.4
D	3	ENE	0.4
D	5	ENE	0.3
D	5	E	0.3
D	5	WNW	0.3

TABLE 3-6d

Stab.	WS,m/s	WD	Obs.#2 P1
D	1	NNE	5.4
D	1	SE	3.2
D	2	ENE	1.0
D	1	NNW	0.7
D	3	ENE	0.7
D	2	NE	0.5
D	5	ENE	0.5
D	2	NNW	0.5
D	2	ESE	0.4
D	2	N	0.4
D	2	NNE	0.4
D	3	NNW	0.3
D	2	S	0.2
D	3	SE	0.2
D	5	NNW	0.2
D	2	SSE	0.2
D	2	SE	0.2
D	5	SE	0.1

TABLE 3-5f

Stab.	WS,m/s	WD	Obs.#2 P3
D	1	ENE	25.2
D	1	SE	17.3
D	5	ENE	1.6
D	5	SE	1.0
D	3	NNW	0.7
D	2	ENE	0.5
D	3	ENE	0.5
D	3	SE	0.4
D	1	NNW	0.4
D	5	NNW	0.4
D	2	SE	0.2

TABLE 3-5e

Stab.	WS,m/s	WD	Obs.#2 P2
D	1	ENE	24.8
D	1	SE	17.1
D	3	SE	7.9
D	2	ENE	2.1
D	5	ENE	2.0
D	3	ENE	1.7
D	1	NNW	1.6
D	5	SE	1.2
D	3	NNW	1.1
D	2	NNW	1.0
D	2	SE	0.9
D	5	NNW	0.6

TABLE C-11. Concluded

TABLE 3-5g Obs.#3

Stab.	WS,m/s	WD	P1
D	1	ESE	10.0
D	2	ESE	4.4
D	3	ESE	3.3
D	1	E	3.3
D	5	ESE	2.3
D	2	E	0.7
D	1	NNE	0.6
D	2	SE	0.5
D	2	NNW	0.5
D	3	E	0.5
D	5	E	0.4
D	2	NE	0.4
D	2	NNE	0.4
D	2	ENE	0.4
D	2	N	0.4
D	3	NNE	0.3
D	2	SSE	0.3
D	5	NNE	0.2
D	2	S	0.2

TABLE 3-5h Obs.#3

Stab.	WS,m/s	WD	P2
D	1	ESE	27.3
D	1	E	18.0
D	2	ESE	6.6
D	3	ESE	5.3
D	5	ESE	3.9
D	5	E	1.2
D	1	NNE	1.2
D	3	E	1.0
D	3	NNE	0.6
D	5	NNE	0.4

TABLE 3-5i Obs.#3

Stab.	WS,m/s	WD	P3
D	1	ESE	26.5
D	1	E	18.2
D	5	ESE	3.0
D	2	ESE	2.7
D	3	ESE	2.1
D	5	E	1.0
D	3	E	0.4
D	2	E	0.4
D	1	NNE	0.3
D	3	NNE	0.2
D	2	NNE	0.2
D	5	NNE	0.1

TABLE C-12. Frequency of worst-case morning plume ΔE's for observers #1, #2, and #3 in Class I area.

Wind Speed (m/s)	Wind Direction	Delta E P1 Max.	Delta E P1 Avg.	Delta E P2 Max.	Delta E P2 Avg.	Delta E P3 Max.	Delta E P3 Avg.	Frequency of Occurrence (%) Ann.	Wint.	Spr.	Sum.	Fall
OBSERVER #1												
1	WSW,W,WNW	5.0	4.8	8.2	8.0	2.0	1.9	9.8	17.6	3.4	3.7	13.6
1	NE...SE	4.9	4.7	3.6	3.6	0.8	0.8	31.4	49.6	12.9	15.4	45.9
2	NE...SE	3.0	2.8	2.4	2.4	0.5	0.5	65.0	80.3	42.5	59.8	77.4
3	NE...SE	1.0	0.9	1.9	1.9	0.4	0.4	77.8	84.0	60.3	80.8	87.0
5	NE...SE	0.7	0.6	1.3	1.3	0.3	0.3	86.1	86.9	74.3	93.0	91.4
OBSERVER #2												
1	ENE,E,ESE	5.4	1.5	24.8	5.4	25.2	4.5	1.0	0.8	0.0	1.4	1.9
1	NE...SE	3.2	0.9	17.1	4.2	17.3	3.6	2.2	2.4	0.4	2.3	2.9
2	NNE...SSE	1.0	0.2	7.9	1.9	1.6	0.4	14.2	11.1	9.8	23.8	5.8
3	NNE...SSE	0.7	0.2	2.2	1.2	1.0	0.3	17.4	15.1	14.3	29.9	16.3
5	NNE...SSE	0.5	0.1	1.2	0.5	0.4	0.2	19.0	15.5	16.3	34.1	16.3
OBSERVER #3												
1	SE,ESE,SSE	10.0	3.9	27.3	8.1	28.5	6.1	2.3	2.5	1.1	2.3	3.3
1	NE...SSE	4.4	1.5	18.0	4.0	18.2	3.3	3.2	2.6	1.1	4.7	4.1
2	NNE...S	3.3	1.0	6.6	3.0	2.7	1.0	18.3	12.8	12.4	29.0	20.3
3	NNE...S	0.5	0.2	0.6	0.5	0.2	0.2	22.2	14.0	17.3	36.9	22.2
5	NNE...S	0.2	0.2	0.4	0.4	0.1	0.1	24.0	15.2	19.2	41.1	22.5

Appendix D

VISCREEN LISTING

The source code is now made available through the OAQPS Technology Transfer Network SCRAM Bulletin Board (919-541-5742).

Appendix E

DISPERSION PARAMETER CALCULATIONS

Appendix E

DISPERSION PARAMETER CALCULATIONS

Equations that approximately fit the Pasquill-Gifford curves (Turner, 1970) are used to calculate σ_y and σ_z (in meters) for the rural mode. The equations used to calculate σ_y are as follows:

$$\sigma_y = 465.11628\ (x)\ \tan(TH) \quad (E\text{-}1)$$

where:

$$TH = 0.017453293\ [c - d\ \ln(x)] \quad (E\text{-}2)$$

In Equations (E-1) and (E-2) the downwind distance x is in kilometers and σ_y is in meters. The coefficients c and d are listed in Table E-1. The equation to calculate σ_z is as follows:

$$\sigma_z = ax^b \quad (E\text{-}3)$$

where the downwind distance x is in kilometers and σ_z is in meters. The coefficients a and b are given in Table E-2.

TABLE E-1

PARAMETERS USED TO CALCULATE PASQUILL-GIFFORD σ_y

$$\sigma_y = 465.11628\ (x)\tan(TH)$$

$$TH = 0.017453293\ [c - d\ \ln(x)]$$

Pasquill Stability Category	c	d
A	24.1670	2.5334
B	18.3330	1.8096
C	12.5000	1.0857
D	8.3330	0.72382
E	6.2500	0.54287
F	4.1667	0.36191

where σ_y is in meters and x is in kilometers

TABLE E-2

PARAMETERS USED TO CALCULATE PASQUILL-GIFFORD σ_z

Pasquill Stability Category	x (km)	σ_z(meters) = ax^b (x in km) a	b
A*	<.10	122.800	0.94470
	0.10 - 0.15	158.080	1.05420
	0.16 - 0.20	170.220	1.09320
	0.21 - 0.25	179.520	1.12620
	0.26 - 0.30	217.410	1.26440
	0.31 - 0.40	258.890	1.40940
	0.41 - 0.50	346.750	1.72830
	0.51 - 3.11	453.850	2.11660
	>3.11	**	**
B*	<.20	90.673	0.93198
	0.21 - 0.40	98.483	0.98332
	>0.40	109.300	1.09710
C*	All	61.141	0.91465
D	<.30	34.459	0.86974
	0.31 - 1.00	32.093	0.81066
	1.01 - 3.00	32.093	0.64403
	3.01 - 10.00	33.504	0.60486
	10.01 - 30.00	36.650	0.56589
	>30.00	44.053	0.51179

* If the calculated value of σ_z exceed 5000 m, σ_z is set to 5000 m.

** σ_z is equal to 5000 m.

PARAMETERS USED TO CALCULATE PASQUILL-GIFFORD σ_z

Pasquill Stability Category	x (km)	σ_z(meters) = ax^b (x in km) a	b
E	<.10	24.260	0.83660
	0.10 - 0.30	23.331	0.81956
	0.31 - 1.00	21.628	0.75660
	1.01 - 2.00	21.628	0.63077
	2.01 - 4.00	22.534	0.57154
	4.01 - 10.00	24.703	0.50527
	10.01 - 20.00	26.970	0.46713
	20.01 - 40.00	35.420	0.37615
	>40.00	47.618	0.29592
F	<.20	15.209	0.81558
	0.21 - 0.70	14.457	0.78407
	0.71 - 1.00	13.953	0.68465
	1.01 - 2.00	13.953	0.63227
	2.01 - 3.00	14.823	0.54503
	3.01 - 7.00	16.187	0.46490
	7.01 - 15.00	17.836	0.41507
	15.01 - 30.00	22.651	0.32681
	30.01 - 60.00	27.074	0.27436
	>60.00	34.219	0.21716

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-454/R-92-023	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Workbook for Plume Visual Impact Screening and Analysis		5. REPORT DATE October 1992 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Sigma Research Corporation 196 Baker Avenue Concord, MA 01742		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. Contract 68D90067 Work Assignment WA 3-3
12. SPONSORING AGENCY NAME AND ADDRESS Office of Air Quality Planning and Standards Technical Support Division U.S. Environmental Protection Agency Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This document is a revision of the Workbook for Plume Visual Impact Screening and Analysis, EPA-450/4-88-015. Work Assignment Manager: Jawad S. Touma

16. ABSTRACT

The Prevention of Significant Deterioration and visibility regulations of the U.S. Environmental Protection Agency (EPA) require the evaluation of a type of visibility impairment which can be traced to a single source or small group of sources known as "plume blight." This workbook presents current EPA guidance on the use of screening procedures to estimate visibility impairment due to plume blight and is an update and a revision to the earlier book. It includes the screening model (VISCREEN) that can be run on a personal computer. The VISCREEN model is used for both Level-1 and Level-2 screening analyses, and is designed to evaluate plume visual effects along multiple lines of sight across the plume's length for two different viewing backgrounds and for two different scattering angles. It also provides for the evaluation of the potential perceptibility of plumes using recent psychophysical concepts. The workbook provides the technical basis for the model and contains several example applications to illustrate the use of these methods. This document was issued as a draft for public comment and is now being revised to reflect these comments.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Meteorology Air Quality Dispersion Model Visibility Aerosols Nitrogen Dioxide	New Source Review Air Pollution Control	13B 4A 4B

18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 150
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE