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).

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)

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

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_o,Y_o,Z_o). 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.

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.

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).

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

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 $\sigma_y \sigma_z u$ ($1.89 x 10^5$ 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

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).

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:

<u>Calculating Plume Visual Impacts</u>

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 <u>larger</u> 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.

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.

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

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

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

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

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

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

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

$$X_O = \sum_{i=1}^{3} I_O(\lambda_i)\ \overline{x_i}\ ,$$

$$Y_O = \sum_{i=1}^{3} I_O(\lambda_i)\ \overline{y_i}\ ,$$

$$Z_O = \sum_{i=1}^{3} I_O(\lambda_i)\ \overline{z_i}\ ,$$

$$X = \sum_{i=1}^{3} I(\lambda_i)\ \overline{x_i}\ ,$$

$$Y = \sum_{i=1}^{3} I(\lambda_i)\ \overline{y_i}\ ,$$

$$Z = \sum_{i=1}^{3} I(\lambda_i)\ \overline{z_i}\ .$$

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 $\overline{x}\ \overline{y}\ \overline{z}$ 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., $\Delta E = 2$, 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:

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 $N0_2$), 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 $\gamma = 11.25^\circ$ and ϕ = azimuthal angle of observer line of sight).

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 $7.5x10^5$ 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.

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

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

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

See Table C-5 on page C-28 of the original VISCREEN manual

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

See Figure C-12 on page C-41 of the original VISCREEN manual

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

See Table C-10 on page C-42 of the original VISCREEN manual

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

See Figure C-7a on page C-43 of the original VISCREEN manual

Figure C-7b. Observer No. 2.

See Figure C-7b on page C-44 of the original VISCREEN manual

Figure C-7c. Observer No. 3.

See Figure C-7c on page C-45 of the original VISCREEN manual

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.

See Table C-11 on page C-46 of the original VISCREEN manual

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

See Table C-12 on page C-47 of the original VISCREEN manual

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

See Table C-13 on page C-48 of the original VISCREEN manual

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

See Table C-14 on page C-49 of the original VISCREEN manual

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

See Table C-15 on page C-50 of the original VISCREEN manual

TABLE C-11. Concluded

See Table C-15 on page C-51 of the original VISCREEN manual

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

See Table C-16 on page C-52 of the original VISCREEN manual

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

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:

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

(E-1)

where:

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

(E-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:

$$\sigma_z = ax^b$$

(E-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

See Table 1-1 in User's Guide for the Industrial Source Complex (ISC2) Dispersion Models, Volume II - Description of Model Algorithms (EPA-450/4-92-008b)

TABLE E-2

PARAMETERS USED TO CALCULATE PASQUILL-GIFFORD σ_z

See Table 1-2 in User's Guide for the Industrial Source Complex (ISC2) Dispersion Models, Volume II - Description of Model Algorithms (EPA-450/4-92-008b)

TABLE E-2 (Continued)

PARAMETERS USED TO CALCULATE PASQUILL-GIFFORD σ_z

See Table 1-2 in User's Guide for the Industrial Source Complex (ISC2) Dispersion Models, Volume II - Description of Model Algorithms (EPA-450/4-92-008b)