# LESSON 3

# Locating Proximate Middle Scale $SO_2$ Monitoring Stations for Urban and Isolated Point Sources

## Goal

To familiarize you with the siting of proximate middle scale $SO_2$ monitoring stations for urban and isolated point sources.

## Objectives

At the end of this lesson, you will be able to:

1. select the general siting area for an $SO_2$ monitoring station for assessing the annual $SO_2$ impact from an urban point source.
2. recognize source characteristics that increase the probability of stack downwash.
3. define flat terrain.
4. select the general siting areas for an isolated point source's peak $SO_2$ concentration and for background stations in a flat terrain setting.
5. recognize the usefulness of mobile sampling for determining monitoring site locations.
6. define sea-breeze fumigation and recognize its cause.
7. recognize necessary information for determining a sea-breeze fumigation area.
8. describe the effect of terrain elevation on vertical mixing depth for a sea-breeze situation.
9. select the general siting areas for an isolated point source's peak $SO_2$ concentration and for background stations in a ridge/valley setting under various meteorological conditions.
10. describe the effects of moderately rough terrain on ambient $SO_2$ concentrations resulting from isolated point sources.
11. recognize general siting considerations for locating $SO_2$ monitoring stations for isolated point sources in extremely rough terrain.

## Procedure

1 Read pages 52-82 of EPA-450/3-77-013 *Optimum Site Exposure Criteria for $SO_2$ Monitoring.*

2 Complete the review exercise for this lesson.

3 Check your answers against the answer key following the exercise.

4 Review the pages in the reading for any questions you missed.

5 Continue to Lesson 4.

## Estimated student completion time: 7 hours

## Reading Assignment Topics

- Locating proximate middle scale $SO_2$ monitoring stations for urban point sources
- Locating proximate middle scale $SO_2$ monitoring stations for isolated point sources

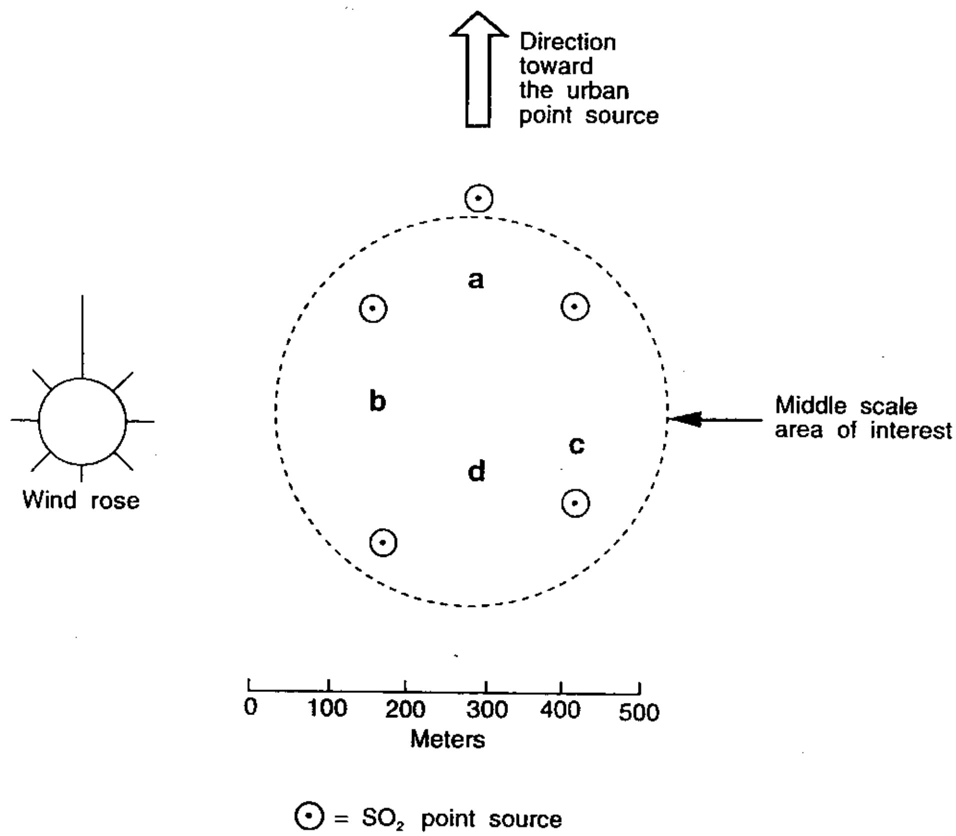
## Reading Guidance

Refer often to the flowchart and figures of the assigned reading material as you progress through the assignment.

# Review Exercise

Now that you've completed the assignment for Lesson 3, please answer the following questions to determine whether or not you are mastering the material.

1. Which of the four general siting areas, labeled a through d, is the best siting area for a proximate middle scale monitoring station for determining the maximum annual $SO_2$ impact from the urban point source?




2. Stack downwash conditions may occur if the ratio between the stack gas velocity and the wind velocity is less than about ________.

   a. 15

   b. 10

   c. 5

   d. 1.5

3. True or False? Stack downwash is likely to occur if the heights of any buildings and other obstructions that exist within a distance of 10 stack heights of the source exceed 2/5 of the height of the stack.

4. Terrain is deemed to be flat if terrain elevations greater than 2/5 the height of the stack do not exist within ________ kilometers of the source.

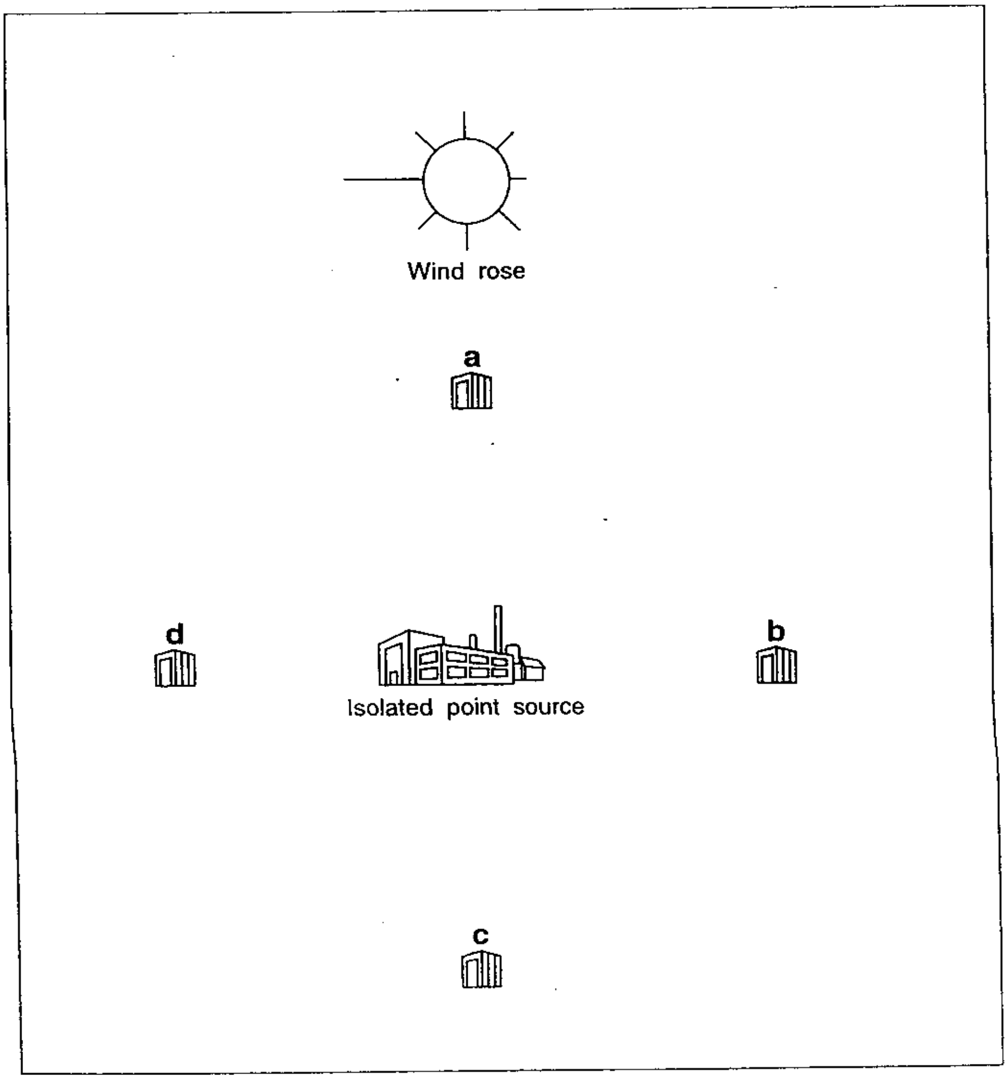
   a. 10

   b. 50

   c. 25

   d. 100

5. Which of the four general siting areas, labeled a through d, is the best siting area for a monitoring station for determining peak $SO_2$ concentrations resulting from the isolated point source?



6. Which of the four general siting areas, labeled a through d in question 5, is the best siting area for an $SO_2$ background monitoring station?

7. True or False? Mobile sampling should be used in locating peak $SO_2$ concentration monitoring stations for determining the air quality impacts of isolated point sources.

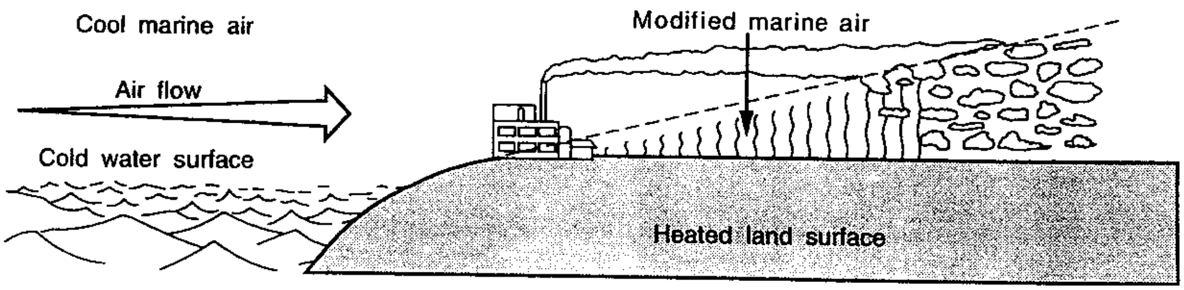
8. The following figure depicts:

   a. plume lofting

   b. plume fanning

   c. sea-breeze fumigation

   d. none of the above




9. Which of the following is necessary for determining a sea-breeze fumigation area?

   a. the difference between the atmospheric temperature at plume height and the sea-surface temperature

   b. the mean wind speed of the marine air/plume layer

   c. the height of the plume

   d. all of the above

10. In a sea-breeze situation, vertical mixing depth ________ as the terrain slopes upward from flat terrain.

    a. decreases

    b. increases

    c. remains the same

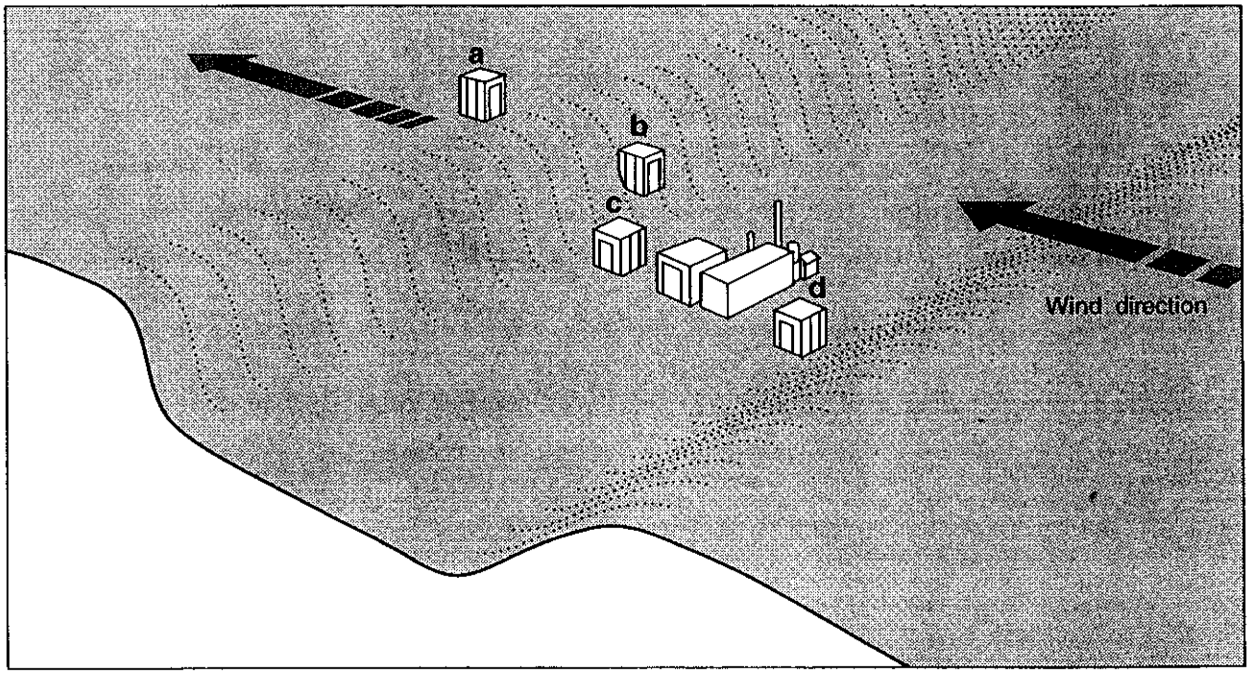
11. In a sea-breeze situation, vertical mixing depth ________ as the terrain slopes downward from flat terrain.

    a. remains the same

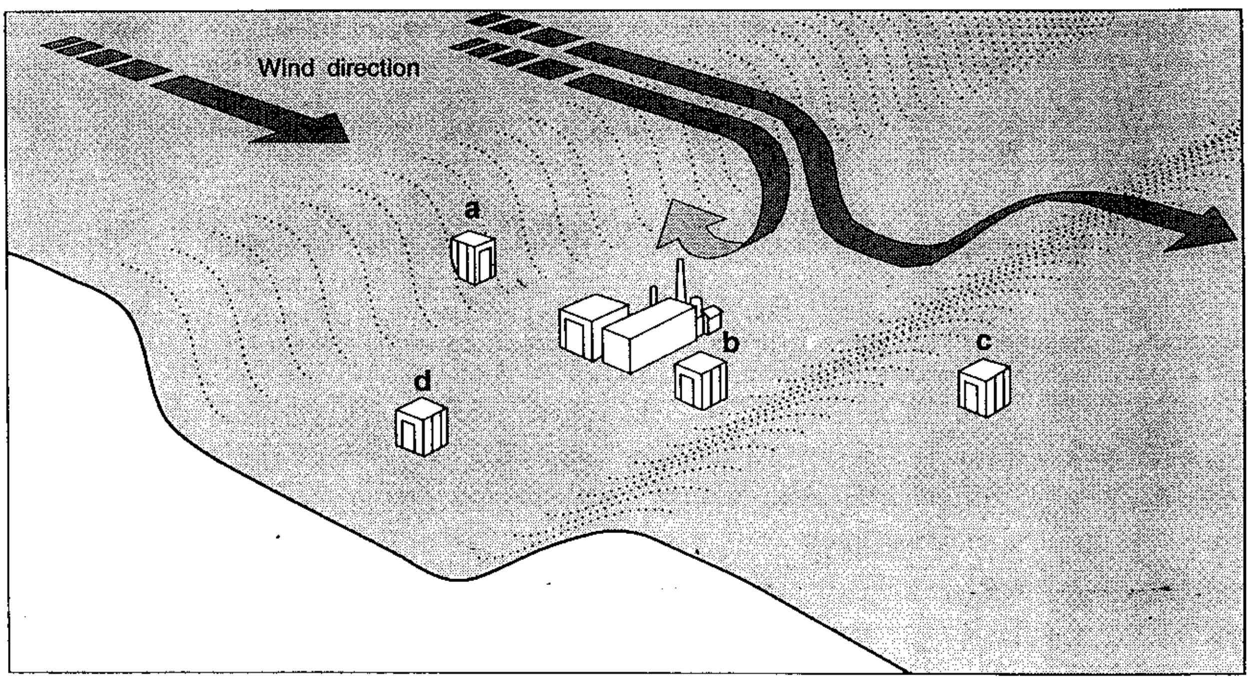
    b. increases

    c. decreases

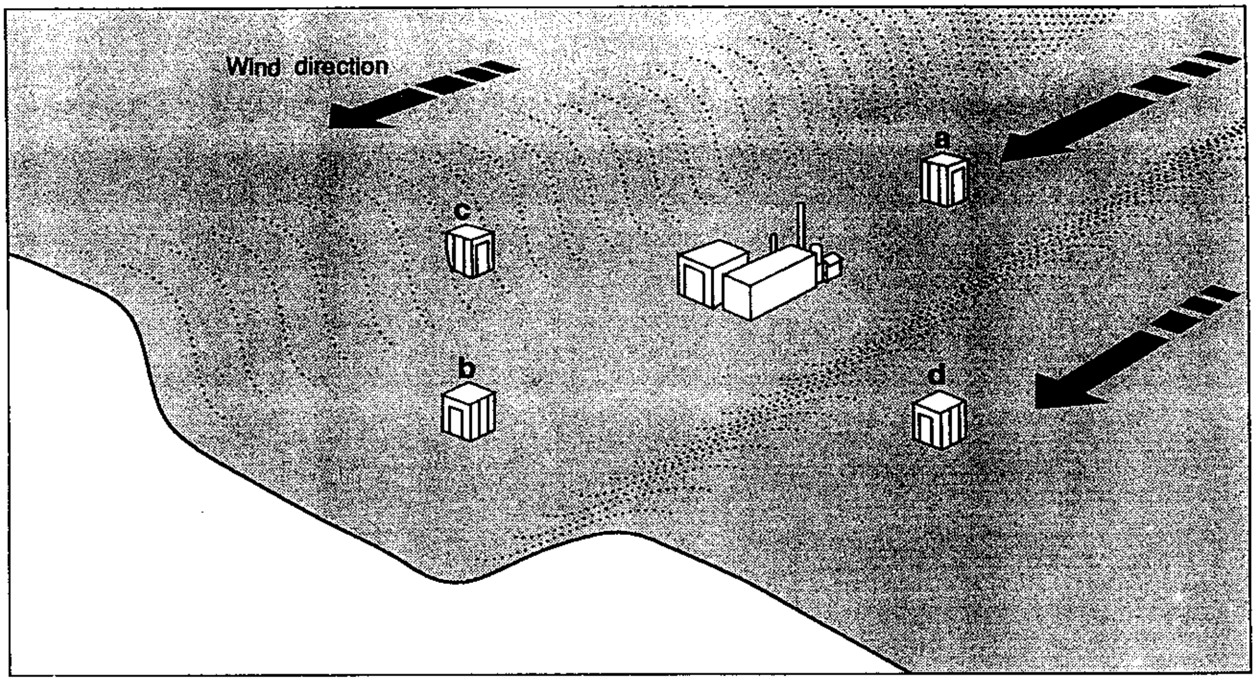
14. Unstable atmospheric condtions




15. Neutral or unstable atmospheric conditions, moderate to strong wind



16. Which of the four general siting areas, labeled a through d, is the best siting area for a background $SO_2$ monitoring station?




17. True or False? When monitoring $SO_2$ resulting from an isolated point source in a ridge/valley setting, one monitoring site should be established at a point nearest the source on the valley wall that is most frequently downwind of the source.

18. True or False? The major effect of moderately rough terrain on a plume is to decrease its rate of dispersal.

19. True or False? In a moderately rough terrain setting, $SO_2$ concentrations are always greater at the top of obstacles.

20. Monitoring stations should be established at which of the following locations when monitoring $SO_2$ impacts from an isolated point source that is located in extremely rough terrain?

   a. for regions subject to periods of low mixing depths, in basins having inlets for the point source's plume

   b. at ridge top locations in the general downwind directions from the point source

   c. both a and b, above

   d. none of the above

# Review Exercise Answers

| | | Page* |
|---|---|---|
| 1. | d | 54-56 |
| 2. | d | 61 |
| 3. | True | 61 |
| 4. | a | 60 |
| 5. | b | 62 |
| 6. | d | 62 |
| 7. | True | 63 |
| 8. | c | 64 |
| 9. | d | 65-66 |
| 10. | b | 66 |
| 11. | a | 66 |
| 12. | a | 71-72 |
| 13. | d | 72-73 |
| 14. | a | 72-73 |
| 15. | b | 74-75 |
| 16. | a | 74 |
| 17. | True | 74 |
| 18. | False | 77 |
| 19. | False | 77 |
| 20. | c | 80,82 |

* Refer to pages 52-82 of EPA-450/3-77-013 *Optimum Site Exposure Criteria for $SO_2$ Monitoring.*

The final site should be chosen such that nearby local sources in this direction also will not unduly impact at the monitoring site.

## 4.5 PROXIMATE, MIDDLE-SCALE STATIONS - Urban Sources

There are two siting objectives associated with proximate, middle-scale stations--assessing the impact of a major point source in a multi-source urban setting, and assessing the impact of an isolated point source. The procedures for siting monitors to satisfy the first objective are heavily dependent on the results of multi-source diffusion model simulations, point source diffusion calculations and "$\chi/Q$" type analyses. For the second objective, knowledge of plume behavior in various terrain environments, special surveys, and mobile sampling results may also be required. Although middle-scale measurements are associated with both objectives, the selection procedures for siting monitors to achieve the two objectives are totally different. In this section, only the first objective is addressed. Isolated point source monitoring is discussed in Section 4.6.

Figure 4-17 is a schematic illustrating the concept of the impact of a major point source in an urban setting. In this situation, the specific siting objectives are to:

- measure the impact of the point source at the urban peak concentration point (Figure 4-17a, point $\chi$), and
- measure the maximum impact of the point source itself (at point $P$ of Figure 4-17a,b).

Averaging times of 3 hours, 24 hours, and one year should be considered, particularly the shorter averaging times.

Figure 4-18 is a flow chart showing the procedure for locating middle-scale stations for assessing the impact of individual urban point sources. The first step is to assemble all background information. This will include:

- Physical data from point source
  - peak and daily mean production rate of $SO_2$
  - stack parameters
  - exact plant location.
- Emission inventory of point and area sources.
- Meteorological data
  - stability wind roses (see Appendix A)
  - wind persistance tables (see Appendix B, Part I).
- USGS/Sanborn maps of urban area.
- Frequency statistics of hourly wind speed and direction (annual data).

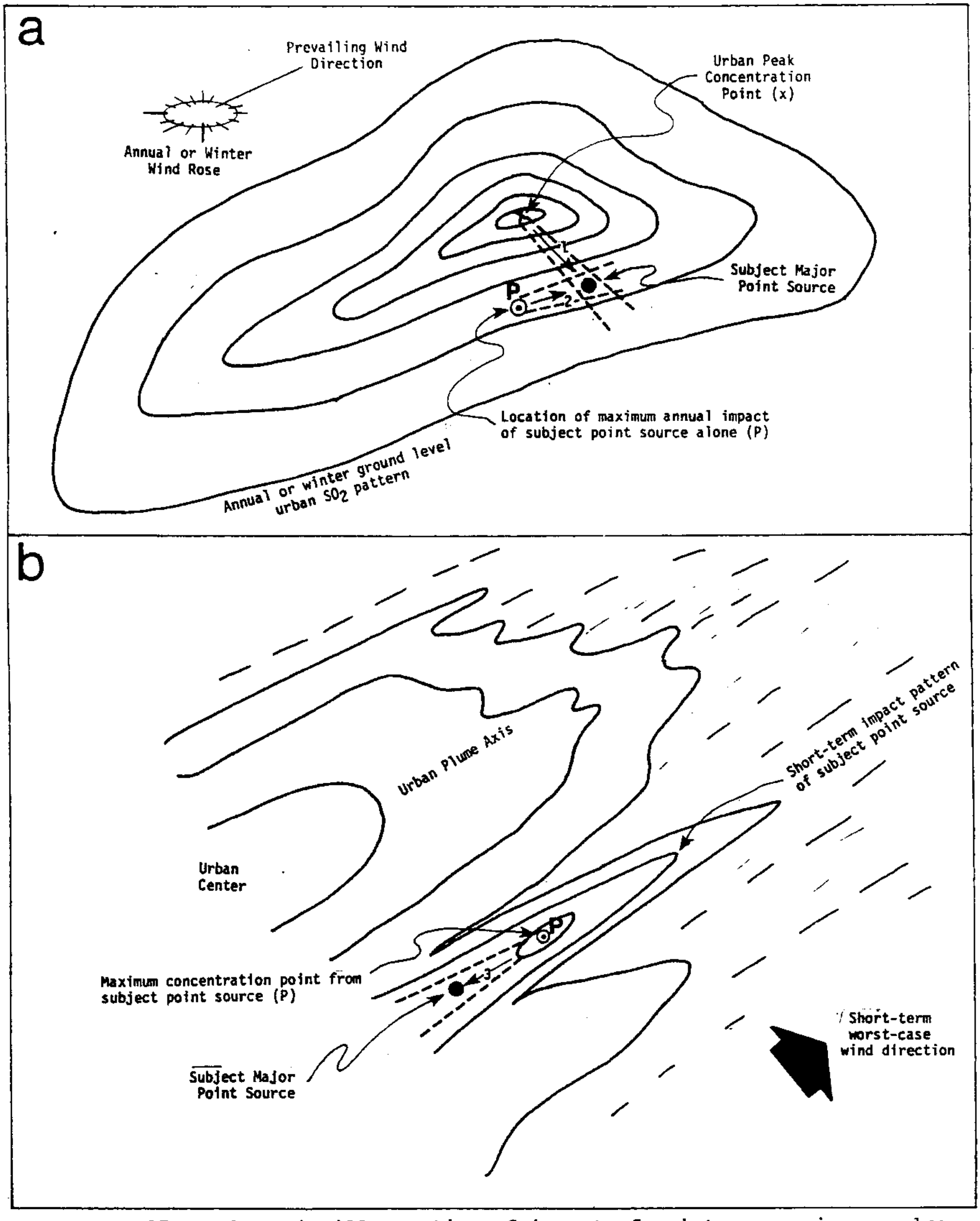



FIGURE 4-17. Schematic illustration of impact of point source in an urban setting for two averaging times: (a) annual pattern, and (b) short-term pattern.

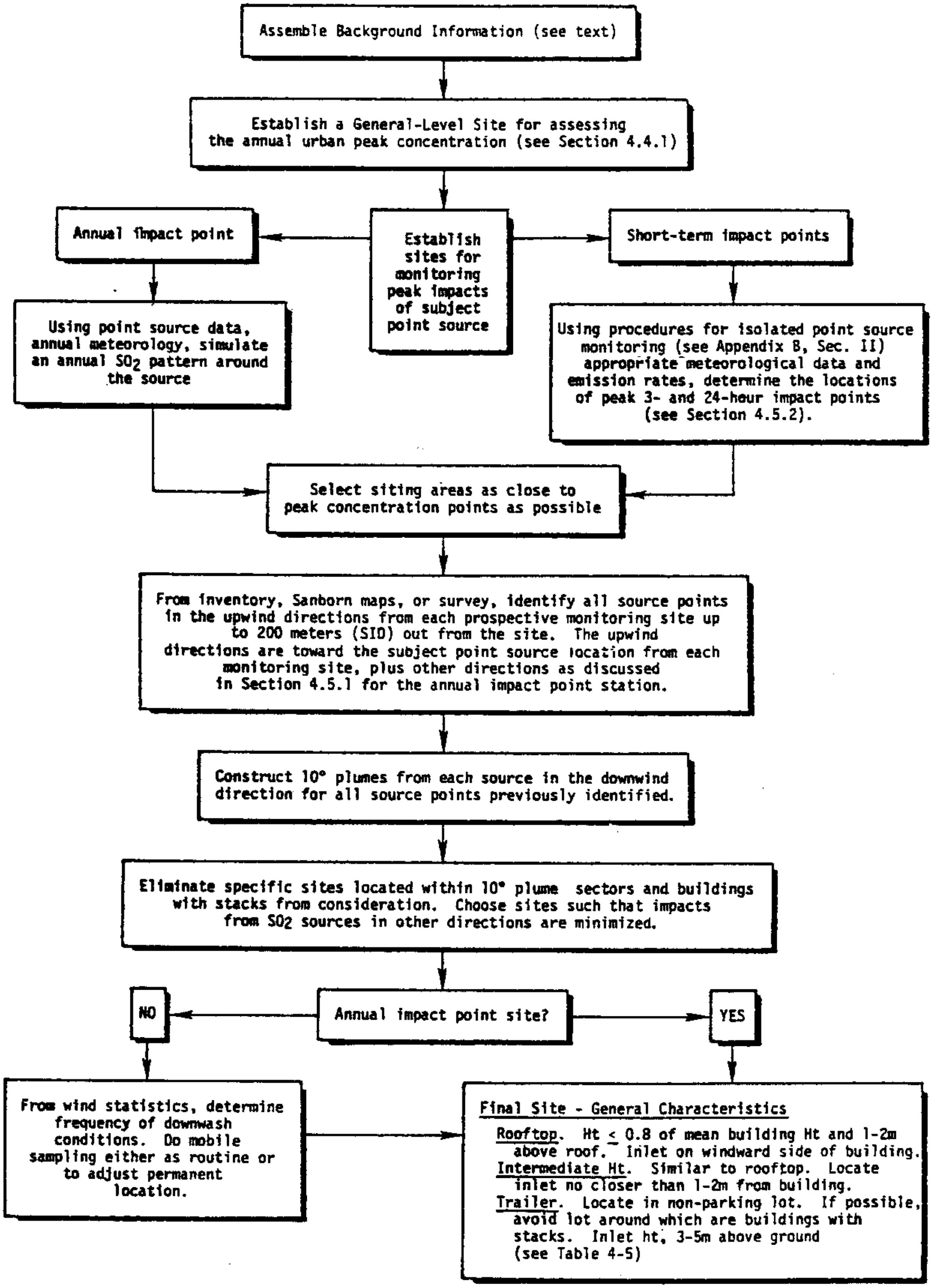



FIGURE 4-18. Flow chart showing procedures for locating proximate middle-scale stations.

### 4.5.1 Annual Peak Concentration Stations

#### 4.5.1.1 General-Level Urban Peak Station

If a monitoring site has not already been established to monitor the general-level (urban) peak annual concentration, establish such a site (point X in Fig. 4-17a) by using the procedures presented in Section 4.4.1.1 for the annual peak stations. However, in the procedure for dealing with undue local impacts (illustrated in Fig. 4-15) consider the direction *toward the subject point source* from the siting area (direction "1", Fig. 4-17a) as well as the winter (or annual) prevailing direction.

#### 4.5.1.2 Proximate Station

The remaining steps of this procedure pertain to the siting of an additional monitor to assess the maximum annual impact from the point source itself. Using the AQDM with annual* meteorological data, appropriate half-life value, annual* average emission rate and stack characteristics of the point source only, simulate the annual* $SO_2$ pattern around the source and establish a siting area centered on the maximum concentration point, Point "P" in Figure 4-19 (which is point "P" in Fig. 4-17a). Figure 4-19 shows the annual $SO_2$ pattern due to the point source only. The next few steps are the same as those discussed in Section 4.4.1 (illustrated in Fig. 4-15 in that section), except that an additional direction must be considered for identifying another critical sector that contains sources which may produce undue influences--*the upwind direction between the siting area and the subject point source* (direction "2", Fig. 4-17a); however, this direction is probably the same as the prevailing wind direction for the time period simulated. Use Table 4-5 for final site characteristics and inlet exposure.

### 4.5.2 24-Hour and 3-Hour Maximum Concentration Stations

These stations are analogous to the 24-hour and 3-hour maximum concentration stations associated with the urban peaks except that these assess the peaks due to the subject point source alone (Point "P" in Fig. 4-17b). In this case, we can pretend that the point source is located in an <u>isolated</u> area of rough topography. The location of the peak 24-hour and 3-hour average concentration points due to the source, and associated "worst case" meteorology can be determined by an approach suggested in Appendix B, Section II. After determining these locations, use the procedure found in Section 4.4.1.1 (regarding annual peak stations) for selecting the siting area and specific station locations. However, in this situation, only one wind direction is used for determining undue influence of nearby sources--the direction from the siting area toward the subject point source (direction "3", Fig. 4-17b).

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* If the emission rates and meteorology vary significantly over the year, it may be better to use the average of four seasonal simulations; if subject point source emissions are degree-day dependent, use winter meteorology.

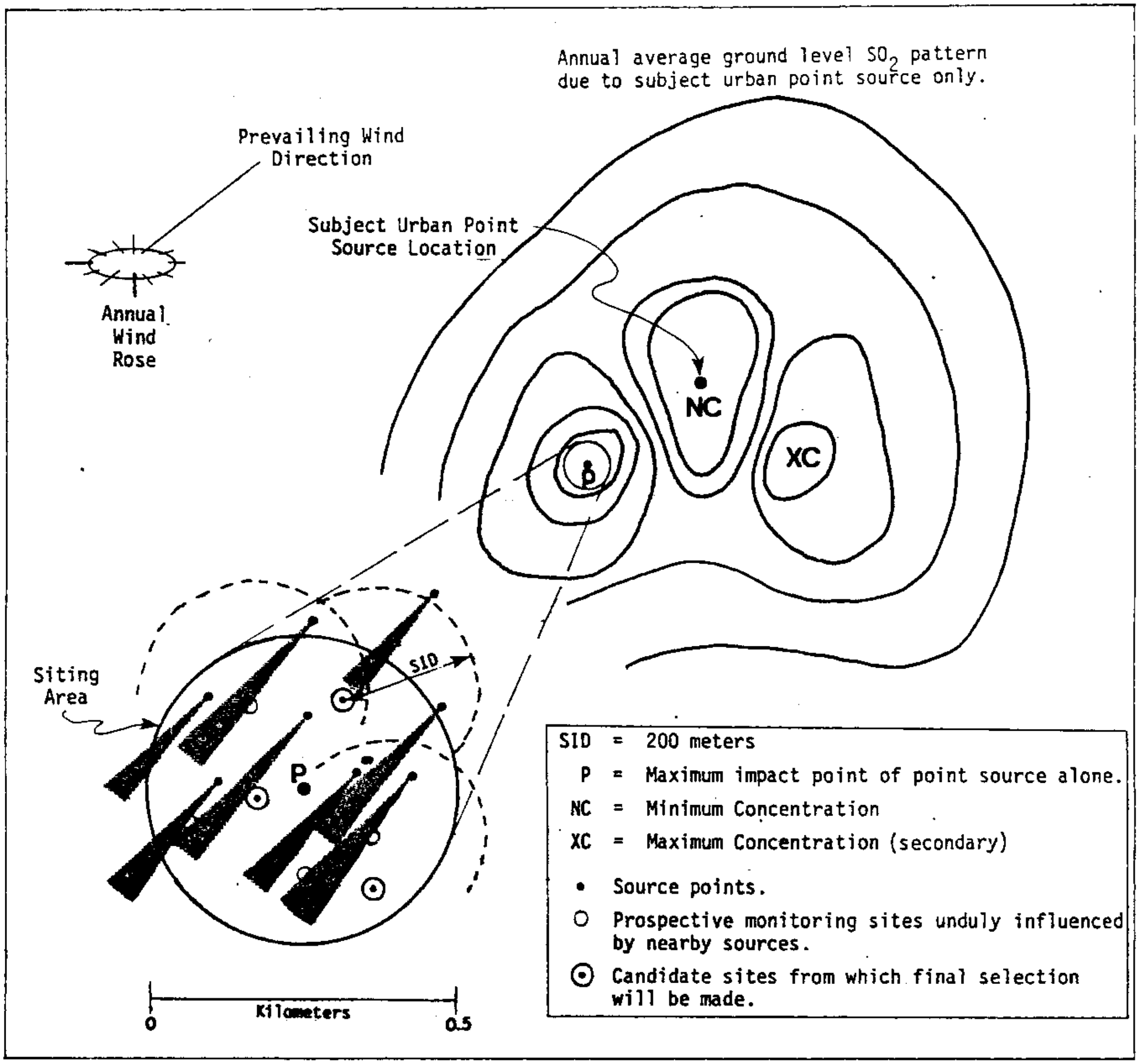


FIGURE 4-19. Schematic illustration showing annual impact pattern due to urban point source alone, the siting area, and final candidate sites for assessing the annual impact from the point source.

Before deciding on a final site location, it might be a good idea to determine the expected frequency of downwash conditions. (It is recognized that over large urban areas in the daytime, downwash conditions are the rule rather than the exception, especially for the lower level sources. However, for the larger (and more elevated) sources such may not be the case; but, because the sources are large, if and when downwash occurs the ground-level impact of such occurrences could be substantial.) If the wind statistics (e.g., see Table 4-6) for the area show that the stack exit velocities are less than 1.5 times the wind speed (Sherlock and Stalker, 1941), or if the height of the stack is not at least 2.5 times the height of the highest surrounding buildings (Hawkins and Nonhebel, 1955), downwash conditions are likely. Sanborn maps or surveys will resolve the latter situation. To resolve the former, the following procedure is recommended:

> From load curve and/or hourly fuel consumption data obtained from the source, determine the typical hourly exhaust gas flow and velocity rates. Then tabulate these velocities by the hour and compare them to the hourly wind speed frequencies of Table 4-6 for the same hour. If downwash conditions will be frequent, mobile sampling may be necessary, either as a routine operation to monitor the 3-hour peak or to determine the location of a final permanent site, or, perhaps, even to delineate a new siting area within which a permanent site will be selected. Use Table 4-5 (see Page 45) for final site characteristics and inlet exposure.

TABLE 4-6

Percentage Frequencies of Sky Cover, Wind, and Relative Humidity (Taken from NCC)

| HOUR OF DAY | CLOUDS SCALE 0-10 | | | WIND SPEED (M.P.H.) | | | | RELATIVE HUMIDITY (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0-3 | 4-7 | 8-10 | 0-3 | 4-12 | 13-24 | 25 & OVER | 0-29 | 30-49 | 50-69 | 70-79 | 80-89 | 90-100 |
| 00 | 18 | 8 | 75 | 4 | 46 | 46 | 5 | | 4 | 17 | 30 | 32 | 20 |
| 01 | 17 | 7 | 75 | 4 | 46 | 46 | 4 | | 1 | 18 | 27 | 35 | 19 |
| 02 | 15 | 6 | 79 | 5 | 45 | 45 | 5 | | 1 | 16 | 79 | 34 | 20 |
| 03 | 17 | 5 | 78 | 5 | 45 | 46 | 5 | | 1 | 16 | 30 | 33 | 20 |
| 04 | 15 | 7 | 77 | 4 | 48 | 43 | 5 | | 1 | 15 | 28 | 34 | 22 |
| 05 | 15 | 9 | 76 | 4 | 47 | 42 | 7 | | 1 | 16 | 28 | 34 | 21 |
| 06 | 14 | 7 | 79 | 5 | 48 | 41 | 6 | | 2 | 15 | 32 | 32 | 20 |
| 07 | 10 | 11 | 78 | 5 | 47 | 42 | 6 | | | 15 | 34 | 32 | 20 |
| 08 | 10 | 8 | 82 | 4 | 48 | 43 | 5 | | 1 | 14 | 33 | 34 | 18 |
| 09 | 12 | 10 | 78 | 5 | 44 | 44 | 7 | | 1 | 20 | 34 | 28 | 16 |
| 10 | 12 | 12 | 76 | 4 | 38 | 52 | 6 | | 2 | 29 | 28 | 27 | 14 |
| 11 | 11 | 14 | 75 | 2 | 40 | 52 | 6 | | 3 | 35 | 25 | 22 | 15 |
| 12 | 10 | 14 | 77 | 2 | 35 | 54 | 9 | | 3 | 36 | 28 | 18 | 15 |
| 13 | 10 | 13 | 77 | 5 | 31 | 54 | 11 | | 3 | 40 | 25 | 16 | 15 |
| 14 | 9 | 15 | 76 | 4 | 35 | 55 | 7 | | 5 | 42 | 22 | 16 | 15 |
| 15 | 10 | 14 | 76 | 3 | 35 | 55 | 8 | | 5 | 40 | 22 | 18 | 15 |
| 16 | 11 | 15 | 74 | 2 | 41 | 52 | 5 | | 4 | 37 | 25 | 18 | 16 |
| 17 | 14 | 15 | 71 | 3 | 47 | 45 | 5 | | 2 | 31 | 30 | 21 | 16 |
| 18 | 15 | 13 | 72 | 5 | 45 | 46 | 4 | | 2 | 27 | 29 | 27 | 16 |
| 19 | 18 | 9 | 73 | 5 | 43 | 48 | 5 | | 1 | 24 | 29 | 29 | 17 |
| 20 | 16 | 11 | 73 | 4 | 42 | 50 | 5 | | 2 | 21 | 31 | 28 | 19 |
| 21 | 18 | 11 | 71 | 4 | 43 | 50 | 4 | | 1 | 21 | 31 | 30 | 18 |
| 22 | 18 | 9 | 73 | 4 | 44 | 47 | 5 | | 4 | 18 | 35 | 29 | 18 |
| 23 | 20 | 8 | 72 | 5 | 44 | 45 | 6 | | 1 | 16 | 31 | 32 | 19 |
| AVG | 14 | 10 | 76 | 4 | 43 | 48 | 6 | | 2 | 24 | 29 | 27 | 18 |

## 4.5.3 Data Interpretation

The total concentration of $SO_2$ in the samples taken at the above sites consists of contributions from most of the sources in the urban area as well as that from the subject point source. The former may be considered as background noise that cannot be separated from the total. Therefore, to estimate the percentage of the sampled concentration due to the subject point source alone, diffusion modeling must be utilized. Figure 4-20 illustrates the recommended approach very well for the annual situations. The two vertical profiles on the right side of the figure are source contribution results computed by the AQDM model at the indicated points of interest. Displayed as seen in the figure, they may be interpreted as "source contribution profiles" and represent the best estimate of what each source contributes to the total concentration at those points. In this case, there are two points of interest--the urban annual peak concentration point, and the corresponding impact point "P" (pattern, lower left corner), where the maximum annual impact from the point source of interest ("10") occurs. The upper profile represents the highest total concentration in the entire urban area, and in this particular case, source 10 contributes the least to that concentration. (However, it is more than likely that in the real world any point source worthy of individual attention will almost certainly contribute substantially to the highest urban peaks.) The lower profile represents the total concentration at source 10's maximum impact point, with source 10 being the largest contributor to that concentration.

In a similar approach, for the short-term impacts, the 3-hour and 24-hour worst case meteorology, and emission data (appropriate for season in which the worst cases occur) for the entire urban area can be input to the AQDM to determine the short-term background concentrations at the maximum impact points of the subject point source. Source contribution profiles may also be generated by the model and analyzed in a manner similar to that discussed above.

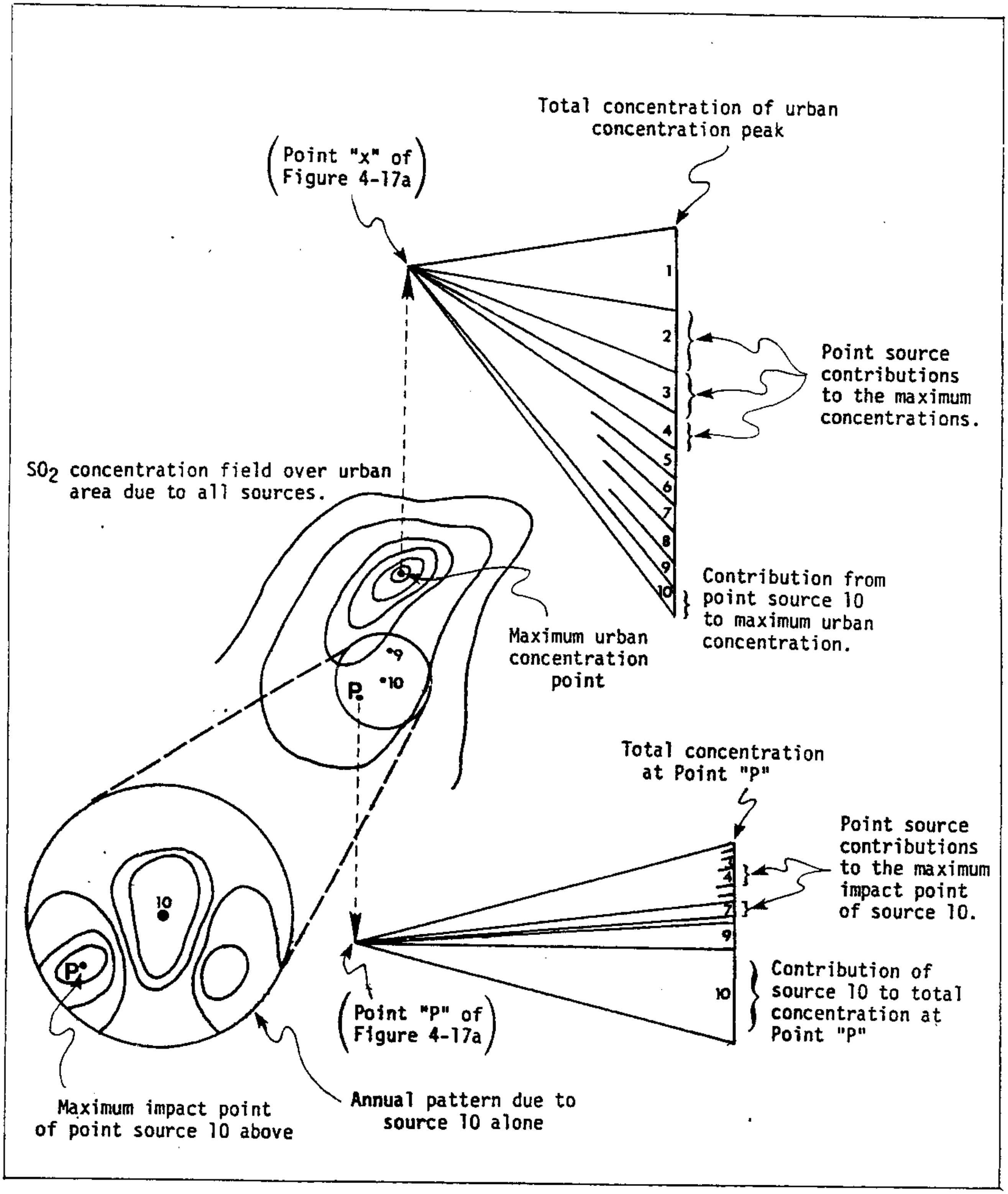


FIGURE 4-20. Schematic illustration of the concept of the source contribution profile in an urban area for the annual pattern (a synthesis of Figures 4-17a and 4-19).

These kinds of analyses should be performed at each monitoring site to estimate the percentage of the measured concentration due to the point source of interest. The model used can be run either calibrated or uncalibrated, but appropriate half-life decay factors should be used. A yearly analysis with updated meteorological and emissions data is recommended in order to explain trends and to determine relative effects of control strategies.

## 4.6 PROXIMATE, MIDDLE-SCALE STATIONS - Isolated Sources

Because of the great variety of physical environments in which isolated point sources* are found, it was not possible to develop a single set of procedures for selecting sites for monitoring the impacts of such sources applicable uniformly, in all environments. Therefore, where possible, it was decided to present examples of monitoring site configurations, each reflecting an approach to the site selection problem in a given characteristic physical environment. In other situations where typical settings can be extremely varied and complex, only a general description of the kinds of siting problems expected to be encountered in such settings is discussed, mainly in terms of "points to consider". It is hoped that these examples will serve as guides for the site selector in developing the steps necessary for the proper siting of monitors in specific situations. In presenting the examples, specific points will be addressed wherever possible to help the site selector in developing and executing the steps.

The material presented is essentially an expansion of existing guidelines (EPA,1974b) but with more emphasis placed on the use of the diffusion equation and graphical aides in selecting monitoring sites. Additional points addressed include problems of plume behavior in various terrain environments and the role of mobile sampling in the site selection process. In this regard, in some situations it may be necessary to determine the distribution of the plume material in order to ascertain the plume's statistical characteristics; this will require microscale measurements, most easily accomplished via mobile sampling. For a rather comprehensive overview of isolated point source monitoring, the reader is referred to a paper by Paulus and Rossano (1973).

The situations described in this section will also be applicable to monitoring networks established to satisfy supplementary control system (SCS) requirements. Since these systems are rather complex and comprehensive (i.e., they integrate ambient and in-stack monitoring, diffusion modeling, emission controls, etc. in a predictive scheme) detailed treatment of the subject was considered beyond the scope of this report. However, a description of the components of a typical supplementary control system can be found in the Federal Register, Vol. 38, No. 178, Friday, September 14, 1973. See also Montgomery, et al. (1975) for a description of TVA's SCS system.

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* Point sources in this context consist of power plants, sulfide smelters, sulfuric acid plants, coal conversion plants, or refineries located away from populated or developed areas.

The material presented below includes typical examples of isolated point source monitoring problems expected to be encountered in a variety of physical terrain settings. The major role expected to be played by mobile sampling would be either in routine monitoring or in the refining of preliminary site locations for permanent monitoring stations. (To maintain the continuity of the section, the concept of mobile sampling, *per se*, is discussed briefly in Appendix C.)

The specific objectives in monitoring the $SO_2$ impact of isolated point sources, regardless of terrain setting, are to:

- determine the short-term maximum concentrations downwind of the source and where they occur. (Samplers may be placed where the highest peak is likely to occur and where relatively high peaks are likely to occur very often. It can be assumed that the annual standard will not be threatened by emissions from an individual <u>isolated</u> source.)

- determine the background concentrations by establishing a monitoring site in the direction from the source opposite to those above.

The major problem is to account for the effects imposed by the various terrain settings in determining where to place the monitors to measure the peak values. The terrain settings addressed below are: flat, near coastline, ridge-valley, and irregular-rugged.

### 4.6.1 Monitoring in Flat Terrain Settings

The recommended procedures in this situation are very similar to those given in EPA (1974b). Plumes behave rather well in this kind of setting and are amenable to treatment with standard diffusion equations.

The first step is to assemble the background information. It should include:

- USGS maps of the area.

- Physical data from point source:
  - peak daily mean production rates of $SO_2$,
  - stack parameters,
  - exact plant location.

- Stability wind roses (climatological).
- Wind persistence tables.

(See Appendices A and B.)

The next step is to confirm that the terrain is flat so that the recommended siting techniques are applicable. The terrain is deemed to be flat if:

- Terrain elevations more than 2/5 the height of the stack do not exist within 10 km of the source (EPA, 1974c).

#### 4.6.1.1 Peak Concentration Stations

After determining that the terrain is flat, a determination must then be made whether the source should be monitored. A screening technique suggested by the EPA (EPA, 1974b, Appendix C) is also suggested here for this purpose. If the technique indicates that monitoring need not be undertaken, check for the possibility of downwash situations occurring. Downwash is likely to occur if:

- the heights of any buildings and other obstructions that exist within a distance of 10 stack heights of the source exceed 2/5 of the height of the stack.

Downwash conditions may also result if the ratio between the stack gas velocity ($V_S$) and the wind velocity ($V$) is less than about 1.5. In this case, the effective stack height would be no more (and probably less) than the physical stack height and ground-level concentrations would increase. To assess this, one can do an analysis similar to that described in Section 4.5.2 to estimate the frequency of downwash conditions. Vary the production rates (and $V_S$ ) and then compare $V_S$ to the wind speed frequency (see Table 4-6, Page 57) expected over the area to estimate an expected frequency of downwash conditions. Then determine the expected ground-level concentrations by assuming that the effective stack height equals 1/2 of the physical stack height. If the resulting concentrations exceed the threshold concentration prescribed in the screening technique, then use mobile sampling when downwash conditions are predicted. Permanent monitoring sites may be located in "favored" areas if the mobile sampling results show ground-level peaks consistently occurring in about the same place. Site characteristics, etc. are discussed in Section 4.6.1.5.

If a need for monitoring has been determined by the screening technique, but not due to downwash conditions, the estimated locations of the peak 24-hour and 3-hour maximum concentration points can be determined by a technique suggested in Appendix B, Part II for isolated point sources. From Appendix B, Part II, and/or from downwash analyses, then, we have determined the approximate locations of:

- the near-worst 24-hour average concentration,
- the near-worst 3-hour average concentration,
- where a very high concentration occurs very often.

#### 4.6.1.2 Background Stations

The locations of the background stations should be selected to measure the quality of the incoming air. The difference between this background concentration and the peak concentrations measured downwind of the source is equal to the contribution due to the source alone. Background stations should be located:

- in the direction from the source opposite the peak concentration stations, These sites should be located within a few kilometers of the source. Figure 4-21 illustrates a possible monitoring site configuration around an isolated point source in flat terrain.

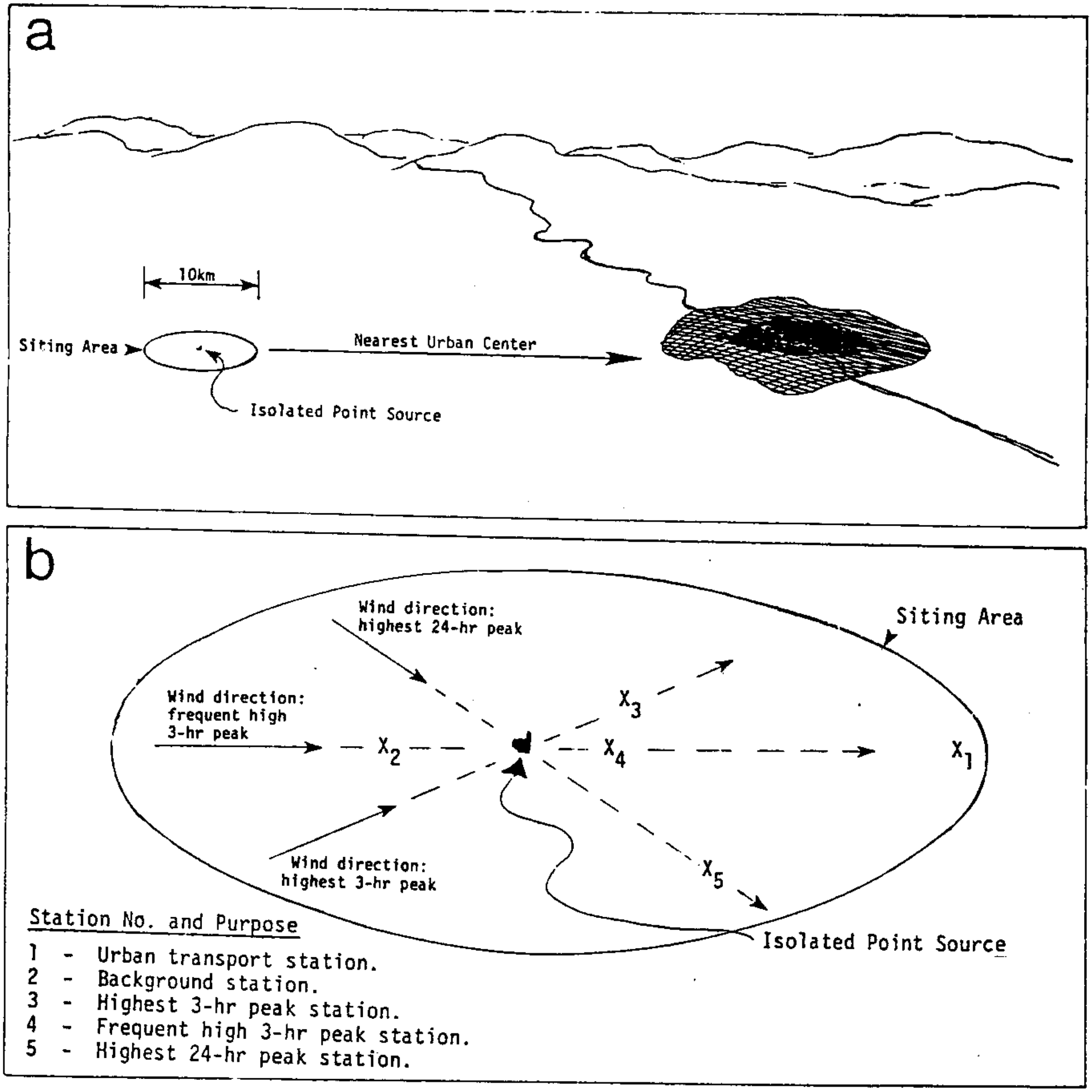


FIGURE 4-21. Illustration of possible monitoring site configuration around an isolated point source in flat terrain; (a) relationship to local geography, and (b) blowup of siting area.

#### 4.6.1.3 Fumigation Effects

It is possible that the highest 3-hour concentrations result from "fumigation". This phenomenon usually occurs as a result of inversion "breakup" after sunrise. Because of the flat terrain and the characteristic light and variable wind conditions associated with such a situation, it is unlikely that a single stationary sampling site could be established for the sole purpose of measuring such concentrations. The recommendation is to use mobile sampling when fumigation is predicted to occur. It is also likely that at least one of the other sampling stations will detect the phenomenon occasionally. Several analysis techniques for estimating fumigation concentrations and where they occur are available--e.g., see EPA (1974c), Turner (1974), and Slade (1968).

#### 4.6.1.4 Role of Mobile Sampling and Final Site Selection

The above procedures can only approximate the location of the peak concentration points because:

- The available meteorological data may not be exactly representative of conditions in the vicinity of the source (main reason for erecting meteorological towers).
- For a given wind direction and stability class (from a stability wind rose) the frequency of wind speed events is reported as occurring within a range of speeds. This wind speed range would correspond to a distance range along the azimuth.
- Diffusion equations are only accurate to within a factor of two or so.

Accordingly, terrain roughness and road accessibility permitting, mobile sampling should be utilized to refine the site locations, particularly those for the 3-hour peak stations. When the meteorological conditions that produce the peak concentrations are predicted, the mobile unit can be dispatched. After a number of occurrences, a plot of observed peak concentration points could probably be enclosed by a circle of middle-scale dimensions (up to 500 m in diameter); the final site should be located near the center of the circle.

#### 4.6.1.5 Site Characteristics and Inlet Placement

The site characteristics and inlet placement for these sites are similar to those for regional monitoring stations. Since the topography is flat, low lying areas should not be a problem; in any case, they should be avoided. Open or sparsely forested areas are recommended with the instruments housed in either a trailer or other stationary structure. Inlet height should be no higher than about 3 to 5 meters. If any buildings in the vicinity are heated by fossil fuels, be sure that they are not between the monitoring site and the source. Otherwise, such buildings and clumps of trees create little cavity wakes which tend to increase the effective sampling volume of the instrument.

If locating a site in a densely forested area is unavoidable, the inlet tube should be raised a few meters above the tops of the surrounding trees. Locate on the lee side of clearings, if possible.

### 4.6.1.6 Instrument Type and Supplementary Instrumentation

Since we are concerned with the short-term peak concentrations, continuous instrumentation will be required at all stations. Instrumented towers for measuring pertinent meteorological variables, such as temperature lapse rates and wind variation with height (also, air quality as well), are often constructed in the vicinity of a large source or source complex (Munn and Stewart, 1967). They are usually required in situations where the available meteorological data is not representative of the source area, as is often the case in conjunction with the preparation of environmental impact statements (EIS) prior to the construction of large sources. Gill, et al. (1967) and the AEC (1972) describe optimal design configurations for towers and how resulting data should be interpreted, respectively.

## 4.6.2 Monitoring in Near Coastline Settings

When a tall stack is located near a seacoast or other large body of water such that sea or lake breezes may influence the $SO_2$ plume, a phenomenon known as a "sea-breeze fumigation" may occur. It results when the stack plume, initially embedded in a stable, sea-breeze flow is convectively mixed down to the ground downwind. The mixing is caused by a vertically growing mixing layer resulting from the stable marine air being heated from below by the land surface as it moves inland (van der Hoven, 1967).* An effort to model fumigation occurring inland from a large lake has recently been reported by Peters (1975). Figure 4-22 is a schematic illustrating the phenomenon. Unlike fumigation resulting from a nocturnal radiation inversion, which might only last for about a half-hour or so, sea-breeze fumigations may last for several hours due to the constant replacement of stable air by the on-shore flow. These short-term sea breeze fumigation concentrations may very well exceed those observed over flat terrain away from marine influences and, therefore, should be monitored, either with appropriately placed permanent stations, or via mobile sampling.

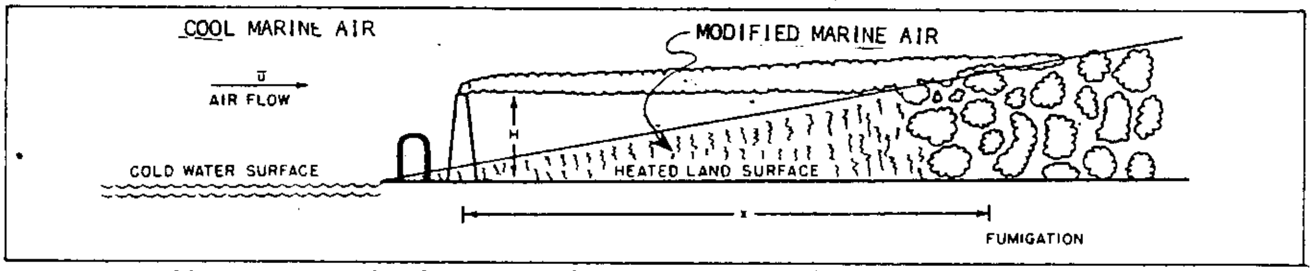


FIGURE 4-22. Schematic illustration of a sea-breeze fumigation situation (taken from Van der Hoven, 1967).

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* In actuality, this phenomena may occur in any on-shore flow if the associated marine air becomes less stable as it moves inland over a heated ground surface.

A recommended procedure for such monitoring is presented below. It is based on the results of a study by Collins (1971) in which the occurrence of sea-breeze fumigations and where they occurred were accurately predicted. The concept is essentially universally applicable except where the coastal topography is extremely rough. The procedure also requires that mobile sampling be utilized. As an illustration of the procedure, consider a plume embedded in a layer of cool marine air at an elevation of 100 meters and moving inland. Data from the 100-meter level (the same elevation as the plume) of an instrumented meteorological or TV tower (or equivalent) are assumed to be available as well as sea-surface temperatures (either estimated or specially taken). For the next series of steps, refer to Figure 4-23 for flat terrain or to Figure 4-24 for rising terrain (height of terrain is subtracted from height of plume above MSL). From the tower data and sea-surface temperatures, the following values are computed:

- $\Delta\theta$ (potential temperature difference) - the 100-m temperature (°C) + 0.91°C* minus the sea-surface temperature (see Figure 4-25).

  $\Delta\theta$ indicates the stability of the layer between plume height and the ground with higher values indicating the more stable conditions. The more stable the atmosphere, the longer it takes for the mixing layer to grow and farther inland the plume will advance before intercepting the mixing layer.

- $\bar{u}$ The mean wind speed within the layer of interest (the wind speed observed at the 50-m level).

  $\bar{u}$ indicates the mean wind speed at which the plume and the stable air is transported inland. The slope of the upper boundary of the mixing layer to the terrain is related to this speed; i.e., at a very low wind speed the mixing layer would intercept the plume relatively close to its source (everything else being equal).

Then, from Figure 4-23 or 4-24, the distance to where the plume intercepts the mixing layer and, therefore, to the initial point of plume touchdown (fumigation) is ascertained (typically, ~0.2 to 2.0 km from the source). In a sea-breeze situation, the direction toward which the plume blows is usually a compromise between the direction normal to the mean shoreline orientation and the flow dictated by the large-scale pressure field. If the wind direction at the 50-meter level on the tower is available (after the sea-breeze has passed), this could be used. The point defined by the distance from the source to where the fumigation is predicted to take place and the 50-meter wind direction could be considered the initial starting point of a search for the maximum fumigation concentration via mobile sampling. In this instance, a vertical sensing capability would be quite helpful.

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* 0.91°C is the adiabatic temperature change that a parcel of air will undergo when brought down to the surface from a 300-ft (100-m) elevation.

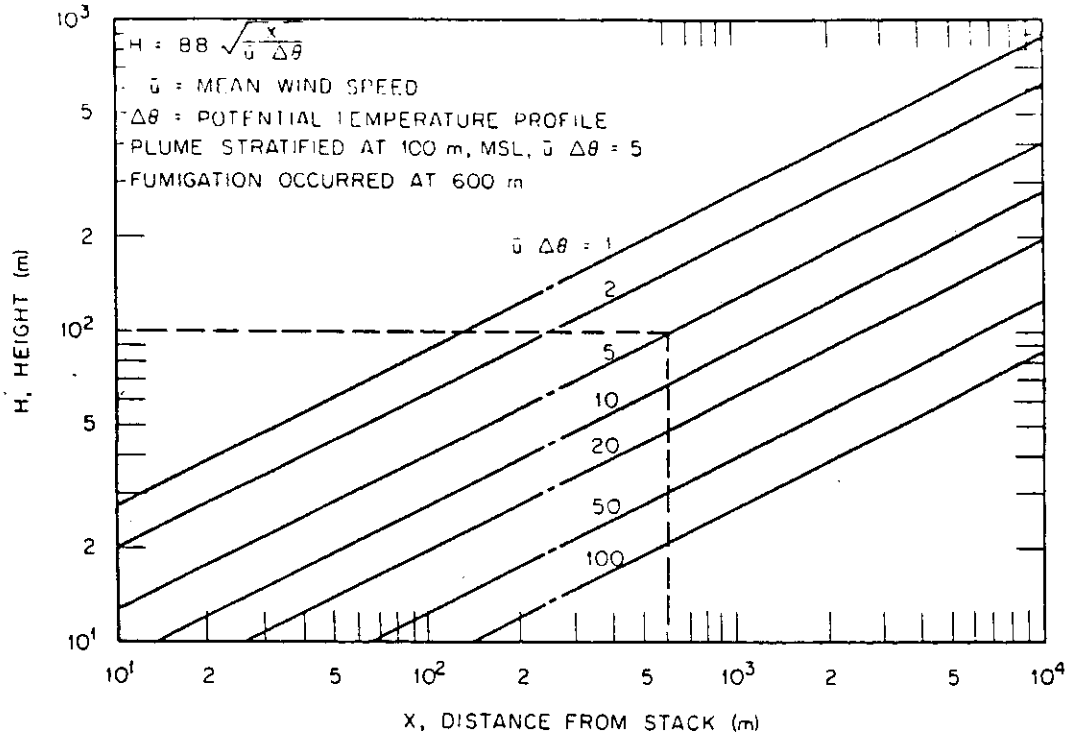


FIGURE 4-23.

Mixing depth as function of stability, wind speed, and inland travel distance (taken from Collins, 1971).

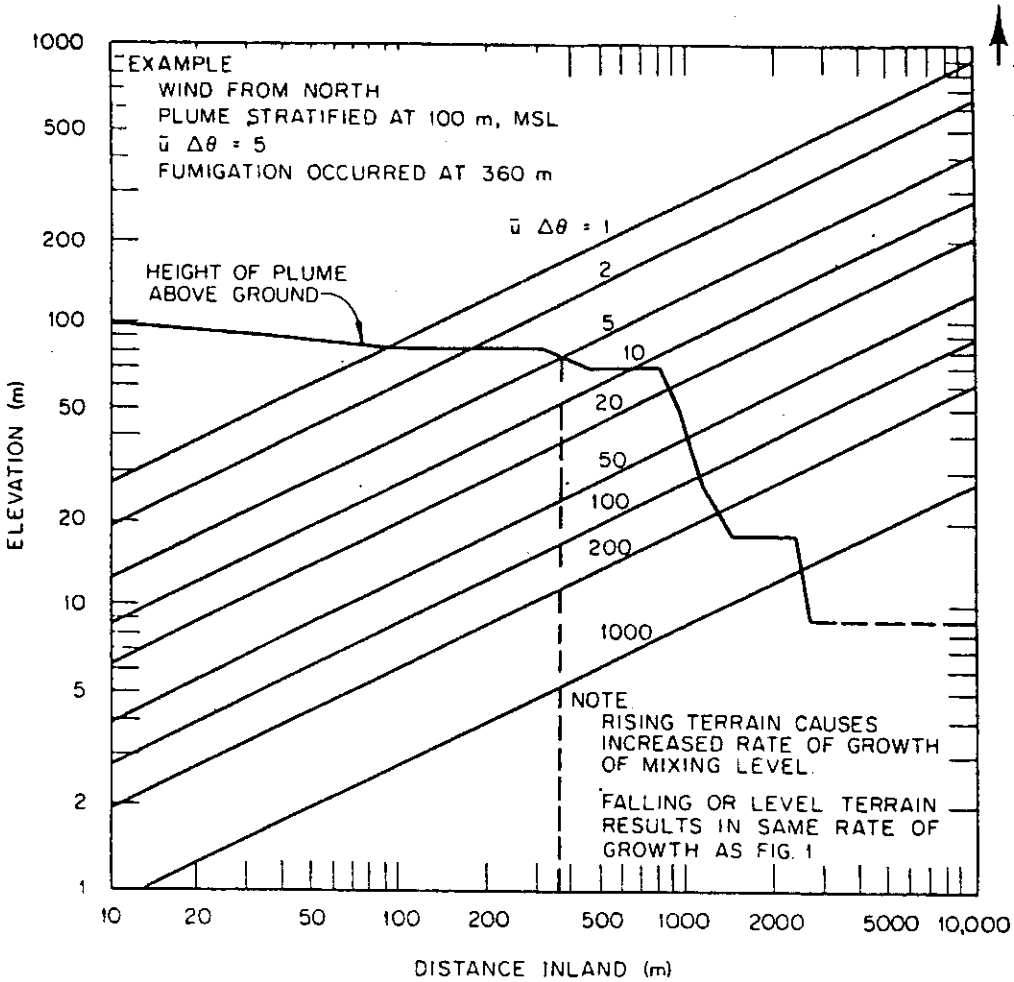


FIGURE 4-24.

Vertical mixing depth adjusted for terrain (taken from Collins, 1971).

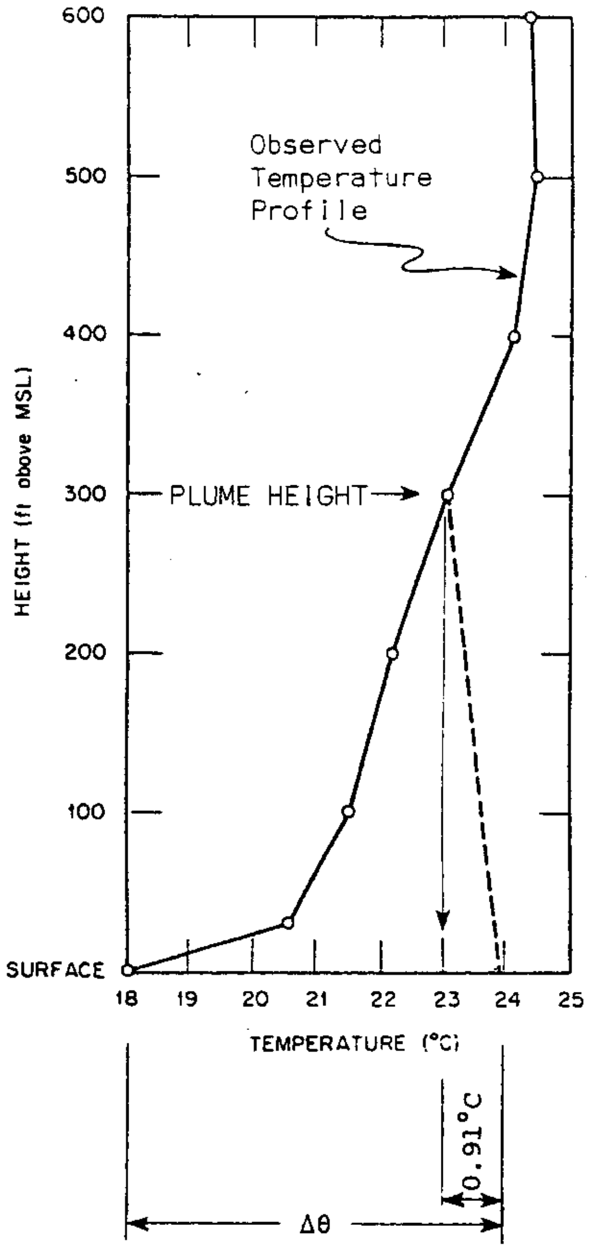


FIGURE 4-25. Example of computation of Δθ (adapted from Collins, 1971).

Regarding a permanent station, it would be feasible to establish one only if the plume tended to touch down within "favored" areas.

Over flat terrain, the monitoring of the sea-breeze fumigation phenomenon would be in addition to the monitoring objectives described in Section 4.6.1. In practical applications of the procedure, there is a problem of obtaining temperatures aloft at plume height (effective height). In the illustration (Figure 4-25), the temperature sensor was exactly at plume height--an ideal situation not likely to be encountered in the field. Figure 4-23 is universally applicable in flat coastline topography if temperatures are taken at effective plume height. Figure 4-24 would have to be modified to reflect the slope of the ground in the coastline area of concern. In all situations, the services of a diffusion meteorologist is strongly recommended.

4.6.2.1 Site Characteristics and Instrument Inlet Placement

In the event that a favored area does exist--i.e., a small area over which fumigation occurs--the site characteristics and inlet placement should be the same as those for the flat terrain stations (see Section 4.6.1.5). In irregular, rough terrain areas, choose well exposed locations.

4.6.3 Monitoring in Ridge/Valley Settings

This kind of terrain is found mainly in the Appalachian Mountain area and in parts of the upland region of several of the western states. For purposes of this discussion, characteristics of such areas are, typically, a valley of arbitrary width with parallel walls or ridges and a more or less definable "up-valley/down-valley" direction.

Because no two ridge/valley configurations are exactly alike, a detailed treatment of the subject is difficult and the development of siting procedures uniform for all possible scenarios is impractical. (For a detailed discussion of the subject of plume behavior in valleys, the reader is referred to the work of Hewson, et al., 1961; Smith, 1968; and Flemming, 1967.) However, from the descriptions provided by these references, typical situations were derived from which a general procedural guideline for siting monitors was developed. The situations include the likely kinds of impacts expected to result from a large, elevated point $SO_2$ source located in a valley with steep walls and under a variety of meteorological conditions. The kinds of $SO_2$ problems associated with such a scenario will be briefly summarized below, and followed by recommended siting procedures.

#### 4.6.3.1 $SO_2$ Problems

- "Fumigation" occurring shortly after sunrise (see Figure 4-26). A plume may be embedded in a down-valley drainage flow then brought down to ground level after sunrise via the fumigation mechanism.

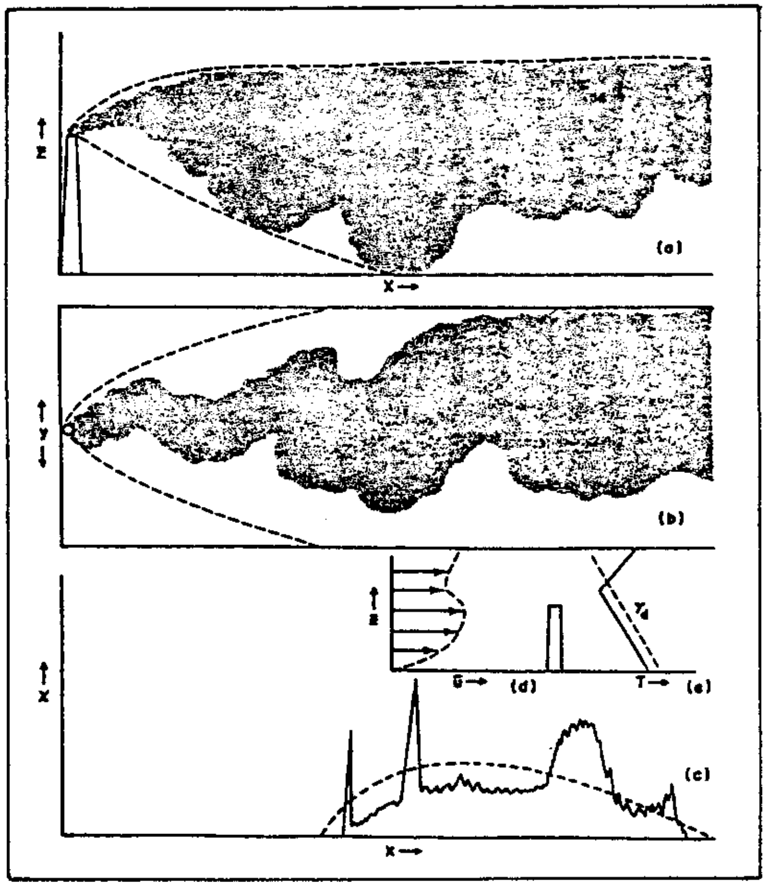


FIGURE 4-26. Inversion aloft-above stack ("fumigation"), (taken from ASME, 1968).

- Near intersection of plume with valley wall with a cross-valley wind flow under stable to unstable conditions (see Figure 4-27).

- Distortion and downwash of the plume due to wake effects on lee side of upwind wall (see Figure 4-28).

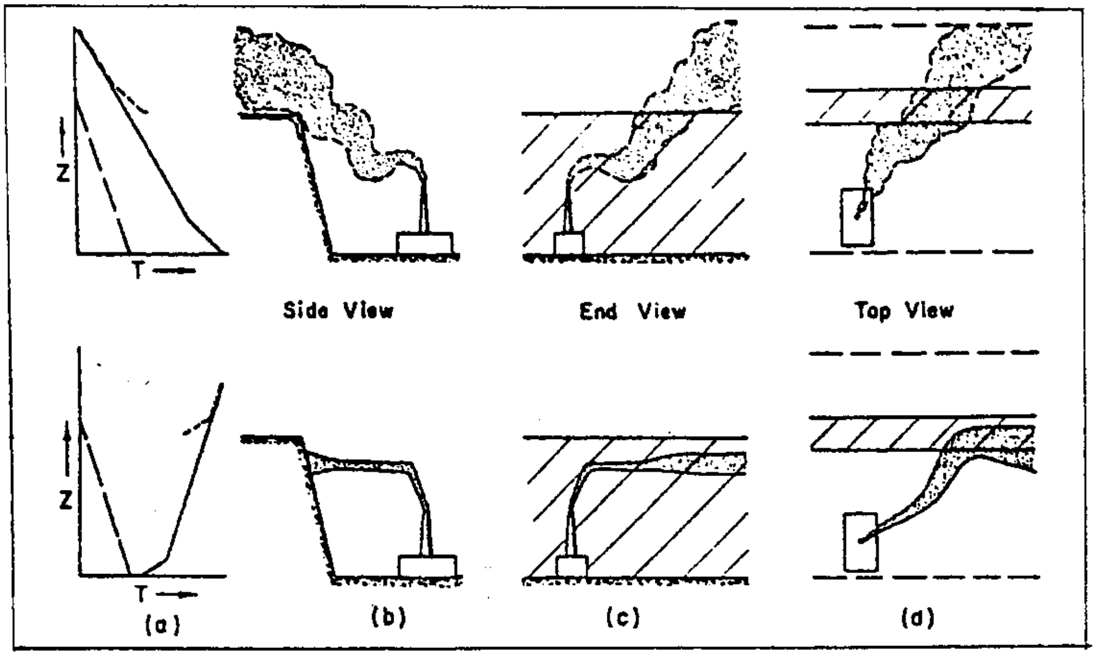


FIGURE 4-27. Plume behavior near a steep bluff when the air is unstable(above) and when it is very stable(below). (a) Vertical temperature lapse rates in relation to the critical lapse rate of 5°F/1000 ft, shown by broken line sloping upward to left: full line--lapse rate measured from grade at plant; dotted line--lapse rate measured from top of bluff; both show effect of ground surface. Corresponding plume features as observed (b) looking horizontally parallel to steep bluff, (c) looking horizontally toward steep bluff, and (d) looking vertically downward from above. Note that when air is unstable, effluent moves up and over the bluff, but when the air is very stable, as with the inversion as shown, the bluff acts as a barrier to deflect the plume. (Taken from Hewson, et al., 1961.)

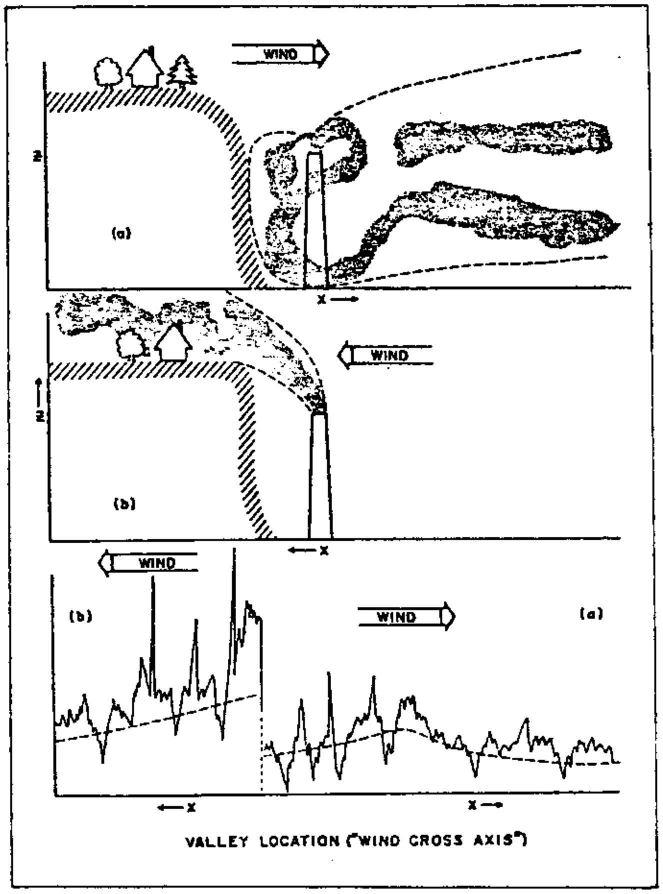


Figure 4-28.

Plume dispersion in a deep valley. With a wind from left to right, as in Section (a), the plume may be brought quickly to ground level by aerodynamic eddies. Wind from the opposite direction may create high concentrations on the plateau. (Taken from ASME, 1968.)

- Maximum impact points at ground level in the valley when wind direction is parallel to valley (see Figure 4-29).

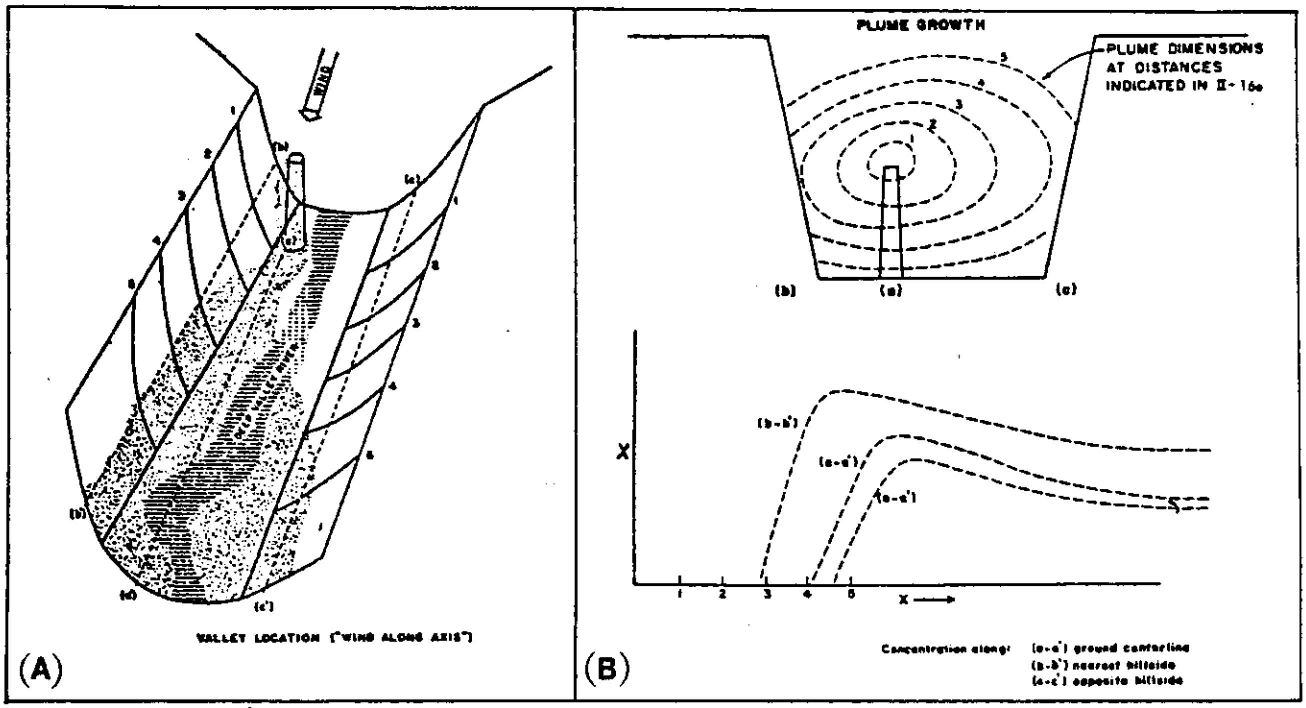


FIGURE 4-29. Plume dispersion in a deep valley. When the wind is parallel to the valley, dispersion tends to occur fairly normally until confined by the valley walls. Section (A) is a pictorial representation of the dispersion; Section (B) shows the associated concentration patterns. (Taken from ASME, 1968.)

#### 4.6.3.2 Siting Procedures.

The first step common to any monitor siting study in this kind of terrain is to acquire supporting data, information, and equipment such as that listed below:

- USGS map of area.
- Physical data from the $SO_2$ source
  - peak and daily mean production rates,
  - stack parameters,
  - exact plant location.
- Stability wind rose (climatological) } See Appendices A and B.
- Wind persistence tables } See Appendices A and B.
- Portable wind measuring system.
- Smoke bombs.

- Mobile sampling system.

- Cameras.

If the meteorological data originates at an observing site located on the high terrain outside of the valley,* adjustments of the wind data will be necessary because of the channeling effect of the valley (a meteorologist should be consulted to determine these adjustments)

<u>4.6.3.2.1 Fumigation Concentration Stations</u>. Fumigation situations in valleys usually occur under inversion break-up conditions (e.g., see Hewson and Gill, 1944). Winds are often calm or variable at typical airport locations (higher terrain). However, down in the valley drainage and valley flows may carry plumes down the valley (see Figure 4-30). Since there may be little or no correlation between airport winds and valley winds in these situations, it is suggested that plume behavior (e.g., typical direction of movement) be determined through visual observations via photography, smoke bombs, or photographing the panorama from a ridgetop vantage point. If the plume follows a similar trajectory--e.g., consistently downvalley--whenever an inversion situation occurs, it may be possible to site a monitor in a permanent location (see Figure 4-31a). While data for developing the plume "climatology" is being gathered (photographs, etc.), mobile sampling could be conducted to determine fumigation concentrations and where the maxima are typically located; again, a vertical sensing capability would be quite useful. Permanent sites could be located if "favored" areas are observed, otherwise mobile sampling may have to be conducted routinely. As an option, fumigation concentrations may be calculated (by procedures as discussed, for example, in EPA, 1974c) to estimate the maximum expected concentrations and the distances downwind where they theoretically should occur. The 3-hour peak concentration is the averaging time of concern.

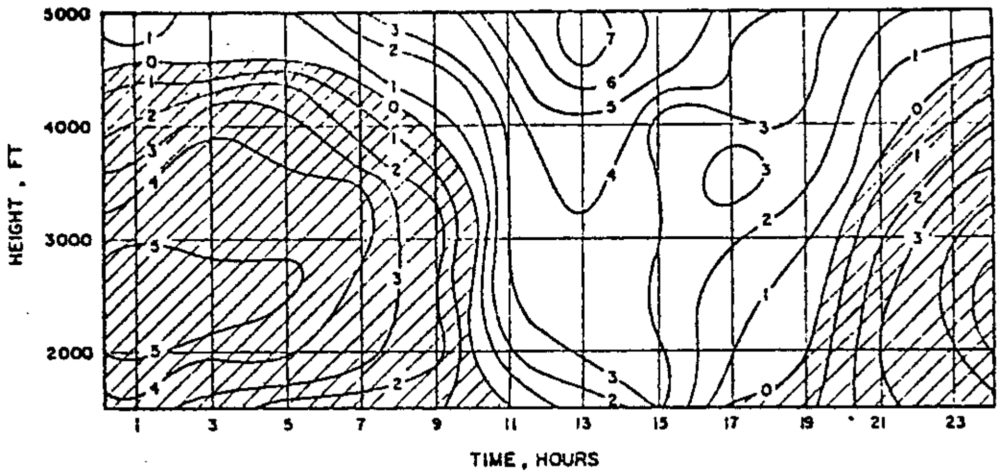


FIGURE 4-30. The diurnal variation of valley winds during the summer in the Columbia River Valley near Trail, B.C. Isopleths give average wind speed components (mph): hatched areas - downvalley (north); unhatched areas - upvalley (south). (Taken from Hewson, et al., 1961.)

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* For purposes of discussion, assume that such an observing site is a first order NWS airport weather station taking regular observations.

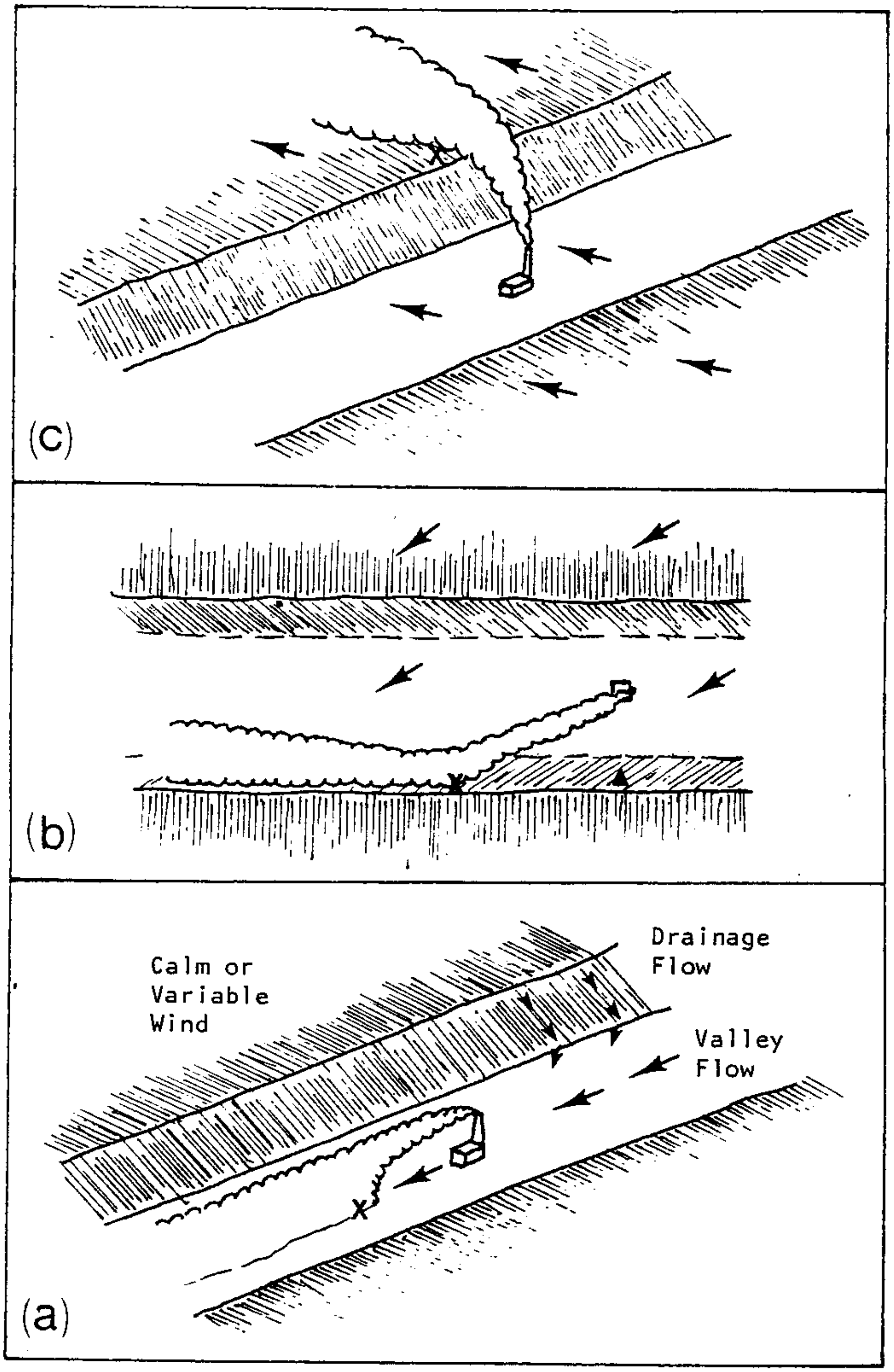



FIGURE 4-31. Illustration of plume configurations under a variety of meteorological conditions and relative locations of sampling sites (X); (a) fumigation situation, (b) plume deflected by valley wall (channeled flow in valley), (c) plume either deflected over wall under unstable conditions or passing out of valley due to excessive plume rise. Symbol ▲ is location at point on wall nearest the source (downwind wall).

4.6.3.2.2 Valley-Wall Impact Stations. When the large-scale wind blows in a cross-valley fashion, the valley wind direction is often channeled; i.e., the resulting direction on the valley flow is a compromise between the large-scale flow direction and the valley orientation. Depending on the wind speed, direction, and stability, the plume may either pass over the valley wall or interact with it (not impinge upon it) and move downwind along it. Under stronger winds, aerodynamic downwash conditions may prevail.

A wind station will need to be established on the valley floor; utilizing the services of a meteorologist, determine the wind climatology on the valley floor for various speed ranges and stability classes. From wind climatology, several basic valley-wall impact situations can be deduced. These situations are listed below along with recommended siting procedures, or points to consider for siting monitors, mainly for measuring 3-hour impacts.

- Stable to unstable conditons, light to moderate winds, high terrain (airport); channeled wind in valley.

  In this situation, we are assuming that the plume will not, in the case of the stable conditions, clear the top of the valley walls; neither will it intersect it but will approach, then be deflected by it and move along downwind parallel to it (see Figure 4-31b). To assess this situation, the first step is to determine the most frequently occurring wind direction at the airport (from its stability wind rose) for stable conditions and determine the associated valley resultant direction.* This direction is the vector sum of the valley flow wind direction and airport wind direction. This direction defines the azimuth of "intersection" with the valley wall. A tentative siting area should be established above the half-way point between the valley floor and top of the wall where the azimuth intersects the valley wall (see Figure 4-31b). The final site should be selected on the basis of visual observations. Caution should also be exercised regarding possible prolonged and continuous downwash conditions; cavity flows on the lee side of the upwind wall may distort the plume near its source.

  Under unstable conditions, the plume will either be deflected over the valley wall rather than along it, or will pass out of the valley without any significant impact as shown in Figure 4-31c. (See Appendix E for available models that can deal with such situations.)

- Stable conditions, light (not variable) cross-valley wind at the airport; drainage flow in valley.

  This situation is very similar to the one above except for the following points:

* The valley resultant direction as used here is an estimate of the direction between the source and the closest approach point of the plume to the valley wall (or "impact" point). Visual confirmation is recommended.

- To estimate the azimuth of intersection in this case, the valley resultant direction is considered a compromise between the valley orientation and the airport wind direction.
- Also, since the winds are light, the effective height of the plume may be above the valley wall and pass out of the valley with reduced impact at the valley wall and beyond (see Figure 4-31c).

Visual observations and the use of standard diffusion equations, making the proper adjustments for terrain elevation (see Appendix E for available models), should be made to determine degree of impact and direction of plume movement under such circumstances. If plume does not clear valley wall, then the problem is similar to that above (see Figure 4-32a).

- Neutral or unstable conditions, moderate to strong winds at the airport; cross-valley direction.

  Under this situation, the plume is expected to be subjected to downwash conditions due to either wake effects on the lee side of the upwind wall or to the contravention of the 1.5 $V_S/u$ ratio rule or both. In this instance, siting procedures are difficult to generalize. However, suffice it to say that the highest concentration would occur near the stack and measured most effectively via mobile sampling. Even in this case though, if favored plume touchdown areas are observed, this would provide a basis for establishing a permanent station (see Figure 4-32b). Guidance for analyzing the 1.5 ratio rule contravention problem was discussed in Section 4.5.2.

4.6.3.2.3 Worst-Case Conditions for Along Valley Flow. This situation can be handled in a manner similar to that for the flat terrain case for both 24-hour and 3-hour average impact assessments. However, a meteorologist should be consulted for advice. Locate tentative 3-hour and 24-hour peak monitoring sites using the procedures discussed in Section 4.6.1. Finalize location via mobile sampling. See Figure 4-32c for illustration.

4.6.3.2.4 Supplementary Monitoring Stations and Concluding Comments. In all situations, one site should be established at a point nearest the source on the wall most frequently downwind (based on annual wind rose) and one background site located a kilometer or so upvalley from the source. Instrument types, inlet placement, site characteristics and supplementary equipment for all stations are the same as those discussed in Section 4.6.1. If instrumented towers are erected, the elevated point source-in-valley situations and related monitoring site selection problems can be treated in a manner more rigorous than that described above.

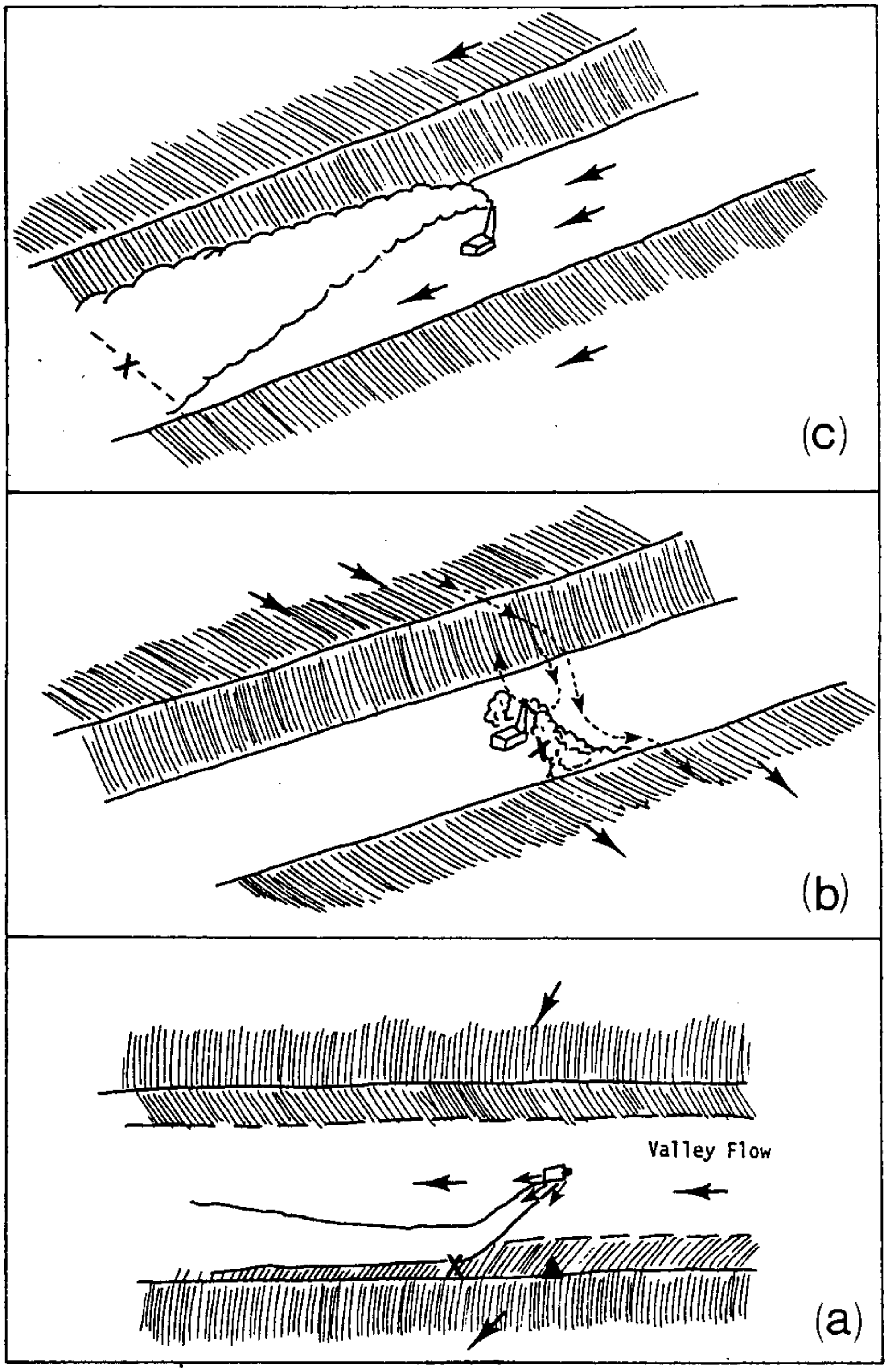



FIGURE 4-32. Illustration of plume configuration under a variety of meteorological conditions and relative locations of sampling sites; (a) plume deflected by valley wall (calm or valley wind in valley), (b) plume influenced by wake effects, and (c) maximum concentration configuration in valley with along-valley flow.

### 4.6.4 Monitoring in Rough, Irregular Terrain Settings

Rough, irregular terrain may range in texture from nearly flat to extremely severe (e.g., the mountainous areas of Idaho, Utah, etc.). Since this terrain is "irregular" by definition, no typical setting exists. Thus, we were considerably hampered by this situation in that it did not permit us to develop a "typical" scenario from which a site selection rationale or methodology could be presented, as, for example, in the previous discussion. However, we dealt with the problem by separating the terrain type into two "regimes", one in which the setting was characterized by irregular topographic features of sizes no larger than a typical physical stack height of a point source (roughly 300 ft), and the other which was characterized by larger features, up to and including the extreme mountainous. The former is reasonably amenable to diffusion model analysis in the more or less traditional sense, as for example shown by Leahey (1974). In this regard, as will be seen, the monitor siting approach in this regime can be developed in a manner similar to that described for flat terrain (see Section 4.6.1). However, plume behavior in the latter regime is extremely complex and beyond the simulation capability of most models. For example, two rather detailed tracer studies that were conducted by the National Oceanic and Atmospheric Administration (NOAA) in mountainous terrain in Utah (Start, et al., 1973, 1974) showed the extremely complex behavior of tracer material under various meteorological conditions; the preparation of uniform site selection procedures for achieving specific monitoring objectives in such terrain is clearly impractical. In view of this, it seems likely that any effort short of an individual diffusion study, uniquely designed for a given situation, to assess the $SO_2$ impact of a new or existing source will probably be unsuccessful, at least in the extreme terrain cases. At the "smooth" end of this rough topographical regime, tracer and numerical meteorological/diffusion modeling have been conducted (Hinds, 1970; and Hino, 1968, respectively). The reader is urged to consult these and the other references cited above to gain a better insight of the problems of monitor siting in rough terrain. The services of a diffusion meteorologist is also strongly recommended.

#### 4.6.4.1 Monitor Siting Procedures in Terrain of Up to Moderate Roughness

In the context of this discussion, the mean elevations of the terrain are considered to be reasonably level with the maximum deviations from the mean not exceeding a value equal to the height of a typical point source stack. The recommended approach for selecting $SO_2$ monitoring sites is identical to that for flat terrain; however, the specifics of the approach differ in the following respects.

- Diffusion Coefficients. Because of the mechanical turbulence induced by the rough topography, the graphical solutions to the Gaussian equation--viz., Fig. B-2, Appendix B, Part II--must be modified by incorporating diffusion coefficients appropriate for such terrain. The coefficients suggested by Bowne (1973) for suburban and urban areas seem appropriate. These would correspond to slightly rough (features up to sizes of three-story buildings) to moderately rough (up to stack height) topography. As a more accurate alternative, diffusion coefficients could be derived sepcifically for the area of interest as shown by Leahey (1974).

- <u>Corrections for Terrain Elevation</u>. Because of the scattered and irregular nature of the terrain features, as opposed to a solid barrier to the wind, caution should be exercised in correcting concentration estimates, or in estimating locations of ground-level concentration maxima. The major effect of the terrain on the plume will be to increase its rate of dispersal, which would tend to bring the ground-level concentration maxima closer to the stack. Concentrations would also likely be higher at the top of obstacles. However, a lower level plume (effective H below the tops of the obstacles) would tend to split and move around the obstacle, particularly under stable conditions, resulting in lower concentrations at the top of the obstacle. In more undulating topography, the plume would tend to follow the terrain. However, height corrections would need to be made where the terrain elevation changed abruptly. For example, Figure 4-33 is a numerical model simulation of the ground-level pattern produced by an elevated plume, showing increased concentrations over elevated terrain (Hīno, 1968).

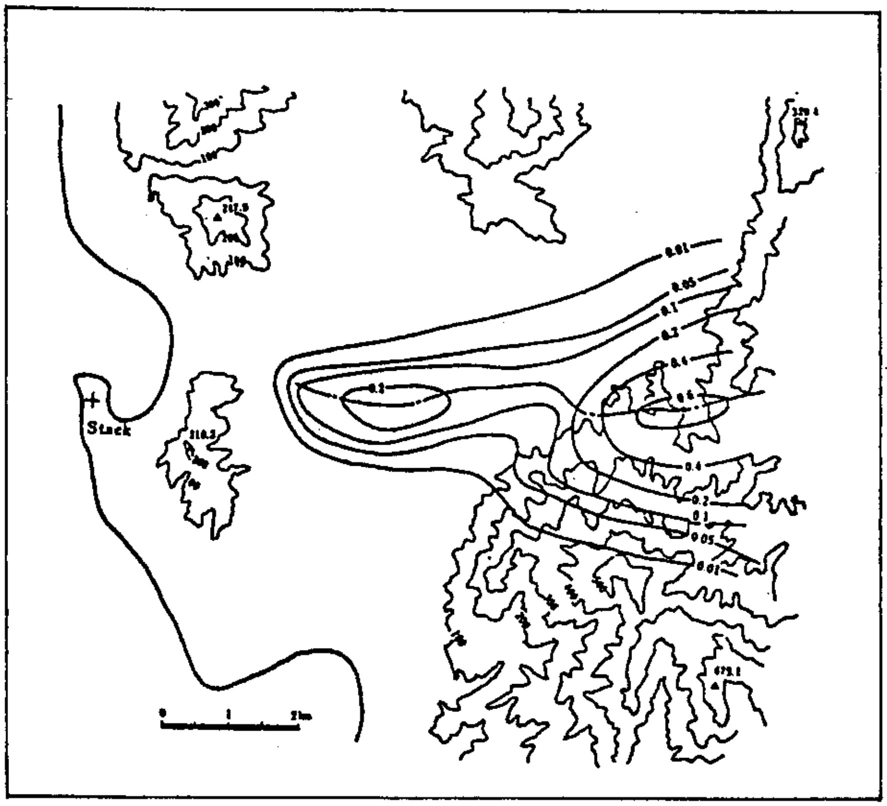



FIGURE 4-33. Distribution at height of 40m from ground surface ($\zeta = z-h = 40m$) of concentration of smoke emitted from a source with height 400m which is derived from the computer experiment (taken from Hīno, 1968).

- Downwash Situations. If obstacles higher than 2/5 of the height of stack exist within 10 stack heights of the stack, downwash due to wake effects is very likely. Downwash analyses, such as those discussed in previous sections, would be necessary.

Taking into account the above points, the procedure discussed in Section 4.6.1 can be utilized in selecting monitoring stations. However, because of the heterogeneous nature of the setting, more reliance on mobile sampling and visual observations of plume behavior may be required.

- General Comments on Site Characteristics. The site characteristics should be similar to those discussed in Section 4.6.1.5. However it is recognized that wake disturbances on the lee sides of obstacles will be the rule. These disturbances, which may extend to twice the height and five to ten obstacle heights downwind, should not be considered as things to avoid entirely. Such obstacles close to a stack may downwash the plume to the ground to complicate the picture. However, if downwash does not occur near the stack, any wake effect produced by an obstacle located near the expected ground-level maximum point would have very little influence on where the actual maximum concentration would be found, since the plume has already diffused down to the ground naturally over an area probably larger in size than the obstacle itself.

### 4.6.4.2 Conditions in Extremely Rough Terrain

The nature of this terrain precludes the development of monitoring site selection procedures that could be uniformly applied to any given mountainous terrain configuration. However, describing some of the gross characteristics of plume behavior in such terrain may be instructive in terms of "points to consider" when contemplating establishing $SO_2$ monitoring sites to assess the impact of individual point sources so located.

The following summary was abstracted from the two NOAA studies (Start, et al., 1973, 1974) and from the study by Hinds (1970) cited previously. The studies described the behavior of plumes over specific sections of California and Utah characterized by extremely rough terrain. Plume behavior in these areas may or may not typify such behavior in other similar topographic areas.

- Elevated Plume. Centerline concentrations are reasonably well predicted by the standard Pasquill-Gifford diffusion curves when the plume does not pass over mountainous terrain. However, over mountainous terrain elevated centerline concentrations average from 3 to 4 times more dilute.

- Lateral Plume. Spreading is almost twice that expected for over flat terrain. Several physical processes contribute to this increased spreading.
  - Plumes tend to be deflected around obstacles.

- The descending portions of looping plumes spread laterally as they approach steeply sloped canyon floors.
- Increased mechanical turbulence enhances lateral spreading.
- Vertical shearing of wind direction with height enhances lateral spreading.

- When a low, strongly stable layer aloft combines with flow-blockage effects of the terrain, a quasi-stagnant air pocket can develop that may contain an elevated plume layer. Prolonged ground-surface contact with this layer is probable.

- A higher stable layer will allow the plume to flow over the ridge-tops and the plume tends to become uniformly distributed in the vertical. Because of ground-reflection effects, ground-level concentrations may be twice as large as those aloft.

- With no stable layer aloft, plumes are deflected aloft over the ridges and follow a path similar to the shape of the underlying topography. The lateral distribution of pollutants from the centerline is generally Gaussian.

- The locations of the maximum ground-level concentrations were at the ridgetops. Specific impact areas were identified best via pilot balloon (pibal) wind observations near the effective plume height.

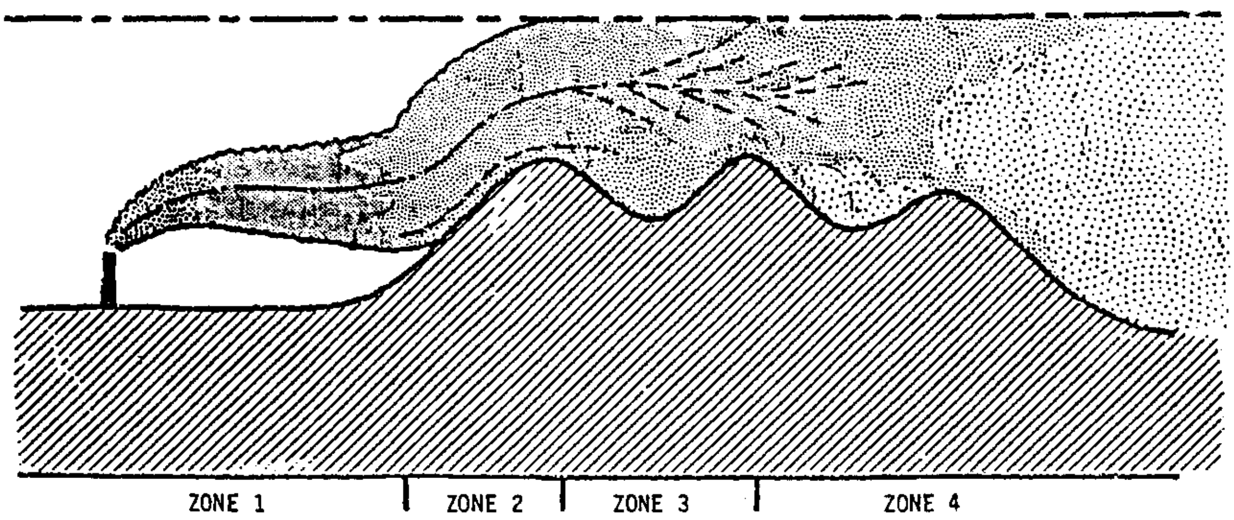
- Figure 4-34 is a schematic illustrating the dilution of an airborn plume as it interacts with elevated, rough topography.

- In unstable conditions rates of dilution in mountainous terrain are about the same as those over flat terrain; the rates increase by a factor of 5 in neutral conditions and a factor of 15 in stable conditions.

- Peak to mean concentration ratios in mountainous terrain are lower than those over flat terrain.

- In canyon settings within mountainous terrain, mechanical turbulence is enhanced by:
  - Turbulence generated near the mountain tops and the upper confines of the canyon.
  - Airflows originating within side canyons.
  - Wake effects of airflows over and around canyon topographic variations.

- Because of strong diurnal wind cycles characteristic of canyon topography, synoptic stagnation conditions are not the worst diffusion conditions.




ZONE 1: "Simple" elevated plume with buoyant rise, becoming the bent-over form. Near Gaussian vertical distribution.
ZONE 2: Deflection zone with plume tending to parallel ground surface. Near Gaussian vertical distribution.
ZONE 3: Mixing or transitional zone affected by turbulence about the topography. Quasi-Gaussian vertical distribution.
ZONE 4: Well-mixed zone. Quasi-uniform vertical distribution of plume mass.

Plume effluent concentrations are greatest where the shading is the most dense.

FIGURE 4-34. Schematic illustration of the dilution of an airborne plume as it approaches and flows over nearby elevated terrain. Four zones of plume behavior and the postulated vertical mass distributions are depicted. (Taken from Start, et al., 1974.)

- Figure 4-35 illustrates the turbulent wake effects of obstacles characteristic of canyon topography.

- Diffusion over a ridge-canyon system often results in substantially lower concentrations on the canyon floor than would occur at the same distance over flat terrain.

### 4.6.4.3 Implications for $SO_2$ Monitoring

Based on the above observations, the following general guidelines for selecting $SO_2$ monitoring sites in extremely rough terrain are suggested.

- In regions subject to at least occasional periods of low mixing depths, locate monitors in basins that have inlets for $SO_2$ source plumes. Very high concentrations could result from stagnant air pockets that could develop in such areas. The rough terrain, upland areas of the west coast of the United States would seem to be particularly liable.

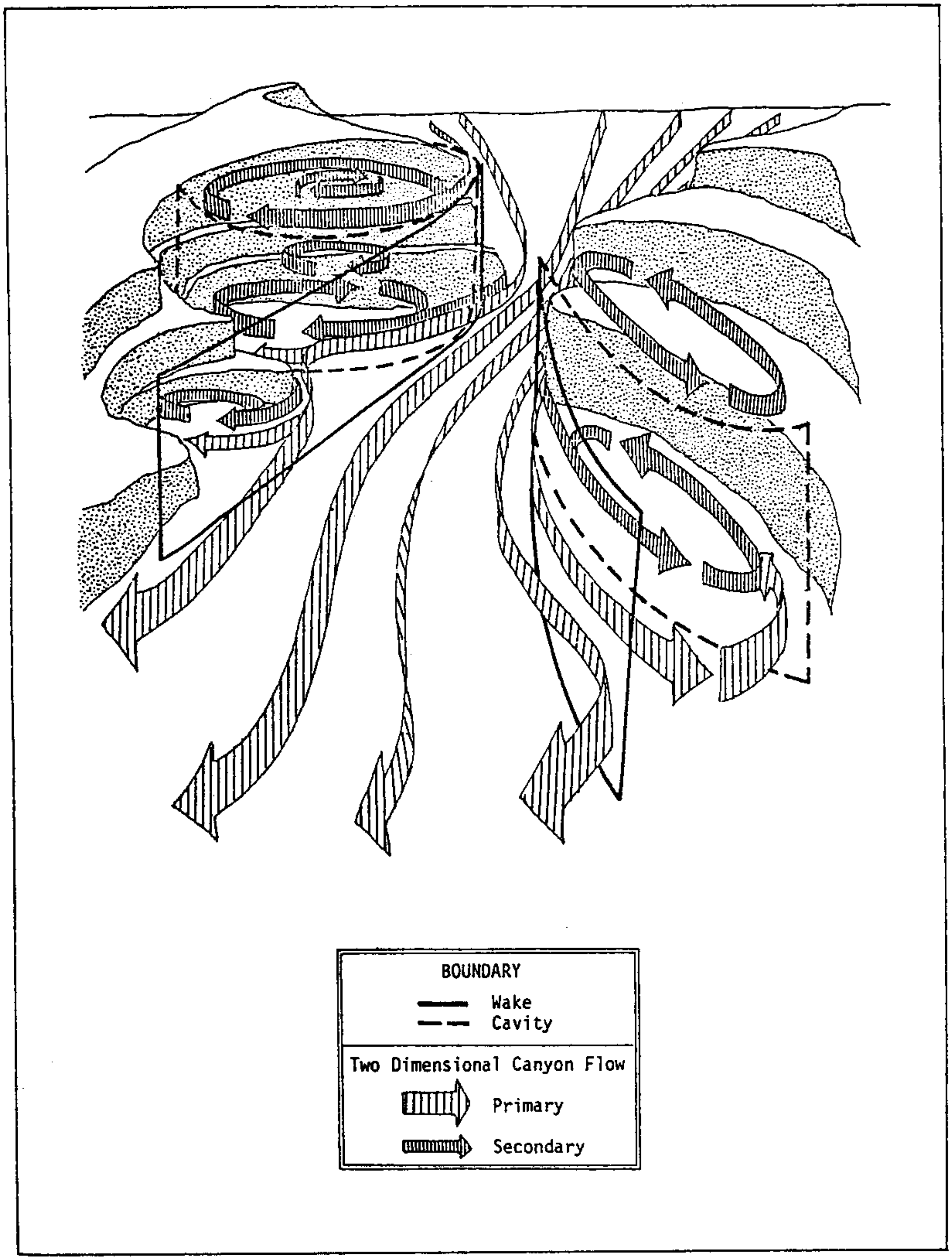



FIGURE 4-35. Schematic illustration of turbulent wake effects caused by obstacles protruding into the primary flow pattern. (Adapted from Start, et al, 1973).

- Site monitors at rigetop locations in the general downwind directions from the source, or perhaps at ridgetop locations surrounding the source, particularly those nearest the source at near effective height (H) elevations.

- Site monitors in passes that may receive the plume advected either by drainage or channeled winds.

- A complete survey of the entire area influenced by the $SO_2$ source would almost certainly be required in all situations. Visual observations, aerial photography, mobile sampling, remote sensing, etc. would probably be the most important means for conducting such surveys.