ATTACHMENT 1

Technical Issues Concerning Wind Tunnel Modeling to Determine Equivalent Building Dimensions (EBD) for input to the Industrial Source Complex (ISC2) Model

Introduction. The following represents a final list of technical issues developed at the 1994 Regional Office/State Modelers Conference associated with the review of wind tunnel modeling protocols to determine equivalent building dimensions (EBD) for input to the Industrial Source Complex (ISC2) model. It is important to note aspects of these wind tunnel studies in context of the overall objectives of the ambient air quality modeling analyses. First, these wind tunnel studies to determine EBD do not replace ambient air quality analyses based on a preferred air quality model (i.e., Appendix A of the Guideline on Air Quality Models (Revised)). Rather, the wind tunnel studies are used to develop appropriate building dimensions for input to the Industrial Source Complex (ISC2) Model downwash algorithm. Thus, the analyses are viewed as source characterization studies which generally have been considered under the purview of the Regional Offices. As a result, these studies are considered not subject to the requirements under Section 3.2 of the Guideline (i.e., Use of an Alternative Model).

Second, the purpose of the study is to develop appropriate direction-dependent EBD for input to the ISC2 model. Typically using standard techiques the full structure height would be input as building height into the ISC2 model. The wind tunnel protocols have reported that for "lattice-type" building configurations and structures this building height would tend to overestimate the downwash effect and as a result produce unrealistically high ground-level concentration estimates. The first step in the wind tunnel studies is therefore designed to simulate the actual direction-dependent dispersion from the sources with the actual lattice-type building configurations or structures in place. This is done by measuring downwind ground-level concentration profiles. Next, the structures are removed from the wind tunnel and replaced with simplified solid structure more typical of the structure from which the ISC2 downwash algorithm was developed (i.e., "Huber-Snyder"). From this, the simplified structure which matches the concentration profiles with the site structures in place according to pre-determined criteria is selected for input to ISC. Provided the wind tunnel demonstrations are technically sound, this seems to be a reasonable approach for deriving the building dimensions input to the ISC2 model.

1. **Q.** What buildings need to be adjusted? Should BPIP be used to determine which buildings that influence the source? What is the maximum area for which this technique may be appropriate, e.g., should it include all structures within 200-, 800-, 1200-,

etc. meters? Is it preferable to include all structures when a stack is within five building heights/widths of the structures?

A. This question is related to how the wind tunnel is configured to characterize concentrations associated with 1) the actual site configuration, and 2) the equivalent building configuration. A typical wind tunnel configuration is shown in Figure 1. Tests of the actual site configuration are conducted with a model of the site on the turntable. (See Figure 2 which is an example site configuration discussed in the meeting for District Energy St. Paul, Inc.) The remainder of the tunnel floor is covered with a uniform density of randomly distributed roughness elements ("uniform roughness") to simulate the actual aerodynamic roughness upwind and downwind of the site.

In the meeting, we discussed three approaches that have been used in past wind tunnel demonstrations to configure the wind tunnel to simulate the equivalent building flows. These discussions included which buildings have been included/excluded in the actual site configuration and equivalent building configuration in past demonstrations. The approaches discussed were 1) removal of selected buildings on the turntable, 2) use of a turntable of uniform roughness matching the roughness of the actual site, and 3) use of a uniform roughness across the entire tunnel floor. In 1) the tunnel is configured as with the actual site simulation except selected buildings are removed. The intent is to remove the buildings which contribute to the downwash phenomena. This is illustrated in Figures 2 and 3. In 2) the actual site buildings are removed from the turntable and a surface roughness representative of the actual site configuration is uniformally placed on the turntable. This representative surface roughness may be direction-specific. See Figures 4 and 5. In 3) the actual site buildings are removed from the turntable and a uniform surface roughness matching the remaining tunnel floor is installed on the turntable (Figure 6). These approaches are described more fully in Attachment 2 under Wind Tunnel Configurations for Tests.

The meeting participants generally agreed that approach 3, use of a uniform surface roughness across the entire tunnel floor, while the least complicated approach, seems to provide a reasonable EBD as input to ISC. As noted in Attachment 2, this approach is most consistent with the uniform roughness comprising the "universe" of ISC. Also, this approach may avoid some of the complications associated with the other two more complex configurations. However, as improvements in dispersion models progresses in terms of accommodating directional-dependent surface roughness, approaches such as in 1) and 2) above may be more feasible.

Another aspect of the question concerning which buildings to include on the turntable concerns the size of the model domain. The participants discussed the suggestions in the Guideline for Fluid Modeling of Atmospheric Diffusion (EPA, 1981) where cubical-shaped structures should be included if the stack being modeling is within 20 structure heights. A structure much wider than its height should be included if the stack is within approximately 100 structure heights. Past experience suggests that the tunnel model generally includes structures within a 400m to 1000m radius of the stack (Attachment 2). This may be refined based on professional judgement to remove/exclude some buildings.

Attachment 2 provides more detailed description of the model design issues discussed at the meeting.

2. **Q.** What are the appropriate similarity requirements to determine EBD in a wind tunnel if they are different from those for GEP stack height determinations? Is buoyancy an important factor (to match Froude number)? Or does buoyancy produce a more conservative EBD? How can we determine from the data presented that the modeling was done properly? For example, how do we know that valid Reynolds and Froude numbers were considered? Appropriate surface roughness? etc.? What are the parameters the must be considered?

A. The most important similarity requirements were discussed as illustrated in Attachment 3. These requirements basically follow the recommendations contained in Guideline for Use of Fluid Modeling to Determine Good Engineering Practice Stack Height (EPA, 1981) and Guideline for Fluid Modeling of Atmospheric Diffusion (Snyder, 1981). Snyder (1981) provides information on the capabilities and limitations of fluid modeling studies recommendation to follow to conduct such studies. EPA (1981) provides information and recommendations to conduct fluid modeling studies for Good Engineering Practice (GEP) stack height determinations.

It was noted in the discussions that in general conducting the wind tunnel demonstration with a nonbuoyant plume will tend toward a larger effective building height for the equivalent building. This is because buoyancy effects are more important farther downwind from the source than in the near-field. This was illustrated in Attachment 4 which shows the affect of increased stack height (to simulate buoyant plume rise) on equivalent building height. Based on the results shown, it is anticipated that neglecting buoyancy effects would have minimal effect on the estimated building dimensions. However, it was recognized that as experience is gained, some testing may be considered useful to explore the sensitivity of the determined building dimensions to simulated release height. In this regard, it was recommended that raising or lowering the simulated stack height was preferred to actually attempting to simulate the buoyancy of the plume. When such tests are needed could not be defined with the information available. We anticipate clarification of this issue as more cases are examined.

Surface roughness issues were discussed as described above and in Attachment 2 under Wind Tunnel Configurations for Tests. As noted above, the participants generally agreed that a uniform surface roughness across the tunnel seemed adequate for the tests. Representative values for surface roughness for the wind tunnel modeling can be found in Snyder (1981) and the On-Site Meteorological Program Guidance for Regulatory Modeling Applications (EPA, 1987). It was also noted that based on past wind tunnel demonstrations for EBD, larger magnitudes of surface roughness used in the tunnel simulations tend toward larger resulting equivalent building dimensions, other factors being equal.

3. **Q.** What shape should the equivalent building be? Does it have to be a unique, predetermined shape such as Huber/Snyder type? Can more than two types of single buildings qualify for the equivalent building for the same case, i.e., if, or when, they produce the same concentration field?

A. It was noted that the tunnel experiments conducted to date have focussed on developing equivalent building dimensions similar to "Huber/Snyder"-type buildings, i.e., a structure with crosswind dimensions approximately double the building height. This was done to be consistent with the type of building used in the wind tunnel experiments to construct the ISC downwash algorithm. Thus, it seemed reasonable that the wind tunnel demonstrations focus on these types of "Huber/Snyder" structures. However, there were cases where this type of structure when used in the wind tunnel simulations did not provide an adequate characterization of the ground-level concentration profiles. Also, there may be actual site configurations where "Huber/Snyder"-type structures are not appropriate (e.g, tall, narrow structures). Thus, It was suggested that a resolution to such cases would be to use BPIP or some other equivalent technique to define the building dimensions for ISC input.

4. **Q.** Where should the single equivalent building be? In front, behind, or at the middle of the source?

A. It was stated that the purpose of the wind tunnel simulation was to develop an equivalent building dimension similar to "Huber/Snyder"-type structure to be consistent with the experiments done to develop the ISC downwash algorithm. In these experiments, the stack was placed midway on the downwind side of the building. Thus, it seemed reasonable that the wind tunnel simulations to determine equivalent building dimensions be done similarly with the stack on the downwind side of the equivalent building. (See Figure 5 for illustration).

5. **Q.** The stack height velocity (2%) (wind speed) in the field in the protocol we reviewed was calculated from the measurements at other than stack height through log-law wind speed profile although the stack height velocity measurements are available.

The stack height (wind speed) velocities calculated from different heights, in this case, may result in a 20% difference which causes a 20% difference in velocity ratio which is one of the similarity parameters. Therefore, the stack downwash could be underestimated and, in turn, the building downwash could be overestimated. Should a general method be set up for the stack height velocity determination?

A. The 2% criteria (i.e., 98th percentile wind speed based on the climatological records of a site) is a guideline for wind tunnel modeling to determine GEP stack height. In the meeting it was suggested that the 98th percentile wind speed is not a necessary criterion for determining EBD. It was suggested that wind speeds ranging from the 94th to 99th percentiles be used in the tunnel simulations. The wind speed should not exceed the maximum observed from the appropriate climatological records. It was also suggested that the wind speed should be set so that the ratio of a realistic exit velocity to simulated wind speed is greater than 1.5 to avoid stack tip downwash.

In a June 28 conference call with the EPA Regional Office Modeling Contacts and technical staff, an alternative approach for modeling the stack top wind speed in the tunnel was discussed and was determined to be reasonable. It was noted that it is more important to simulate in the tunnel a wind speed that maximizes ground-level concentrations than some specified percentile range of wind speeds. It was also suggested that the actual stack exit velocity should be simulated instead of some undefined "realistic" velocity. This alternative approach is as follows;

1. Simulate the actual stack exit velocity or plume momentum in the wind tunnel.
2. Simulate the highest allowable wind speed at stack top that just avoids stack tip downwash.
3. The highest simulated stack top wind speed should not exceed the maximum observed from appropriate records.

6. **Q.** What meteorological conditions should be considered in the fluid modeling, e.g., wind speeds? How many wind directions should be considered? (It is assumed that 36 sectors for ISCST and 16 sectors for ISCLT with appropriate surface roughness replicated will be modeled. Should only mid-sector directions be considered, or should additional directions within each sector be evaluated to determine the dimensions that give the highest concentrations?

A. It was noted that previous wind tunnel experiments have used both 10 degree and 20 degree sectors to determine EBD. For the 20 degree sectors, the highest EBD determined from either side of the sector was used for the 10 degree midpoint. In other cases, EBD have been determined every 10 degree for critical wind directions (e.g., 90-180 degrees) while BPIP or some other technique was used to determine the building dimensions for wind directions outside this range. These techniques seemed reasonable and the issue of appropriate wind direction sectors for the wind tunnel demonstration seemed to be case-specific. Given the limitations in science for accommodating building wake effects on dispersion processes, it was recognized that sectors less than 10 to 20 degrees are likely beyond the state of science and currently are not recommended.

For the ISCLT model, it seemed reasonable to select the largest EBD within each 22.5 degree sector as input (consistent with ISCLT).

Another meteorological condition discussed concerned the representation of the turbulent structure of the boundary layer in the model. It was generally agreed that configuring the wind tunnel to simulate near-neutral stability was the most appropriate approach. This is also consistent with the turbulent structure of the wind tunnel experiments used to develop the ISC downwash algorithm.

7. **Q.** Should sources of heat be simulated, e.g., buildings that have processes that release considerable heat to the atmosphere?

A. This question concerns the simulation in the wind tunnel of enhanced dispersion associated with heat flux from these buildings. This is unrelated to question (2) above concerning the simulation of plume buoyancy in the tunnel. In the discussions, there seemed to be questionable value for simulating these heat sources in the tunnel. However, it may be reasonable to consider these sources if warranted on a case-by-case basis.

8. **Q.** What type of Quality Assurance/Quality Control requirements are needed for these studies?

A. CPP agreed to provide some QA/QC procedures used in previous test programs. An outline of these procedures are provided in Attachment 2. It was suggested that a wind tunnel protocol and report provide adequate information describing these procedures.

Also discussed were repeatability tests of the wind tunnel simulations. This is also described in Attachment 2. The value of some demonstration of repeatability was noted. These tests may demonstrate the variations in concentration profiles that may result due to slight differences in model configuration from one test to a repeat test. An example of a repeatability test discussed could be as follows: After all EBD have been determined for all wind directions, go back and repeat the test for the wind direction that yielded the concentration profile containing the overall maximum observed concentration. Do this with all structures in place. Then repeat the test with the EBD in place and compare the concentration profiles.

9. **Q.** How do we define equivalency?
   * centerline
   * distance to max. concentrations downwind
   * lateral/vertical profile
   * density of profile
   * precision

A. Methods for determining equivalent building dimensions from past wind tunnel studies were discussed. Various criteria have been used in these studies to select the EBD and have been evolving as these studies continued. The approaches used were noted as follows:

* Measure the ground-level longitudinal (alongwind) concentration profile with site structures in place for the wind directions specified in the protocol. This is illustrated in Figure 2 of Attachment 2. Ground-level concentrations are measured at each longitudinal distance using an array of receptors lateral (crosswind) to the tunnel axis.

* Measure the ground-level longitudinal concentration profile with the site structures removed according to the procedures specified in the protocol. Measure ground-level concentrations for various equivalent building dimensions.

* Compare the longitudinal concentration profiles. From this comparison, alternative criteria have been used in past experiments to determine the EBD. The procedure was to select the lowest EBD that meets the criteria. [Note: Figure 7 is an illustration of the longitudinal concentration profiles from several EBD tests and with all site structures in place (i.e., "actual site" in Figure 7).]

The alternative criteria used in past experiments are as follows:

<u>First Define</u>:

CS = maximum ground-level concentration with all site structures in place determined at each longitudinal distance (See Figure 2, Attachment 2).

CE = maximum ground-level concentration for the equivalent building dimension test with site structures removed determined at each longitudinal distance.

CSmax = overall maximum CS value with all site structures in place. Determined from among all longitudinal distances measured.

RSmax = Longitudinal distance to overall maximum CS value (i.e., CSmax).

CEmax = overall maximum CE value for the equivalent building test with site structures removed. Determined from among all longitudinal distances measured.

Alternative Criteria used in Previous Demonstrations to Select the Equivalent Building Dimensions:

- The EBD that produces an overall maximum concentration within 10 percent of the overall maximum observed with all site structures in place (i.e., CEmax ± 10% of CSmax).

- The EBD with a longitudinal concentration profile 90 percent or greater of the concentration profile from all structures in place (i.e., CE ≥ 90% of CS at each longitudinal distance). [Note: This is illustrated in Figure 7. EB3 was chosen for this particular wind direction.]

- The EBD that produces 1) an overall maximum concentration ≥ the overall maximum concentration from all structures in place, and 2) concentrations > 80 percent of the concentrations from all structures in place at all other longitudinal distances [i.e., 1) CE ≥ CSmax at RSmax; 2) CE > 80% of CS at all other distances].

- The EBD that produces 1) an overall maximum concentration ≥ the overall maximum concentration from all site structures in place, and 2) concentrations ≥ 90 percent at all other distances. [i.e., CE ≥ CSmax at RSmax; 2) CE ≥ 90% of CS at all other distances].

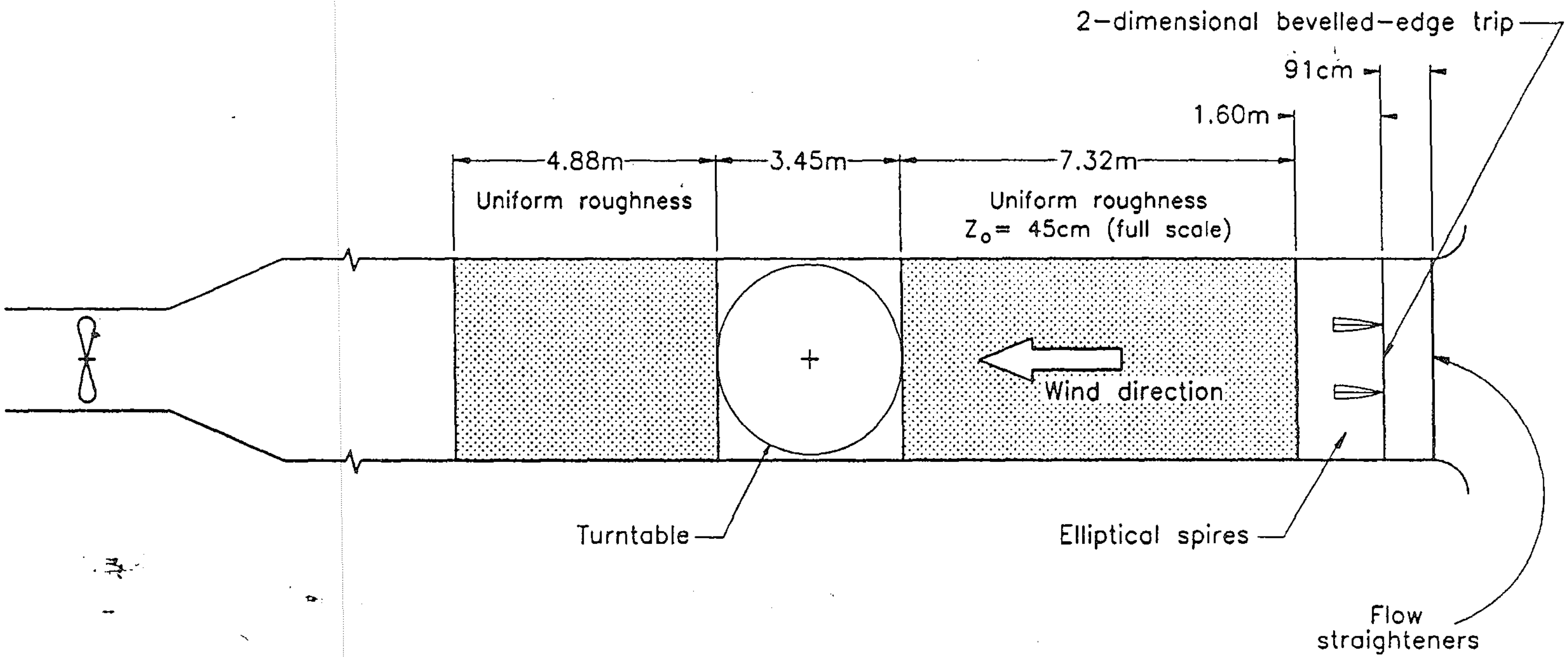
Another more recent procedure was discussed at the meeting and noted in Attachment 2 as follows;

Select the EBD that 1) produces an overall maximum concentration exceeding 90 percent of the overall maximum concentration observed from the all site structures in place (i.e., CE > 90% of CSmax at RSmax), and 2) at all other longitudinal distances, produces ground-level concentrations which exceed the ground-level concentration observed from all site structures in place less 20 percent of the overall maximum ground-level concentration from all site structures in place [i.e., CE > (CS-.20CSmax) at each longitudinal distance]. This is in Figure 8. Note that in this illustration, EB2 would be selected over EB1 according to these criteria.

In discussing this more recent criteria in the June 28 conference call, the appropriateness of the 90 percent criterion for the overall maximum concentration was questioned (i.e., CE > 90% of CSmax at RSmax). It was noted that because larger EBD yield higher ground-level concentrations, it may be appropriate to require 100% or greater matching (CE ≥ CSmax at RSmax) for the EBD test.

Criteria that tests at all locations on the longitudinal concentration profile are more comprehensive than comparisons only of overall maximum concentration values. An examination of the criteria illustrates the fact that a progression of thought has occurred on acceptable criteria as more experience has been gained. It is anticipated these criteria will become more refined as more cases are examined.

It was suggested that these criteria be applied at downwind distances beyond the cavity region of the actual site downwash structure. One suggestion was to apply these criteria to distances greater than 3L from the source and further downwind so long as the longitudinal maximum concentrations resulting with the site structures in place exceed 30% of the overall maximum concentration with the site structures in place. Where L is the lessor of the height or projected width of the dominant downwash structure for that site configuration and wind direction. After some discussion, the participants generally agreed that the 3L criteria might be too restrictive and that all sampling points be included downwind of the structure having concentrations greater than 30% of the overall maximum concentration with site structure in place. Some points may need to be excluded because of cavity region phenomena and will need to be determined on a case-by-case basis.



2-dimensional bevelled-edge trip
91cm
1.60m
4.88m
3.45m
7.32m
Uniform roughness
Uniform roughness
Z_o= 45cm (full scale)
Wind direction
Turntable
Elliptical spires
Flow straighteners

FIGURE 1

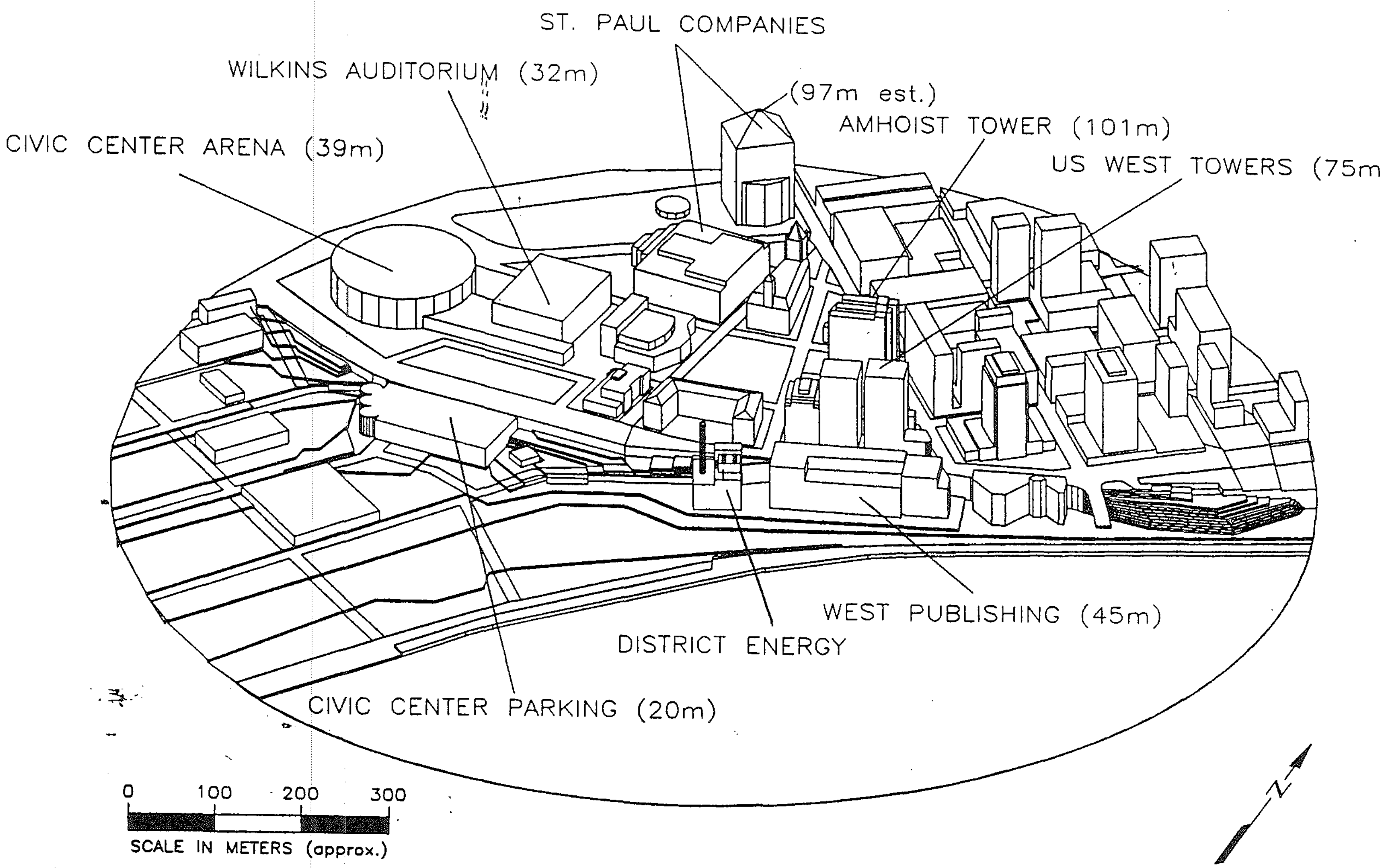

ST. PAUL COMPANIES
WILKINS AUDITORIUM (32m)
(97m est.)
AMHOIST TOWER (101m)
CIVIC CENTER ARENA (39m)
US WEST TOWERS (75m)
WEST PUBLISHING (45m)
DISTRICT ENERGY
CIVIC CENTER PARKING (20m)
0 100 200 300
SCALE IN METERS (approx.)
N

FIGURE 2

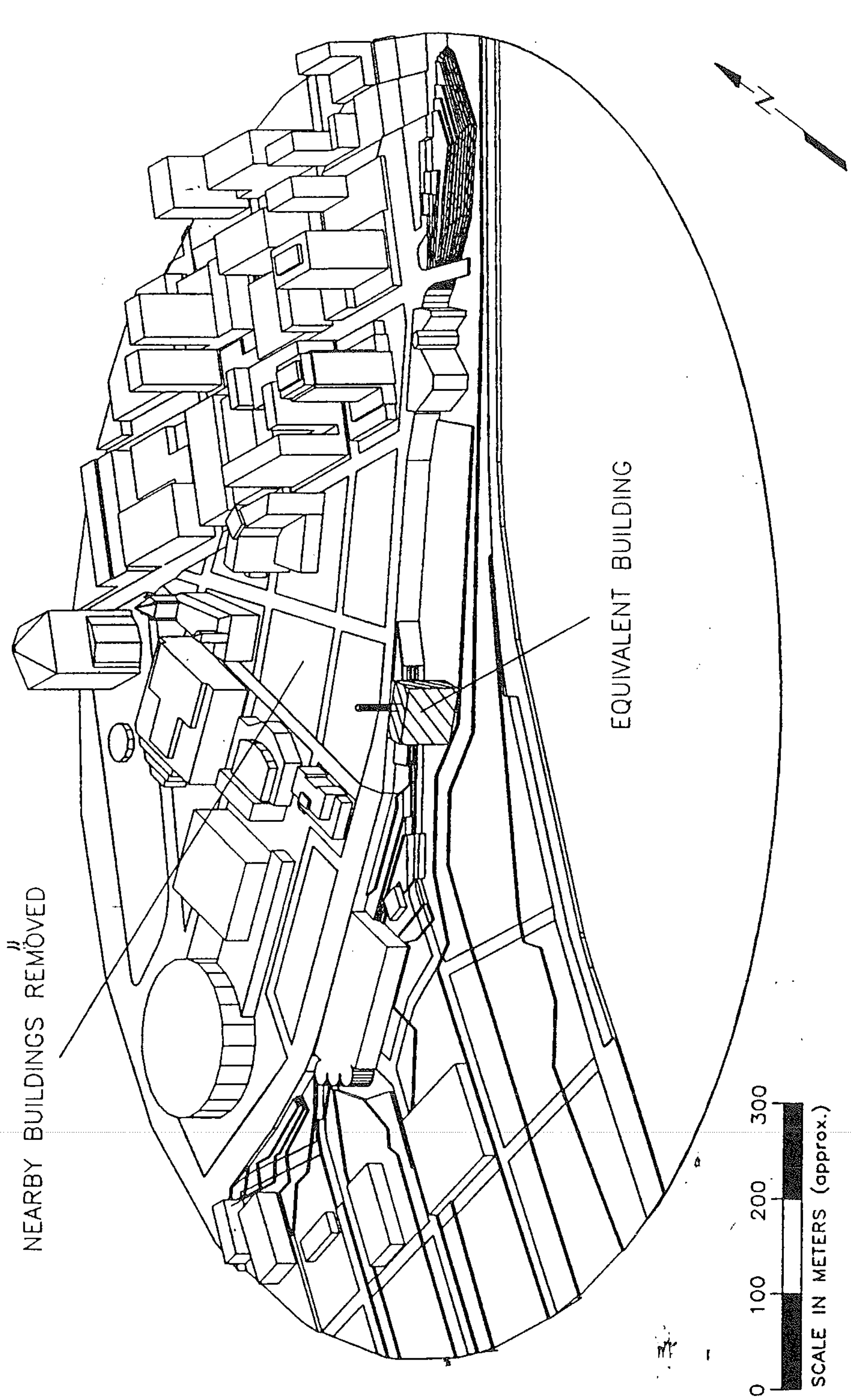

NEARBY BUILDINGS REMOVED
EQUIVALENT BUILDING
N
0
100
200
300
SCALE IN METERS (approx.)

FIGURE 3

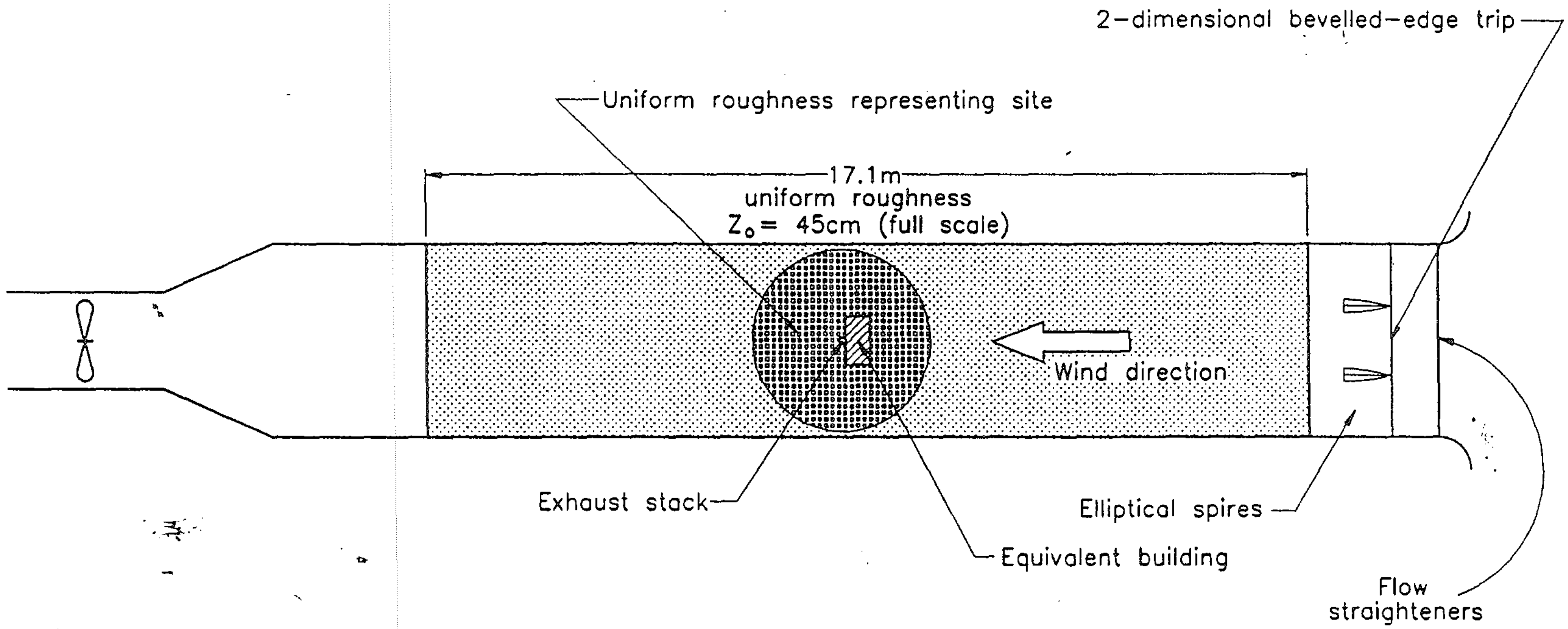

2-dimensional bevelled-edge trip
Uniform roughness representing site
17.1m
uniform roughness
Z_o = 45cm (full scale)
Wind direction
Exhaust stack
Elliptical spires
Equivalent building
Flow straighteners

FIGURE 4

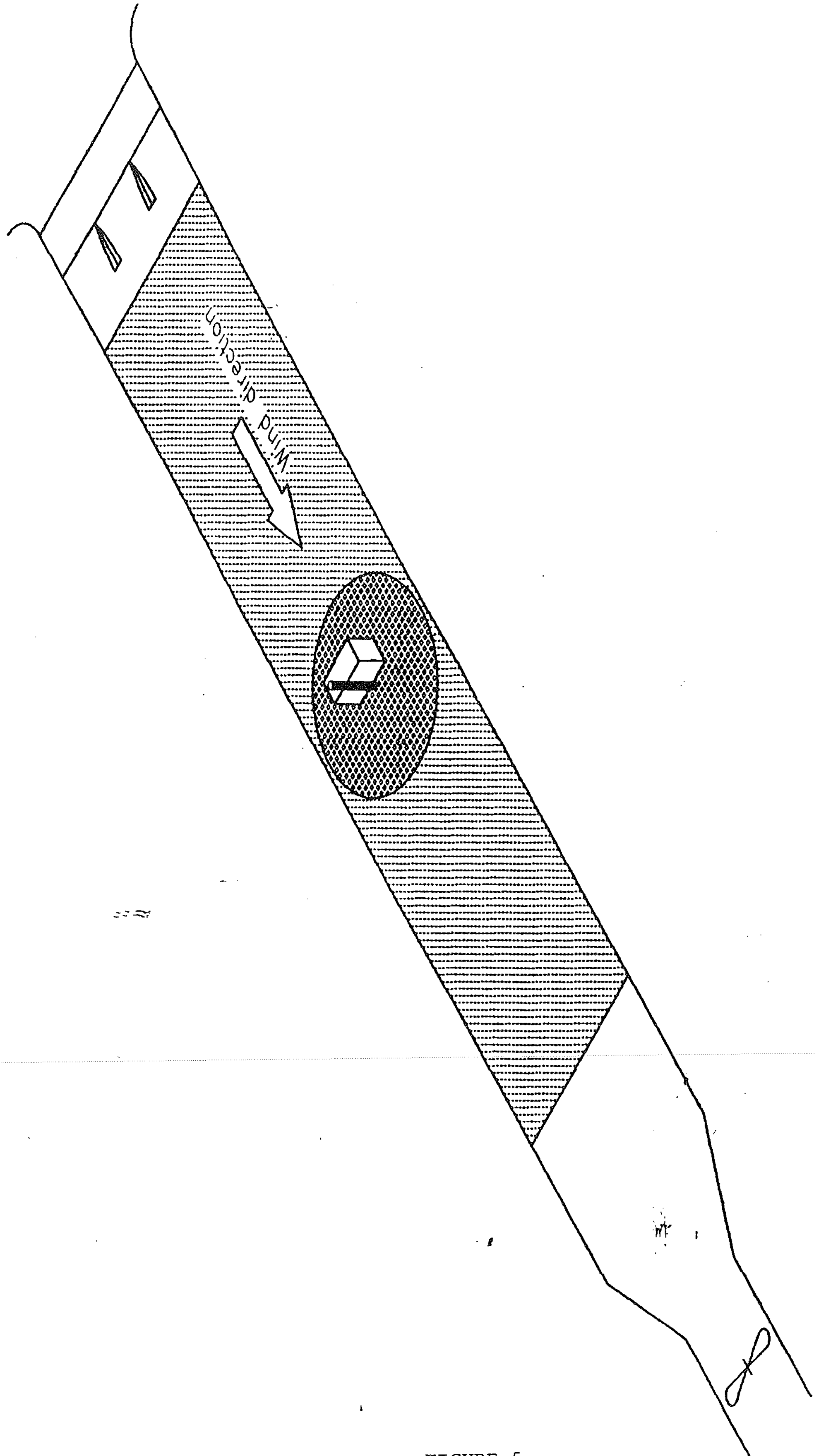


FIGURE 5

Illustration of Uniform Roughness Throughout Tunnel

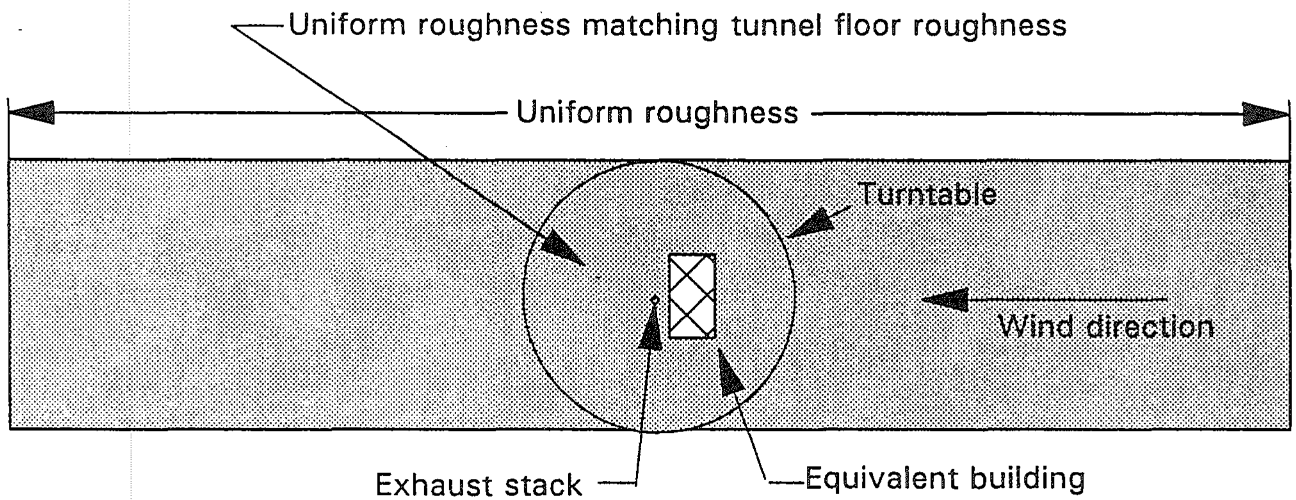
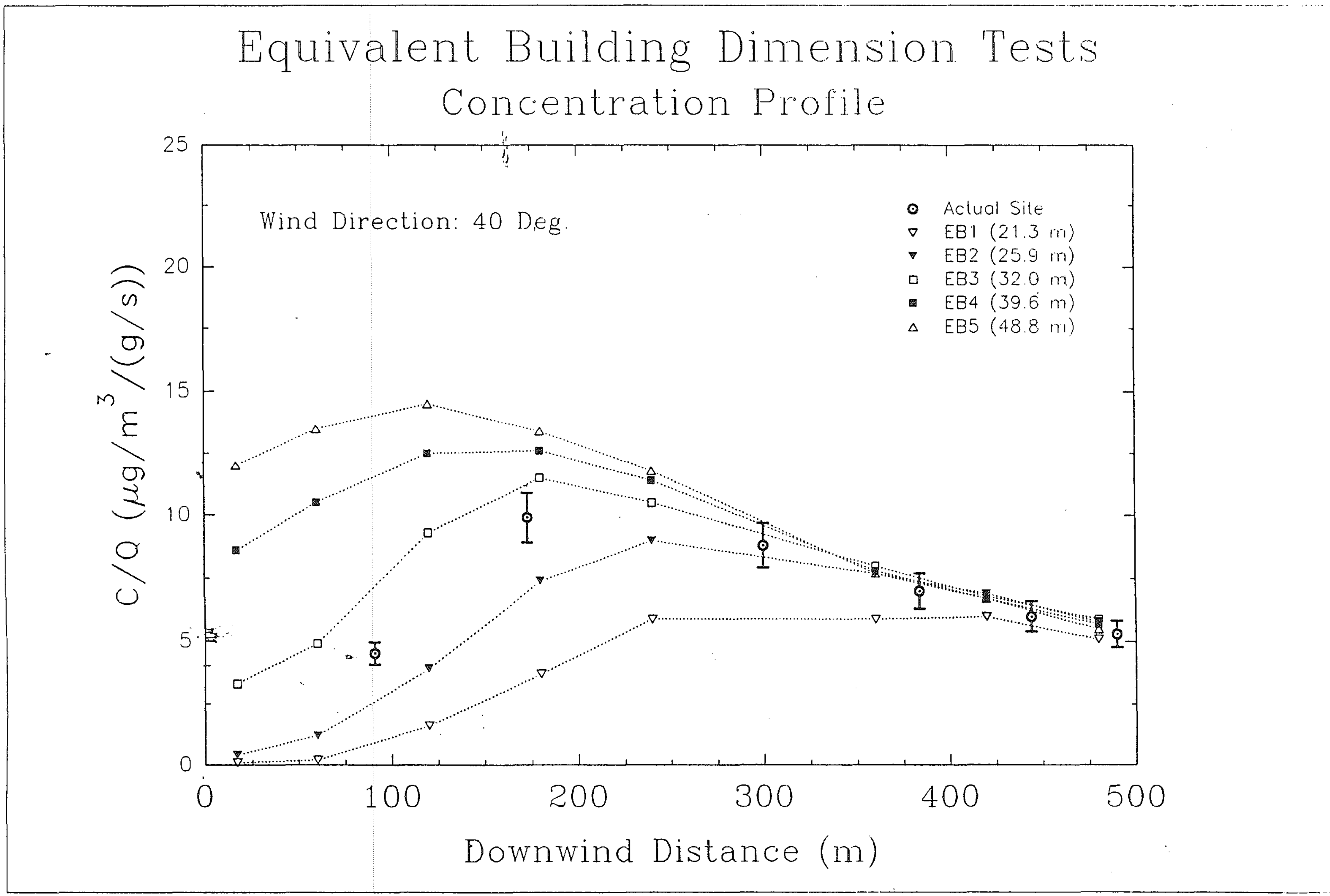


FIGURE 6



Equivalent Building Dimension Tests
Concentration Profile
Wind Direction: 40 Deg.
Actual Site
EB1 (21.3 m)
EB2 (25.9 m)
EB3 (32.0 m)
EB4 (39.6 m)
EB5 (48.8 m)
C/Q (μg/m3/(g/s))
Downwind Distance (m)
0
5
10
15
20
25
0
100
200
300
400
500

FIGURE 7

EQUIVALENT BUILDING DIMENSIONS: ILLUSTRATION OF ACCEPTANCE CRITERIA: CE > .90CSmax at RSmax; CE > (CS-.20CSmax) AT OTHER DISTANCES

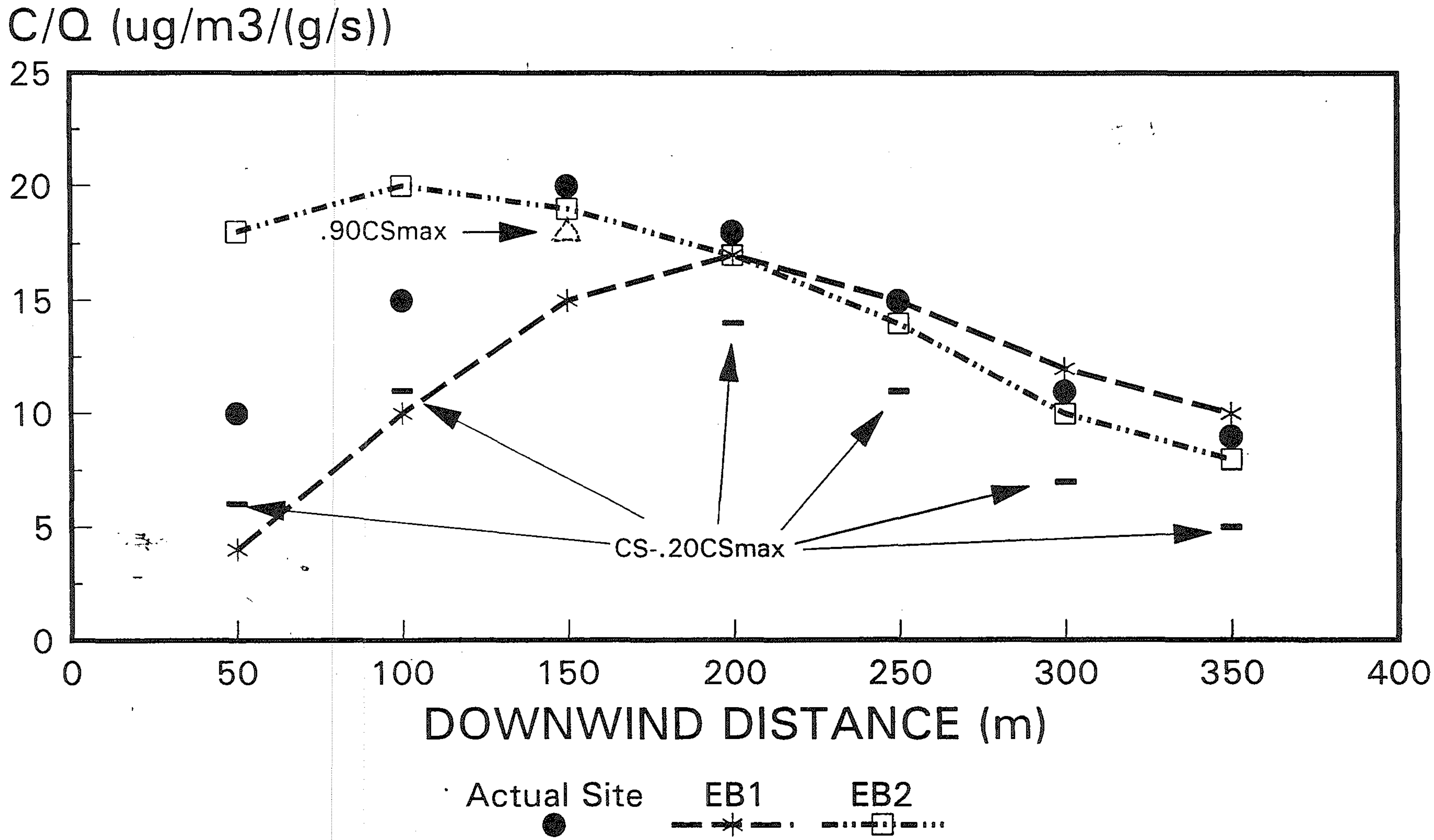


FIGURE 8