ANALYSIS AND COMPARATIVE EVALUATION OF AIRPOL-4

by

William A. Carpenter
Research Engineer

and

Gerardo G. Clemeña
Research Analyst

(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

Virginia Highway & Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways & Transportation and the University of Virginia)

Charlottesville, Virginia

June 1975
VHTRC 75-R55

3326

ABSTRACT

AIRPOL-4, an air quality prediction model, has been developed by the Virginia Highway and Transportation Research Council for use in complying with the requirements contained in the Federal Aid Program Manual, Vol. 7, Ch. 7, Section 9, November 14, 1973. This report, the second in the AIRPOL series, presents definitive experimental evidence which establishes AIRPOL-4 as an advancement in the field of air quality modeling. Specifically, this report demonstrates that AIRPOL-4 is a more cost-effective, versatile, and accurate model than either of the accepted "standards," CALAIR or HIWAY, and that its level of performance warrants its implementation.

The third report in this series provides a detailed introduction to the mechanics and philosophy of using AIRPOL-4.

3338

ACKNOWLEDGEMENTS

The authors thank all those persons who contributed to the success of this project. Many individuals utilized their time and talents to collect data, write computer programs, type reports, and prepare drawings; however, we particularly thank W. R. Lunglhofer, G. T. Gilbert, Jr., and E. G. Kerby II for their expert assistance.

3350

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

ANALYSIS AND COMPARATIVE EVALUATION OF AIRPOL-4

by

William A. Carpenter
Research Engineer

and

Gerardo G. Clemeña
Research Analyst

INTRODUCTION AND PURPOSE

As detailed in the Federal Aid Program Manual, Vol. 7, Ch. 7, Section 9, November 14, 1973, the Virginia Department of Highways and Transportation is required to estimate the impact of proposed highway facilities on the air quality in the region of such facilities. Currently, the CALAIR[1] and HIWAY[2] air pollution prediction models, developed by the California Division of Highways and the United States Environmental Protection Agency (EPA), respectively, are the two prediction models generally accepted by the Federal Highway Administration for use in complying with the above requirement. These models are, however, cumbersome and expensive to use, and they tend to overpredict pollution levels in the critical cases of low wind speeds and small road/wind angles.

The Virginia Highway and Transportation Research Council has developed an air pollution prediction model, AIRPOL-4,[3] which is essentially free of the deficiencies inherent in CALAIR and HIWAY. The purpose of this report is to firmly establish the utility and integrity of AIRPOL-4 relative to CALAIR and HIWAY, the currently accepted "standards",through the presentation of data describing the cost performances of the models and their predictive performances relative to observed field data. The report thus determines both absolute and relative measures of the performances of each of these models.

COMPARISON OF THE STRUCTURE AND CAPABILITIES OF THE MODELS

This section describes only the principal differences between the Virginia, California, and EPA models which have a bearing on this study. For more detailed descriptions of these models, the reader should consult references 1, 2, and 3. The six major differences between these models are in the basic formulations, their methods of determining stability classes, their methods of determining dispersion parameters, their methods of relating carbon monoxide (CO) levels to wind speeds, their abilities to determine emission factors, and their abilities to analyze upwind receptors. These differences are described below.

Basic Formulation

Although all three models are based on the Gaussian theory of dispersion, only AIRPOL-4 and HIWAY are actually Gaussian line source models, while CALAIR is a semi-Gaussian empirical formulation. The major result of this difference is that while AIRPOL-4 and HIWAY must evaluate complex integral equations to make predictions, CALAIR must only perform several simple algebraic operations. This difference is also responsible for the fact that the Gaussian models are inherently continuous throughout all road/wind angles while CALAIR consists of two submodels: one for winds parallel to a highway and one for crosswinds. Another symptom of this difference is that while AIRPOL-4 and HIWAY make predictions based on the lengths of line sources, the crosswind submodel of CALAIR functions independently of line source length yet the parallel-wind submodel requires a knowledge of source length.

Although AIRPOL-4 and HIWAY both evaluate the Gaussian integral to make predictions, the respective methods employed are quite different. AIRPOL-4 uses a specialized segmentation technique in conjunction with Coat's method of order 6 to evaluate the integral while HIWAY uses only the general application technique of Simpson's Rule (Cote's method of order 2) with bisection.

Determination of Stability Classes

CALAIR and HIWAY use atmospheric stability classes determined by the Turner technique.[4] AIRPOL-4 uses stability classes determined by the Pasquill technique.[5] (This report will show that the predictive performance of AIRPOL-4 (Pasquill) is superior to that of AIRPOL-4 (Turner)).

Determination of Dispersion Parameters

HIWAY determines the dispersion parameters σ_y and σ_z from the Turner defined atmospheric stability class by extrapolating Pasquill's empirical curves for σ_y and σ_z to σ_y = 3.0 meters and σ_z = 1.5 meters, and then shifting these extrapolated curves to the left such that σ_{y_o} = 3.0 meters and σ_{z_o} = 1.5 meters. AIRPOL-4 uses this same technique starting, however, with the Pasquill defined class to determine preliminary approximations to σ_y and σ_z. AIRPOL-4 then translates these preliminary values, which are applicable only to rural areas and 3-to 10-minute sampling times, to values applicable to urban areas and a sampling time specified by the user. CALAIR, on the other hand, applies the Turner determined class to a set of modified Pasquill curves. These modified curves were developed by empirically determining values of σ_y and σ_z at 1.0 meter from the edge of a line source and exponentially extrapolating Pasquill's curves to these values, mutating the original curves in the process to facilitate smooth transitions from Pasquill's results to California's results at 1.0 meter.

CO Level vs. Wind Speed Relationship

Both the CALAIR and HIWAY models use the classical Gaussian relationship between pollutant concentration and wind speed. AIRPOL-4, however, uses a modification of this relationship based on the concept of "residual turbulence", which eliminates the asymptotically infinite behavior of the classical Gaussian formulation at low wind speeds.

Ability to Determine Emission Factors

AIRPOL-4 computes line source emission factors according to the guidelines specified in reference 6, with some computational improvements. CALAIR and HIWAY require emission factors determined according to these guidelines, although neither is capable of generating them internally. Thus, for this study the emission factors generated by AIRPOL-4 were used as inputs to the CALAIR and HIWAY models.

Ability to Analyze Upwind Receptors

Since AIRPOL-4 and HIWAY are both Gaussian formulations, they are both inherently capable of estimating CO concentrations for receptors either upwind or downwind of a source highway. AIRPOL-4 takes full advantage of this ability while HIWAY makes predictions for downwind receptors only. CALAIR cannot make upwind predictions since its empirical formulation is inapplicable to the problem.

Table 1 summarizes the major differences between AIRPOL-4, CALAIR, and HIWAY. The next section will analyze and compare the cost performances of these models.

Table 1

Major Differences Between the Models

ITEM	AIRPOL-4	CALAIR	HIWAY
Formulation	Gaussian	Empirical/Semi-Gaussian	Gaussian
Continuity	Continuous	Discontinuous	Continuous over its functional range
Stability Classification Required	Pasquill	Turner	Turner
Determination of σ_y and σ_z	Pasquill's curves with offset technique and corrections for averaging time and urban areas	Empirical extrapolation of Pasquill's curves with resultant distortion of lower end of original curves	Pasquill's curves with offset technique
$CO \propto f(\mu)$	$CO \propto (1.92 + \mu \times \exp(-0.22 \times \mu))^{-1}$	$CO \propto \frac{1}{\mu}$	$CO \propto \frac{1}{\mu}$
Emission Factors	Determined internally	Must be supplied	Must be supplied
Predictions for upwind receptors	Included in model and in computer program	Model and computer program incapable of analyzing upwird receptors	Model theoretically capable, but concept excluded from both model and computer program

COST PERFORMANCE

The total operating costs for AIRPOL-4, CALAIR, and HIWAY were determined for a "typical" project analysis consisting of four sites. Since specific parameters affect the cost performance characteristics of CALAIR and HIWAY significantly, these comparisons were performed using a representative sample of inputs. Fill and at-grade sites were analyzed in a 25:75 ratio, as were source lengths of 4,000 and 6,600 feet (1200 and 2000 m). Road/wind angles were assigned uniformly from the interval 0^{o} to 90^{o}. Finally, all sites consisted of four-lane, dual-divided facilities with 35-foot (10.7-m) medians and representative peak hour traffic. Within each site 16 receptors, 8 each at 0.0-and 5.0-foot (0.0- and 1.5-m) elevations extending from 10 to 220 feet (3 to 67 m) from the downwind edge of the source road, were analyzed. Each receptor was examined under both A and D stability classes for three different prediction years (each having different traffic and emission characteristics) at 6 wind speeds. Thus a total of 576 receptor concentrations were determined per site.

All three models were benchmarked on an IBM 370/158 with 1 megabyte of core running under OS release MFT 21.7 with Hasp II. The source programs were compiled to an object-code library using an IBM FORTRAN IV, G-level compiler. Test runs were made using the object-code programs and the load-step costs were deleted from all test results. Thus, the machine costs cited in this report are for the execution step only.

Analysis of the input requirements for each model indicated that AIRPOL-4 required a high total 0.34 key strokes/data point, CALAIR required an average of 39.00 key strokes/point, and HIWAY required an average of 22.19 key strokes/point. Costs were determined from these figures using Virginia Department of Highways and Transportation (VDHT) estimates of 3,600 equivalent key strokes/hr for data coding, assuming that all necessary data were immediately available (this assumption was, of course, not true for CALAIR and HIWAY, which required side calculations to determine emission rates), and 16,000 key strokes/hr for keypunching.

Table 2 itemizes the resources required to fully analyze these four sites. The most important point to note in this table is the nearly unmanageable volume of input and output for both CALAIR and HIWAY as compared to AIRPOL-4. Since people are not generally capable of comprehending large volumes of data unless the data are available in some compact and meaningful form, there is an additional "cost" to using CALAIR or HIWAY which may be measured in terms of the errors and frustration generated by creating and analyzing unnecessarily expanded data sets.

Table 2

Resource Requirements for Analyses of Four Typical Sites

Resource	AIRPOL-4	CALAIR	HIWAY
Computer Time, cpu-hours	0.004	0.022	0.565
Card Reading, cards	16	4,608	3,294
Printing, lines	620	63,936	5,058
Computer Memory, kbyte-hours	0.19	1.06	21.46
Input Coding, hours	0.22	24.96	14.20
Keypunching, hours	0.05	5.62	3.20
Card Stock, cards	16	4,608	3,294
Paper Stock, pages	8	2,304	144

Table 3 shows the resource cost factors which were applied to the entries in Table 2 to develop the actual dollar costs incurred in using the models. These factors are, of course, specific to the VDHT, but should not change significantly from installation to installation.

Table 3

VDHT Resource Cost Factors

Resource	Cost
Computer Time	$205.00/cpu-hour
Card Reading	1.73/1,000 cards
Printing	0.70/1,000 lines
Computer Memory	0.60/kbyte-hour
Input Coding	5.25/hour
Keypunching	3.65/hour
Card Stock	1.20/1,000 cards
Paper Stock	5.00/1,000 pages

Table 4 shows the actual dollar costs involved in making complete (576 data points/site) analyses of these four typical sites. These figures show that the cost of using AIRPOL-4, \$2.81, is only about 1.2% of the cost of using either CALAIR or HIWAY, \$226.48 and \$228.80, respectively. In fact, even in those cases where a complete analysis is unnecessary, AIRPOL-4 is still less expensive. For instance, the analyses of four "typical" sites with only 16 receptors per site, all analyzed for a single wind speed, stability class, and prediction year combination, would cost about \$1.87 using AIRPOL-4 as compared to \$6.29 using CALAIR and \$6.36 using HIWAY.

Table 4

Incurred Costs for Analyses of Four Typical Sites

Resource	AIRPOL-4	CALAIR	HIWAY
Computer Time	\$0.82	\$ 4.52	\$115.80
Card Reading	0.03	7.97	5.70
Printing	0.44	44.76	3.54
Computer Memory	0.12	0.64	12.88
Input Coding	1.16	131.04	74.55
Keypunching	0.18	20.50	11.66
Card Stock	0.02	5.53	3.95
Paper Stock	0.04	11.52	0.72
TOTAL	\$2.81	\$226.48	\$228.80

PREDICTIVE PERFORMANCE

This section analyzes the predictive performances of AIRPOL-4, CALAIR, and HIWAY relative to 436 one-hour field measurements. AIRPOL-4 has been completely analyzed with respect to both the Pasquill and Turner stability classes to verify the choice of the Pasquill technique as that to be used with AIRPOL-4. CALAIR and HIWAY have been analyzed primarily with respect to the recommended Turner class, although they have also been analyzed with respect to the Pasquill class for the overall data set to illustrate their changes in performance with class determination.

The Field Study

The AIRPOL project included a field study to collect data for the purpose of validating the performance of AIRPOL-4. This study produced simultaneous measurements of CO levels, and geometric, traffic, and meteorological parameters. One-hour data samples were measured intermittently at five test sites on random weekdays during either peak or off-peak hours over a period of approximately one and a half years to ensure representative ranges of geometric, traffic, and meteorological variables. During each test conducted, several simultaneous one-hour bag samples were collected on both sides of the subject roadway at distances ranging from 12 to 385 feet (3.7 to 117.4 m) from the edge of the pavement and at elevations of 5 and 10 feet (1.5 and 3.0 m) above ground level. The 10-foot (3.0-m) samples were taken only at the receptors closest to the roadway.

Test Sites

An attempt was made to locate test sites typifying at-grade, fill, and cut sections of roadway meeting the following criteria:

1. A volume of traffic sufficient to produce detectable levels of CO,
2. a volume of traffic constituting the most significant source of CO in the immediate vicinity,
3. a terrain relatively free of physical barriers such as large buildings, trees, etc.,
4. an adequate safe working area for personnel, and
5. legal and physical accessibility to personnel and equipment.

Subject to these constraints, only five satisfactory test sites, one elevated and four at-grade, were found. Since virtually all major highway cut sections in Virginia are in sparsely traveled areas, no satisfactory test sites could be found for depressed roadways. The five selected sites are described below. Table 5 summarizes the descriptive and measured data for these sites. Percentage breakdowns of the meteorological and traffic conditions for all test sites are shown in Table 6. Figures 1 through 5 are photographs of sites 1 through 5, respectively.

Test site 1, Figure 1, is located on Interstate 495 near Telegraph Road in Fairfax, Virginia (U. S. Geological Survey, 7.5 minute Topographic Map, Alexandria Quadrangle, Virginia - District of Columbia - Maryland, UTM coordinates 4,296,690 m N by 318,580 m E). I-495 at this location is an at-grade, six-lane, dual-divided facility with a 37-foot (11.3-m) median. The highway runs approximately east and west. The area north of the highway is essentially open while the area south of the facility contains scattered single-family dwellings. The nearest external pollutant source of any significance is Telegraph Road, located about 2,500 feet (750 m) east of the site.

Test site 2, Figure 2, is located on Interstate 64 near North Hampton Boulevard in Norfolk, Virginia (Kempsville Quadrangle, Virginia, UTM coordinates 4,081,070 m N by 393,460 m E). I-64 at this location is an at-grade, six-lane, dual-divided facility with a 60-foot (18.3-m) median. The highway runs approximately north and south. The land use in the area is primarily agricultural. There is a two-story school building about 500 feet (150 m) east of the highway and a four-story school building about 850 feet (250 m) west of the highway. The nearest external pollutant source of any significance is North Hampton Boulevard, located about 1,700 feet (500 m) north of the site.

Test site 3, Figure 3, is located on Interstate 95 near Edsall Road in Fairfax, Virginia (Annandale Quadrangle, Virginia, UTM coordinates 4,296,520 m N by 312,900 m E). I-95 at this location is an at-grade, ten-lane, triple-divided facility with two 21-foot (6.4-m) medians separating the reversible two-lane center roadway from the two fixed-direction, four-lane roadways. The highway runs approximately north and south in the area of this site. The land to the east of the roadway is basically open while to the west there are scattered commercial establishments. The nearest external pollutant source of any significance is Edsall Road, located approximately 1,000 feet (300 m) west of the site.

3342

Table 5

Summary of Site Descriptive Data and Observed Traffic and Meteorological Data

Item		Site 1	Site 2	Site 3	Site 4	Site 5
Subject Highway		I495	I64	I95	I264	I64
City/County		Fairfax	Norfolk	Fairfax	Norfolk	Norfolk
U.S.G.S. Topographic Quadrant, 7.5 Minute Map		Alexandria, Va., D.C., Md.	Kempsville, Virginia	Annandale, Virginia	Kempsville, Virginia	Little Creek Virginia
UTM Map Coordinates	mN	4,296,690	4,081,070	4,296,520	4,078,230	4,083,960
	mE	318,580	393,460	312,900	389,080	390,040
Relative Highway Elevation, ft (m)		0 (0)	0 (0)	0 (0)	35 (10.7)	0 (0)
Number of Lanes		3,3 = 6	3,3 = 6	4,2,4 = 10	3,3 = 6	3,3 = 6
Median Width, ft (m)		37 (11.3)	60 (18.3)	21 (6.4) each	42 (12.8)	60 (18.3)
General Highway Direction		E,W	N,S	N,S	E,W	N,S
Land Use		low density residential	agricultural (two schools)	light commercial	low density residential & light industrial	low density residential
Distance to Nearest Significant External Source, ft (m)		2,500 (750)	1,700 (500)	1,000 (300)	2,800 (850)	2,000 (600)
Traffic Volume Range, vph	Low	2,646	3,288	4,510	3,030	2,200
	High	7,910	5,190	8,250	5,060	6,650
Traffic Speed Range, mph (km/hr)	Low	38 (61)	51 (82)	53 (85)	50 (80)	45 (72)
	High	62 (100)	58 (93)	54 (87)	56 (90)	60 (97)
% hdv Range	Low	5	5	4	1	2
	High	22	9	11	15	21
Road/Wind Angle Range, degrees	Low	4	20	10	54	21
	High	86	20	90	85	88
Wind Speed Range, mph (m/s)	Low	0.4 (0.18)	4.2 (1.88)	1.3 (0.58)	4.9 (2.19)	0.6 (0.27)
	High	10.8 (4.83)	6.9 (3.08)	4.6 (2.06)	7.2 (3.22)	8.5 (3.80)
Turner Stability Range	Low	A	B	A	B	B
	High	D	C	D	D	D
Pasquill Stability Range	Low	A	B	A	A	B
	High	D	C	B	C	C

Table 6

Percentage Breakdown of Experimental Conditions

Parameter	Range	% of Total Data	
Wind Direction, degrees	$0 \leq \alpha \leq 30$	27	
	$30 < \alpha \leq 60$	35	
	$60 < \alpha \leq 90$	38	
Wind Speed, mph	$0.0 \leq \mu \leq 2.0$	21	
	$2.0 < \mu \leq 4.0$	31	
	$4.0 < \mu \leq 6.0$	25	
	$6.0 < \mu$	23	
Atmospheric Stability Class		Turner	Pasquill
	A	6	10
	B	29	63
	C	17	17
	D	48	10
Total Traffic Volume, vph	$2{,}000 \leq v \leq 5{,}000$	58	
	$5{,}000 < v \leq 8{,}000$	40	
	$8{,}000 < v$	2	
Traffic Speed, mph	$35 \leq s \leq 45$	4	
	$45 < s \leq 55$	47	
	$55 < s \leq 62$	49	
Vehicle Mix, % hdv	$0 \leq h \leq 10$	65	
	$10 < h \leq 20$	34	
	$20 < h$	1	

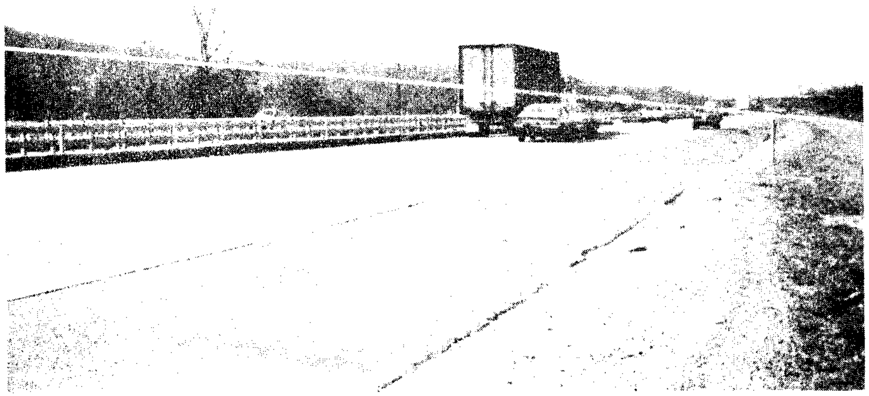


Figure 1. Site 1, an at-grade site located on Interstate 495 near Telegraph Road in Fairfax County, Virginia.

Figure 2. Site 2, an at-grade site located on Interstate 64 near Hampton Boulevard in Norfolk, Virginia.

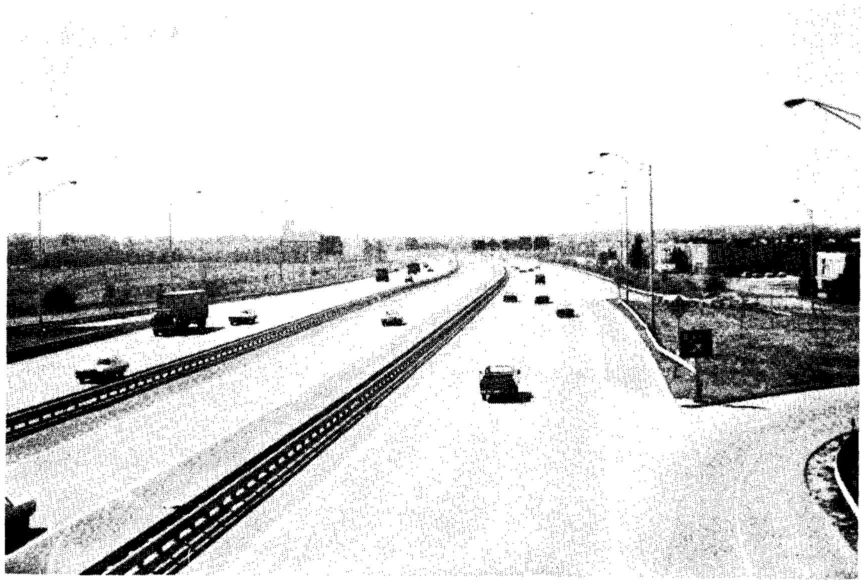


Figure 3. Site 3, an at-grade site located on Interstate 95 near Edsall Road in Fairfax County, Virginia.

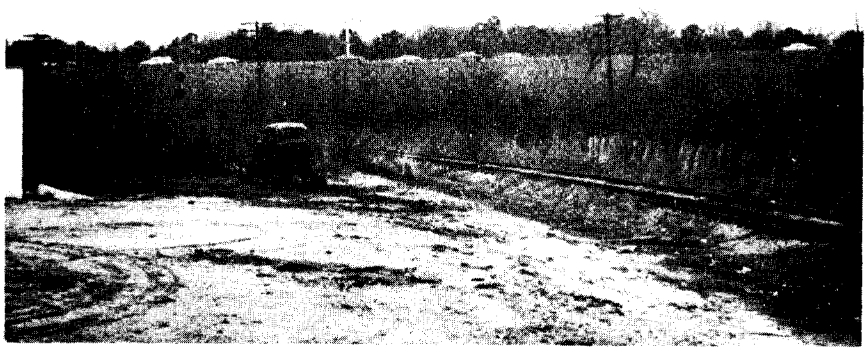


Figure 4. Site 4, an elevated site located on Interstate 264 near Merrimac Avenue in Norfolk, Virginia.

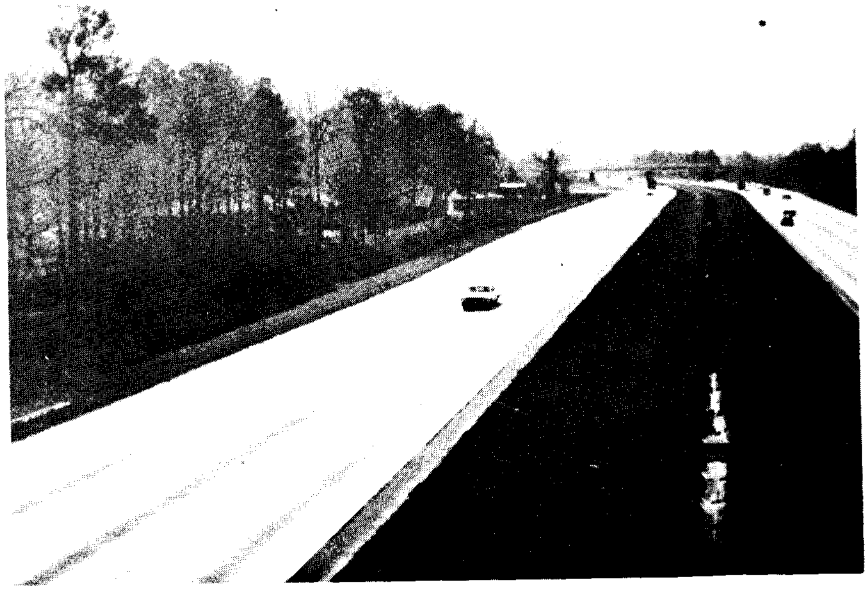


Figure 5. Site 5, an at-grade site located on Interstate 64 near Norview Avenue in Norfolk, Virginia.

Test site 4, Figure 4, is located on Interstate 264 near Merrimac Avenue in Norfolk, Virginia (Kempsville Quadrangle, Virginia, UTM coordinates 4,078,230 m N by 389,080 m E). I-264 at this location is a six-lane, dual-divided, 35-foot (10.7-m) high fill facility with a 42-foot (12.8-m) median. The highway runs approximately east and west. The land on both sides of the roadway contains single-family dwellings and light industrial buildings. The nearest external pollutant source of any significance is Merrimac Avenue, located approximately 2,800 feet (850 m) west of the site.

Test site 5, Figure 5, is located on Interstate 64 near Norview Avenue in Norfolk, Virginia (Little Creek Quadrangle, Virginia, UTM coordinates 4,083,960 m N by 390,040 m E). I-64 at this location is an at-grade, six-lane, dual-divided facility with a 60-foot (18.3-m) median. The highway runs approximately north and south. There is a pedestrian overpass at the site. The land on both sides of the roadway contains one-story, single-family dwellings. The nearest external pollutant source of any significance is Norview Avenue, located approximately 2,000 feet (600 m) away from the site.

Meteorological Data Collection

Wind speeds and directions were monitored continuously during each hourly test period using a vectorvane which was calibrated in a wind tunnel owned and operated by the Department of Environmental Science, University of Virginia. This vectorvane, which is a lightweight, quick-response, low-threshold instrument, and its associated electronics are capable of determining wind azimuths to $\pm 5^\circ$ over the range 0° to $- 540^\circ$, and wind speeds to $\pm$ 0.1 mph (0.04 m/s) over the range 0.4 to 20 mph (0.18 to 8.9 m/s). Wind speeds and azimuths were recorded on strip chart recorders. The strip chart traces were manually digitized and averaged for each one-hour interval.

At each of the test sites, the vectorvane was separated from the nearest obstruction by a distance at least five times the height of the obstruction, which ensured good exposure of the instrument. The elevation of the vectorvane was always 10 meters above the surrounding terrain, a suggested "standard" for measuring surface winds advocated by the World Meteorological Organization and the National Oceanic and Atmospheric Administration.

Information such as cloud covers and ceiling heights needed for atmospheric stability classification were obtained for each one-hour test interval from National Weather Services Offices located at nearby airports. Each of the test sites is within, at most, 7.5 miles (12 km) of a National Weather Service Office. With the surface wind data measured at the sites and the supplementary meteorological data from airports, the Pasquill and Turner atmospheric stability categories for each hour were determined using computer programs based on procedures suggested by Pasquill(4) and Turner(5), respectively.

Traffic Data Collection

Since pollutant concentrations measured at the sites are dependent on traffic parameters such as speed, volume, and vehicle mix, these were measured during each of the hourly study periods.

Traffic speeds were measured by radar, recorded on strip charts, and manually reduced to hourly averages. The radar and recorder systems were calibrated with tuning forks before use each day and recalibrated after every two hours of continuous usage.

Traffic counts and vehicle mixes were determined manually for each test period. Those vehicles with three or more axles and two-axle vehicles having a capacity of 2 tons (2,000 kg) or more were considered to be heavy duty vehicles. All other vehicles were considered to be passenger vehicles.

Site Geometric Data Collection

Geometric data such as median widths, lane widths, shoulder widths, and roadway elevations were obtained from the construction plans for each site. The receptor points, i.e., locations at which air samples were collected, were identified by measuring perpendicular distances from pavement edges and heights above ground. Upwind and downwind source lengths were obtained from topographic maps of the site areas.

Carbon Monoxide Data Collection

Total carbon monoxide concentrations were determined for each test period by analyzing one-hour bag samples collected simultaneously at several points on both sides of a highway site. These bag samples were analyzed for CO concentrations using a gas chromatograph with an accuracy of $\pm$ 1% of full-scale which translates to $\pm$ 0.1 ppm for the 10.0 ppm full-scale setting used in this study.

The chromatograph was calibrated daily using certified span and zero gas samples. As a precaution against the possibilities of improper certification or reaction of the certified gasses with their storage tanks to form metallic carbonyl compounds, each tank of calibration gas was analyzed by the Virginia State Air Pollution Control Board before use in this study.

Highway generated CO levels at each receptor location were determined by subtracting the estimated background CO levels at each site from the measured total CO levels at each receptor location. Background CO levels were assumed to be the lowest observed levels for each test hour at each site, which generally was observed at those receptors farthest upwind from the source roadways.

The collection of air samples was carried out using bag-sampling units. Each of these units consisted of a battery-operated pump, an aluminized polyester bag, teflon tubing, and a padlocked plywood storage box to protect the equipment from natural elements and vandalism. During each test period, about ten such units were placed at incremental distances from both sides of the highway and coordinated to collect air samples simultaneously. The flow rates of the pumps in these systems were calibrated to ensure that the bags were not filled before each test hour was complete. At the conclusion of each test hour, the bags were changed. Collected air samples were analyzed at the end of each test day.

Evaluation Criteria

The predictive powers of AIRPOL-4 (Turner), AIRPOL-4 (Pasquill), CALAIR, and HIWAY are evaluated in this report based primarily on three criteria. The first and most important of these is the average squared error of prediction, which is often translated as an error bound. It can be shown that the assumption that a model is a good predictor may be translated to the assumption that the predictions are normally distributed with constant variances such that $\text{PREDICTION}_i \sim N\ (\text{OBSERVATION}_i, \sigma^2)$. Given this assumption, the average squared error of prediction is a maximum likelihood estimator for σ^2. Thus, the average squared error of prediction and its translations are very powerful performance criteria, since they are direct measures of the variability of prediction relative to the expected true values.

The second and next most important performance measurement used is a comparison of the regression data generated by fitting the observed and predicted CO data to the *SI* statistical equation, OBSERVED = A x PREDICTED + B. These regression data indicate which models most closely approximate the ideal behavior, OBSERVED = PREDICTED, in their average performance. The correlation coefficients associated with these *SI* linear regressions are used to provide measurements of the reliability of the regression equations. The reader should be cautioned that these correlation coefficients measure only the extent to which the data fit the regression equations; they do not measure the accuracy or consistency of the predictions. The only statistically valid measures of model consistency are the average squared error of prediction and its translations. Correlation coefficients have been generated only as measures of the goodness of fit of the regression equations. They must not be misconstrued by those readers accustomed to evaluating performance based on correlation as measures of the goodness of fit of the models themselves.

The third criterion used in this analysis is the 100% confidence limits on the prediction error. This test is very demanding since it concentrates on the extreme behavior of the models as opposed to the average behavior. However, a measure of the extremes of a model's eccentricities is valuable to the potential user.

All tests for statistical significance in this report were carried out at a 0.05 confidence level. The tests for comparison of average squared errors (and all its transforms) and 100% confidence limits were all one-sided *F* tests of the hypothesis H_0: *average squared error of A > average squared error of B*, i.e., H_0: *B superior to A*. The tests for regression lines were all based on two-sided *t* tests of the hypotheses H_0: *slope = 1* and H_0': *slope (A) = slope (B)*. (Almost without exception, *F* tests of the hypothesis H_0: *slope = 1 and intercept = 0* rejected H_0 due to the large sample sizes and high correlations, while *t* tests of the hypothesis H_0: *intercept = 0* accepted H_0. Thus these tests, which were examined at several significance levels, have been omitted from this report since they provide no comparative information.)

Overall Downwind Predictive Performance

The performance measures for each of the models for the overall downwind predictive performance analysis are shown in Table 7. Statistical comparison of these results, using 0.05 confidence levels with the *F* and *t* tests described above, indicates that AIRPOL-4 (Pasquill) is statistically superior to the other three models with respect to all measures of predictive performance.

A particularly interesting group of statistics shown in Table 7 are the statistical error bounds. AIRPOL-4 (Pasquill), and even (Turner), show very comfortable probable errors of ± 0.72 and ± 0.76 ppm CO, respectively, compared to ± 1.50 ppm CO for CALAIR and ± 1.80 ppm CO for HIWAY. Furthermore, the statistical expectations of the percentages of predictions within ± 1 ppm CO, 62% and 65%, and within ± 2 ppm, 92% and 94%, for the Turner and Pasquill versions of AIRPOL-4 are quite respectable and statistically superior to those for CALAIR and HIWAY, 35% and 29% within ± 1 ppm CO, and 63% and 54% within ± 2 ppm CO, respectively.

The data in Table 7 also reveal other interesting information. The reader should note that the CALAIR statistics in this table are based on 29 fewer data points than are those for the other models. This occurred since CALAIR was incapable of analyzing any wind speeds less than 2.0 mph (0.9 m/s), which is a reasonably serious deficiency (the 10% of the sample points it is incapable of analyzing should reasonably constitute a "worst case" analysis), and should therefore be considered when examining the effectiveness of this model.

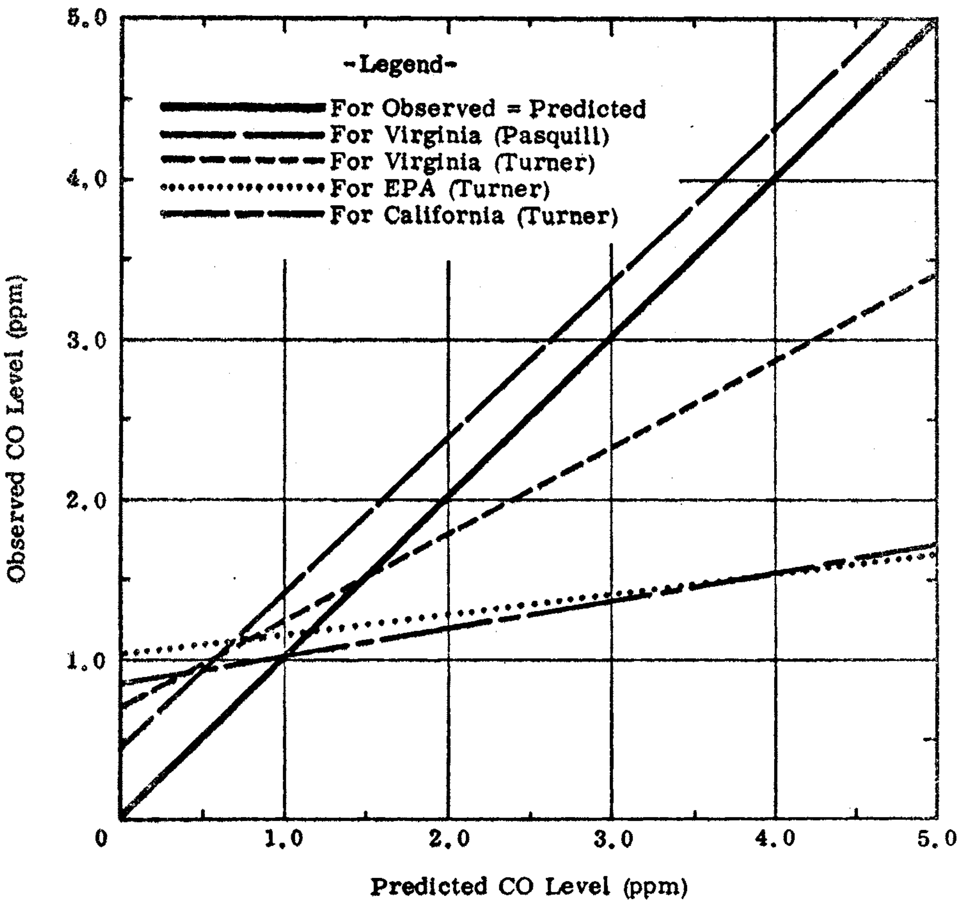
Table 7

Overall Predictive Performances of Models for Downwind Receptors

Statistic	AIRPOL-4 (Turner)	AIRPOL-4 (Pasquill)	CALAIR (Turner)	HIWAY (Turner)
Number of Data Points	254	254	225	254
Average Squared Error	1.28	1.16	5.02	7.22
Probable Error	±0.76	±0.72	±1.50	±1.80
% Correlation Coefficient	42	51	39	31
Regression Slope	0.54	0.96	0.17	0.13
Regression Intercept	0.70	0.49	0.83	1.02
Minimum Error	-4.71	-4.71	-3.94	-4.36
Maximum Error	3.81	1.41	13.38	20.05
100% Error Range	8.52	6.12	17.32	24.41
Expected % Within ± 1 ppm	62	65	35	29
Expected % Within ± 2 ppm	92	94	63	54

Figure 6 supplements Table 7 by visually illustrating the regression lines for the four models. The reader should note that since these regression lines were determined from the *SI* statistical relationship OBSERVED = A x PREDICTED + B, the region of under prediction is the area above the line OBSERVED = PREDICTED. Figure 6 illustrates that, in its average performance, AIRPOL-4 (Pasquill) under predicts slightly while the other models over predict significantly except at the low end, where they under predict. Furthermore, it can be seen that AIRPOL-4 (Pasquill) is consistent in its average performance in that it has a fairly constant under prediction error of about 0.33 ppm CO, while the behavior of the other models is erratic.

3352



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	254	254	225	254
Probable Error	0.76	0.72	1.50	1.80
% Corr. Coeff.	42	51	39	31
Min. Dev.	-4.71	-4.71	-3.94	-4.36
Max. Dev.	3.81	1.41	13.38	20.05
Dev. Range	8.52	6.12	17.32	24.41

Figure 6. Overall predictive performances of models for downwind receptors.

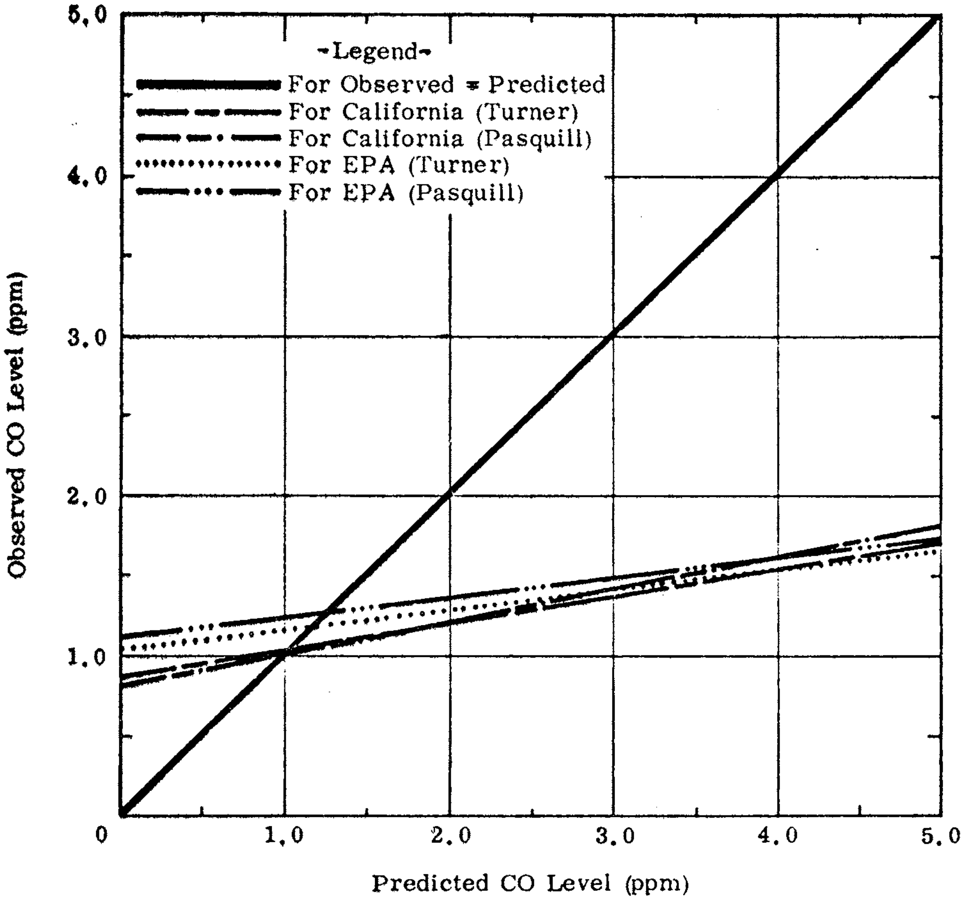
The effects of stability class determination on CALAIR and HIWAY are illustrated in Table 8 and Figure 7. The reader should recall that the developers of CALAIR and HIWAY have specified that the Turner modification of the basic Pasquill technique for determining stability class should be employed to calculate the stability class inputs for these models. Analysis of these results, using the statistical tests described above, shows that a significant improvement in the overall downwind performance of these models is achieved by using the Pasquill stability class. This improvement is demonstrated primarily by a decrease in the average squared error statistic. However, statistical analyses show that this improvement still leaves the performance of CALAIR and HIWAY significantly below the performance of the Virginia model. Furthermore, consideration of Figure 7 indicates that although the use of the Pasquill stability class produces significant improvements in the prediction variabilities of CALAIR and HIWAY, it does not materially improve the average predictive performance of either.

Table 8

Effects of Stability Class Determination on the Performances of CALAIR and HIWAY

Statistic	CALAIR (Turner)	HIWAY (Turner)	CALAIR (Pasquill)	HIWAY (Pasquill)
Number of Data Points	225	254	225	254
Average Squared Error	5.02	7.22	3.71	6.41
Probable Error	1.50	1.80	1.29	1.70
% Correlation Coefficient	39	31	39	31
Regression Slope	0.17	0.13	0.20	0.13
Regression Intercept	0.83	1.02	0.79	1.05
Minimum Error	-3.94	-4.36	-3.98	-4.36
Maximum Error	13.38	20.05	9.18	20.05
100% Error Range	17.32	24.41	13.12	24.41
Expected % Within ± 1 ppm	35	29	40	30
Expected % Within ± 2 ppm	63	54	70	57

3354



Statistic	California (Turner)	EPA (Turner)	California (Pasquill)	EPA (Pasquill)
Data Points	225	254	225	254
Probable Error	1.50	1.80	1.29	1.70
% Corr. Coeff.	39	31	39	31
Min. Dev.	-3.94	-4.36	-3.94	-4.36
Max. Dev.	13.38	20.05	9.18	20.05
Dev. Range	17.32	24.41	13.12	24.41

Figure 7. Effects of stability class determination on the performances of CALAIR and HIWAY.

Overall Upwind Predictive Performance

Table 9 summarizes the performance measures of the Virginia* model based on field data for 182 receptors on the upwind sides of source roadways. Analysis of these statistics, using 0.05 confidence levels and the *F* and *t* tests described above, demonstrates that AIRPOL-4 (Pasquill) is statistically superior to AIRPOL-4 (Turner) for predicting CO levels on the upwind sides of roadways.

Table 9

Overall Predictive Performances of Models for Upwind Receptors

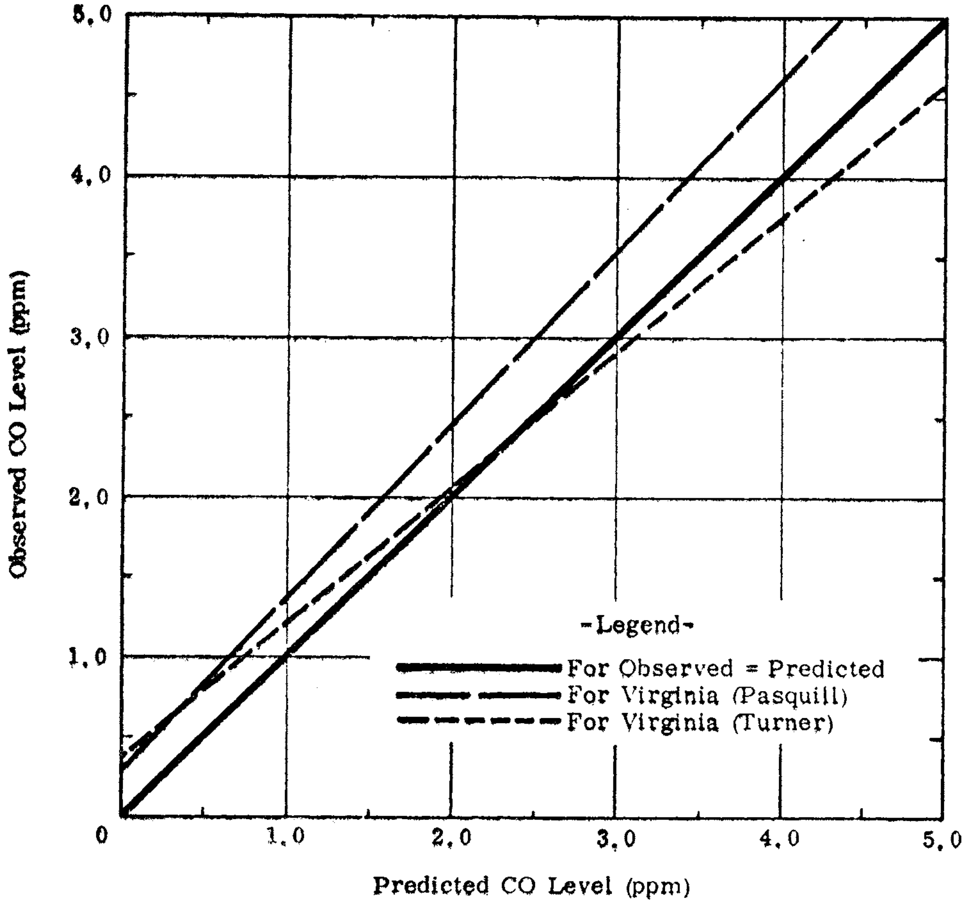
Statistic	AIRPOL-4 (Turner)	AIRPOL-4 (Pasquill)
Number of Data Points	182	182
Average Squared Error	0.58	0.50
Probable Error	±0.51	±0.47
% Correlation Coefficient	62	69
Regression Slope	0.85	1.08
Regression Intercept	0.35	0.29
Minimum Error	-3.94	-3.94
Maximum Error	3.15	1.20
100% Error Range	7.09	5.14
Expected % Within ± 1 ppm	81	84
Expected % Within ± 2 ppm	99	100

These results show that AIRPOL-4 (Pasquill) is an accurate predictor of CO levels upwind from line sources. This accuracy is strongly reflected in the average squared error statistic, 0.50,

*Since CALAIR and HIWAY are incapable of producing predictions for receptors upwind from a roadway, they have been excluded from this analysis.

which translates to a probable error of ± 0.47 ppm CO and an expected prediction error of less than 1 ppm 84% of the time and less than 2 ppm virtually 100% of the time. Furthermore, Figure 8, which supplements Table 9, demonstrates that, in its average performance, AIRPOL-4 (Pasquill) behaves almost perfectly for upwind receptors. It has a regression slope of 1.08 and an intercept of 0.29 with a correlation of 69%.

As a final point, the observant reader may have noticed that AIRPOL-4 appears to perform better in the upwind case than in the downwind. This conclusion should, however, be mitigated by the fact that the range of observed upwind CO levels is about 30% smaller than the range of observed downwind levels. Thus, since observations and predictions alike are bounded below by zero but are unbounded above, the smaller ranges of observations and predictions account for this apparent difference.



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	182	182	—	—
Probable Error	0.51	0.47		
% Corr. Coeff.	62	69		
Min. Dev.	-3.94	-3.94		
Max. Dev.	3.15	1.20		
Dev. Range	7.09	5.14		

Figure 8. Overall predictive performances of models for upwind receptors.

3358

Overall Upwind and Downwind Predictive Performance

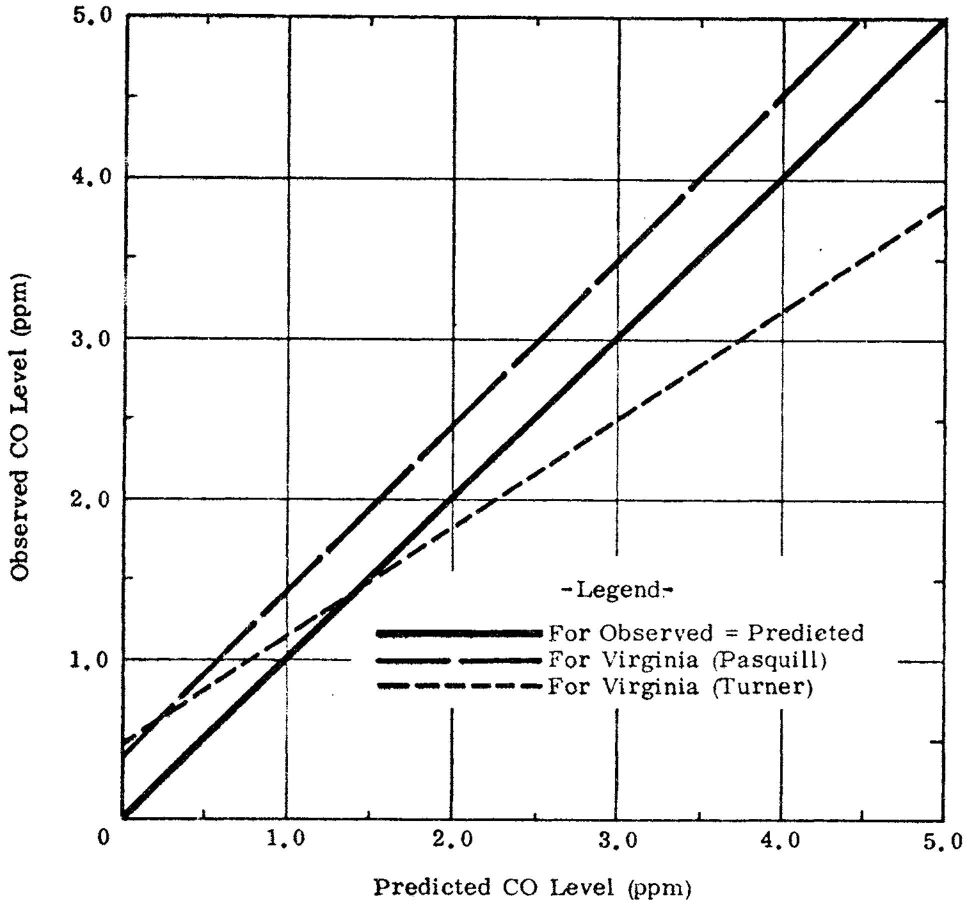
Table 10 contains the performance measures for the combined upwind and downwind receptor analysis. These results characterize the overall predictive performance of AIRPOL-4.* Analysis of these statistics, using 0.05 confidence levels and the F and t tests described above, shows that predictions generated by AIRPOL-4 (Pasquill) can be expected to be within ± 1 ppm of the true CO value 71% of the time and within ± 2 ppm of the true value 97% of the time based on a data set of 436 observations. Figure 9, which supplements Table 10, depicts the average behavior traits of both versions of the Virginia model.

Table 10

Overall Predictive Performances of Models for Upwind and Downwind Receptors

Statistic	AIRPOL-4 (Turner)	AIRPOL-4 (Pasquill)
Number of Data Points	436	436
Average Squared Error	0.99	0.89
Probable Error	0.67	0.63
% Correlation Coefficient	54	62
Regression Slope	0.67	1.04
Regression Intercept	0.50	0.37
Minimum Error	-4.71	-4.71
Maximum Error	3.81	1.41
100% Error Range	8.52	6.12
Expected % Within ± 1 ppm	69	71
Expected % Within ± 2 ppm	96	97

*Since CALAIR and HIWAY are incapable of making upwind predictions they have been excluded from Table 10. Tables 7 and 8 and Figures 6 and 7 contain the CALAIR and HIWAY results for the downwind-only analysis.



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	436	436	—	—
Probable Error	0.67	0.63		
% Corr. Coeff.	54	62		
Min. Dev.	-4.71	-4.71		
Max. Dev.	3.81	1.41		
Dev. Range	8.52	6.12		

Figure 9. Overall predictive performances of models for upwind and downwind receptors.

These results, as well as those in Tables 8, 9, and 10 and Figures 6, 7, and 8, demonstrate that the predictive performance of AIRPOL-4 (Pasquill) is generally superior to the performances of the other models, and that its level of performance is acceptable for general implementation.

In the Appendix of this report, the downwind receptor performance of each of these models is examined under several subsets of the total data base. Tables 11 through 16 summarize the results detailed in the Appendix. Examination of these tables and the remainder of the Appendix will afford the reader an opportunity to evaluate the particular strengths and weaknesses of each of the models in predicting CO levels for downwind receptors.

SUMMARY

This report has shown that AIRPOL-4 represents a significant advancement in the field of air quality modeling. It is a cost effective and versatile model, and the AIRPOL-4 (Pasquill) version is a reliable and accurate prediction tool. Specifically, this report has demonstrated (see Appendix for further details) that AIRPOL-4 (Pasquill) —

1. costs less and is simpler to use than either CALAIR or HIWAY,

2. is significantly more accurate than either CALAIR or HIWAY,

3. is capable of accurately determining CO levels on both the upwind and downwind sides of roadways,

4. yields accurate CO predictions for a wide variety of meteorological conditions, including small road/wind angles and very low wind speeds, and

5. yields accurate CO predictions for a wide variety of topographies and source/receptor geometries. (Note exception for elevated sources.)

3362

RECOMMENDATIONS

The cost effectiveness, ease of application, range of capabilities, and accuracy of AIRPOL-4 (Pasquill) warrant its implementation. Thus, the authors recommend that AIRPOL-4, in conjunction with the Pasquill method of determining stability class, be employed in the preparation of environmental impact statements.

REFERENCES

1. Beaton, J. L., A. J. Ranzieri, E. C. Shirley, and J. B. Skog, "Air Quality Manual, Vol. IV: Mathematical Approach to Estimating Highway Impact on Air Quality," Department of Transportation, Report FHWA-RD-72-36, 1972.

2. Zimmerman, J. R., and R. S. Thompson, "HIWAY — A Highway Air Pollution Model," Environmental Protection Agency, January 1974.

3. Carpenter, W. A., and G. G. Clemeña, "Theory and Mathematical Development of AIRPOL-4," Virginia Highway and Transportation Research Council, Report No. VHTRC 75-R49, May 1975.

4. Turner, D. B., "A Diffusion Model for an Urban Area," Journal of Applied Meteorology, 3, 83-91, 1964.

5. Ludwig, F. L., A. E. Moon, W. B. Johnson, and R. L. Mancuso, A Practical, Multipurpose Urban Diffusion Model for Carbon Monoxide, Stanford Research Institute, Menlo Park, California, 1970.

6. Environmental Protection Agency, "Compilation of Air Pollutant Emission Factors," Publication No. AP-42, 1973.

7. Carpenter, W. A., G. G. Clemeña, and W. R. Lunglhofer, "AIRPOL-4 Algorithms," Virginia Highway & Transportation Research Council, Report No. VHTRC 75-R70, May 1975.

0364

APPENDIX

DETAILED PREDICTIVE PERFORMANCE ANALYSES

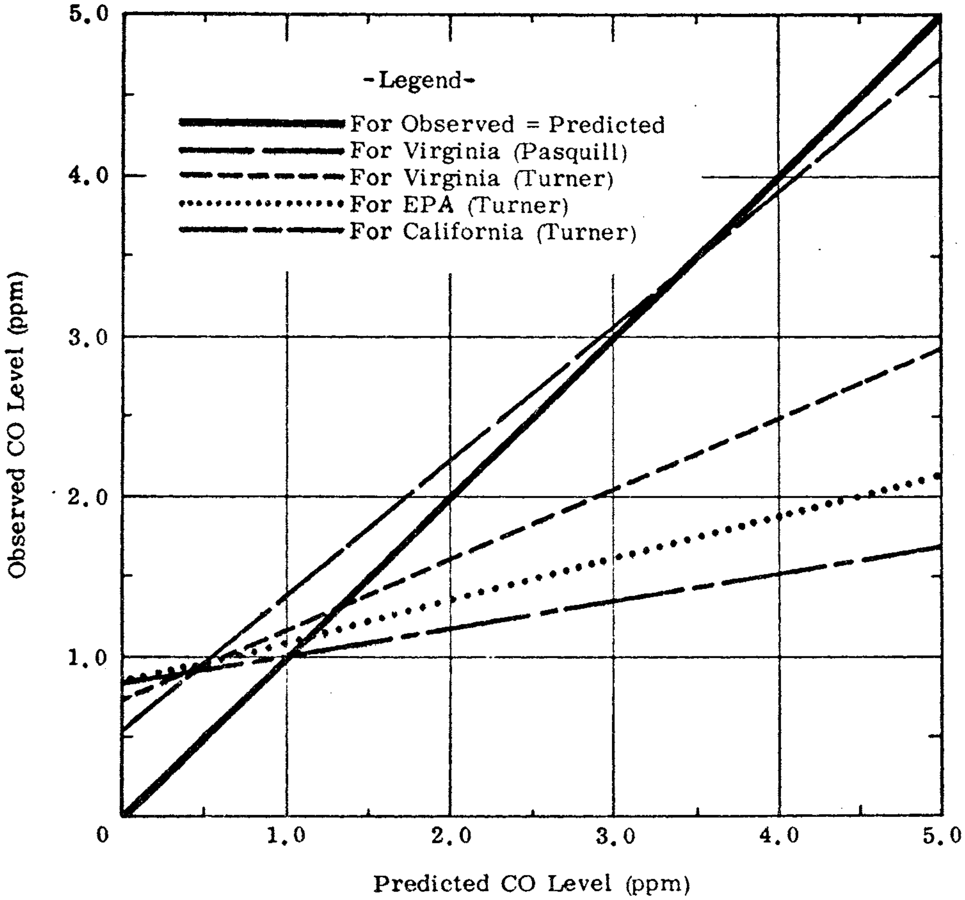
Downwind Predictive Performance Relative to Meteorology

Wind Speed

Figure 10 contains the regression lines and sufficient statistics for the analysis of model performance relative to all downwind data points taken at wind speeds ≥ 2.0 mph (0.9 m/s), Figure 11 contains the performance results for wind speeds < 2.0 mph (0.9 m/s), and Table 11 summarizes the predictive performances of the models relative to wind speed. Analysis of these results shows that the performances of all the models are statistically poorer for wind speeds below 2.0 mph (0.9 m/s) than above. However, the degradation of AIRPOL-4 is markedly less than that of HIWAY (recall that CALAIR cannot generate low wind speed predictions), and the performance of AIRPOL-4 (Pasquill) is statistically superior to the other models in both wind speed categories. These results thus help to substantiate the claim that AIRPOL-4 performs reliably at low as well as high wind speeds.

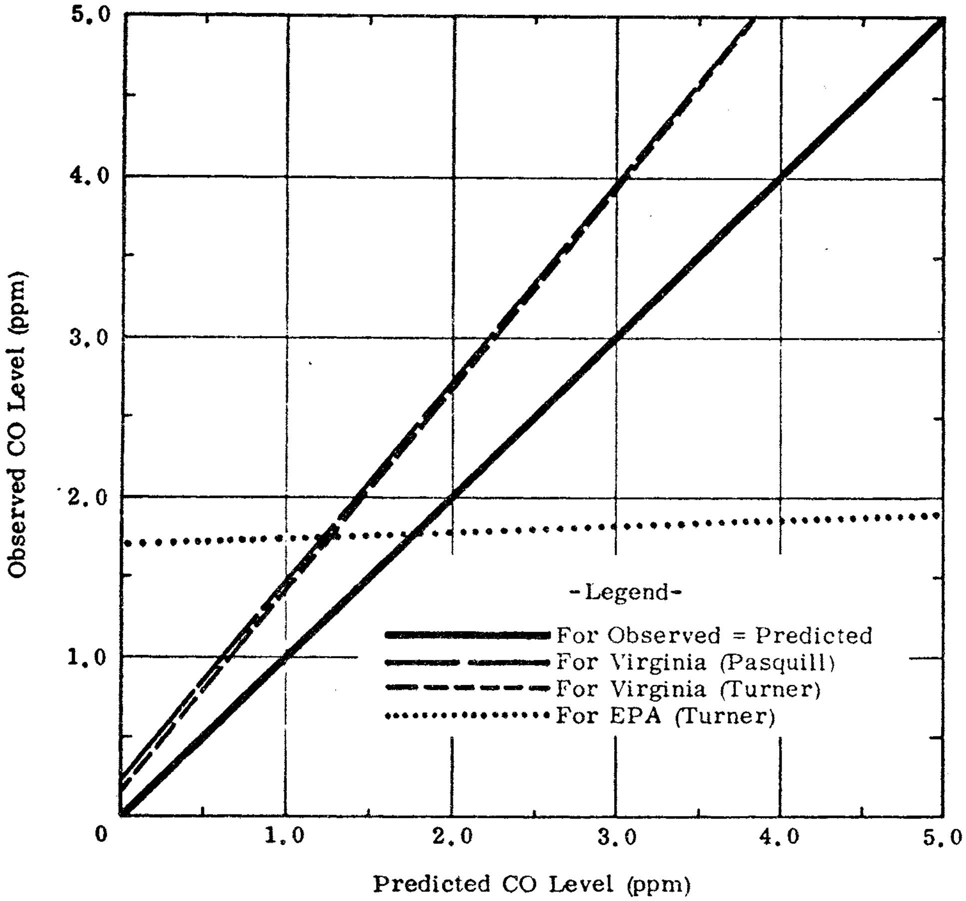
As an aside, note that for wind speeds < 2.0 mph (0.9 m/s) the Pasquill and Turner versions of the Virginia model have virtually identical performance measures. This resulted from the fact that in this category the Turner and Pasquill stability classes were identical in all but one instance.

3366



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	225	225	225	225
Probable Error	0.72	0.67	1.50	0.90
% Corr. Coeff.	39	45	39	33
Min. Dev.	-4.43	-4.43	-3.94	-4.36
Max. Dev.	3.81	1.23	13.38	6.70
Dev. Range	8.24	5.66	17.32	11.06

Figure 10. Downwind predictive performance for windspeeds, $\mu \geq 2.0$ mph (0.9 m/s).



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	29	29	——	29
Probable Error	1.03	1.04		4.70
% Corr. Coeff.	55	56		14
Min. Dev.	-4.71	-4.71		-2.45
Max. Dev.	1.41	1.41		20.05
Dev. Range	6.12	6.12		22.50

Figure 11. Downwind predictive performance for wind speeds, $\mu < 2.0$ mph (0.9 m/s).

3368

Table 11

Summary of Predictive Performances Relative to Wind Speed

Model	Wind Speed	No. of Data Points	Probable Error	Regression Slope	Regression Intercept	Minimum Deviation	Maximum Deviation	Deviation Range
AIRPOL-4 (Turner)	$\mu \geq 2.0$ mph (0.9 m/s)	225	0.72	0.44	0.73	-4.43	3.81	8.24
AIRPOL-4 (Pasquill)		225	0.67	0.83	0.56	-4.43	1.23	5.66
CALAIR		225	1.50	0.17	0.83	-3.94	13.38	17.32
HIWAY		225	0.90	0.26	0.84	-4.36	6.70	11.06
AIRPOL-4 (Turner)	$\mu < 2.0$ mph (0.9 m/s)	29	1.03	1.26	0.17	-4.71	1.41	6.12
AIRPOL-4 (Pasquill)		29	1.04	1.24	0.24	-4.71	1.41	6.12
CALAIR		—	—	—	—	—	—	—
HIWAY		29	4.70	0.04	1.17	-2.45	20.05	22.50

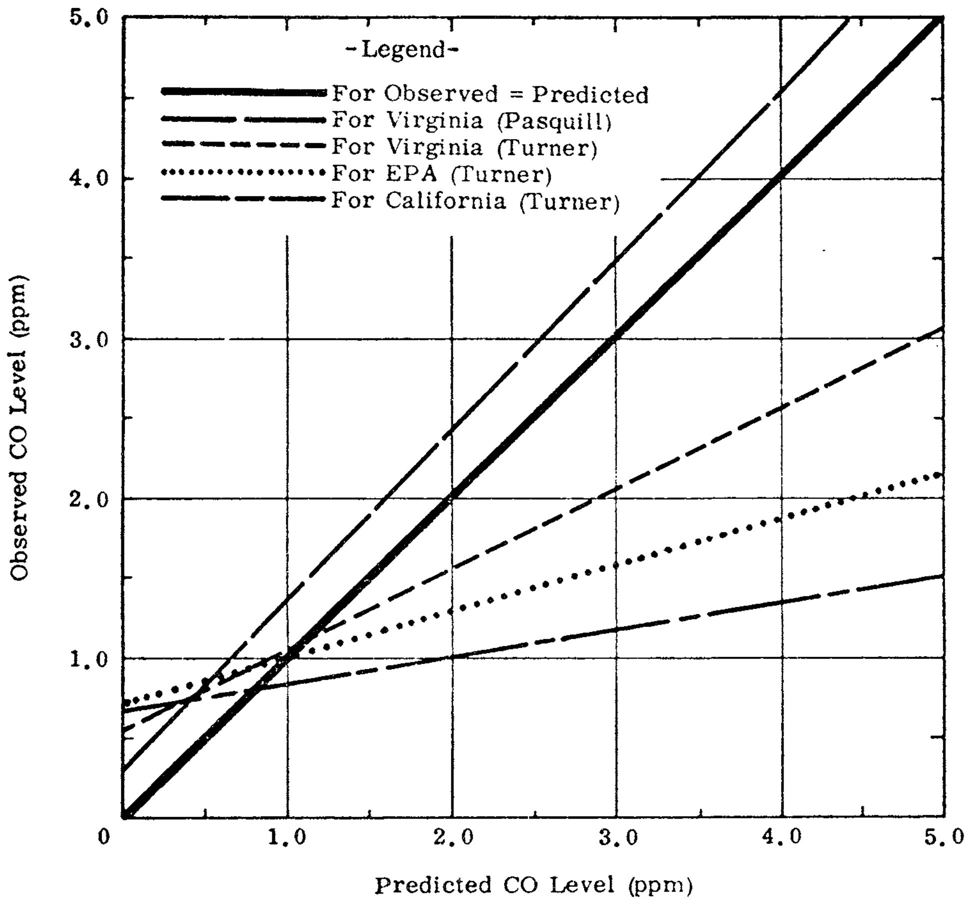
Road/Wind Angle

Figures 12, 13, and 14 illustrate the performance results of the models relative to all downwind receptors for road/wind angles of $0^\circ \leq \alpha \leq 30^\circ$, $30^\circ < \alpha \leq 60^\circ$, and $60^\circ < \alpha \leq 90^\circ$, respectively, and Table 12 summarizes the predictive performances of the models relative to road/wind angle. Analysis of the results in Figure 12 shows that in the range of $0^\circ \leq \alpha \leq 30^\circ$ AIRPOL-4 (Pasquill) is statistically superior to the other models. Analysis of the results for the range $30^\circ < \alpha \leq 60^\circ$, shown in Figure 13, produces somewhat nebulous conclusions. Here it is found that among AIRPOL-4 (Turner), AIRPOL-4 (Pasquill) and CALAIR, no model is statistically superior with respect to either probable errors or 100% error ranges. Each of these models is, however, statistically superior to HIWAY with respect to both of these measures. Only in the comparison of their regression results is there a significant statistical difference among these three models. The slope of the AIRPOL-4 (Pasquill) regression line, 1.06, and the AIRPOL-4 (Turner) regression line, 0.87, are statistically identical to each other and statistically superior to the slope of the regression line for CALAIR, 0.50. The regression lines for all three of these models are significantly superior to HIWAY's, 0.07.

On the surface, the reader might conclude that in the range $30^\circ < \alpha \leq 60^\circ$ AIRPOL-4 (Pasquill) has a slight superiority, HIWAY is hopelessly inept, and the other two models are more or less acceptable. However, this deduction should be tempered by the fact that 20% of the observations in this data set were collected at wind speeds < 2.0 mph (0.9 m/s). Thus, in this range of road/wind angles, HIWAY's performance has been severely degraded by the effects of wind speed while CALAIR has failed to make a prediction for 20% of the sample.

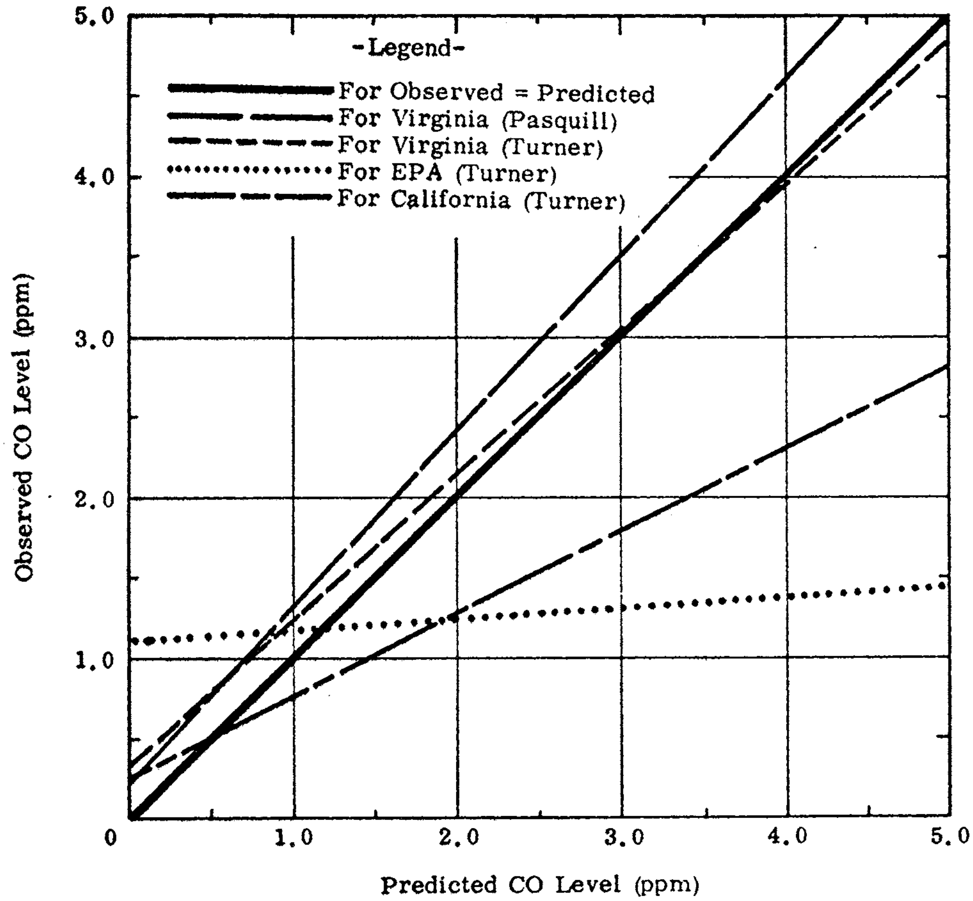
The performances over the range $60^\circ < \alpha \leq 90^\circ$ are shown in Figure 14. The reader should note that over this range nearly 10% of the sample points were collected at wind speeds < 2.0 mph (0.9 m/s). Analysis of these results demonstrates that among the two Virginia models and CALAIR, no model is statistically superior with respect to probable errors or 100% error ranges. Each of these models is, however, significantly superior to HIWAY with respect to both of these statistics. Again only in the comparison of regression results is there a significant statistical difference between the two Virginia models and CALAIR. The slope of AIRPOL-4 (Pasquill) is the only slope which is not significantly different from 1.

3370



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	69	69	67	69
Probable Error	0.75	0.59	2.54	1.36
% Corr. Coeff.	58	69	56	61
Min. Dev.	-2.84	-2.84	-0.65	-2.01
Max. Dev.	3.81	1.07	13.38	6.70
Dev. Range	6.65	3.91	14.03	8.71

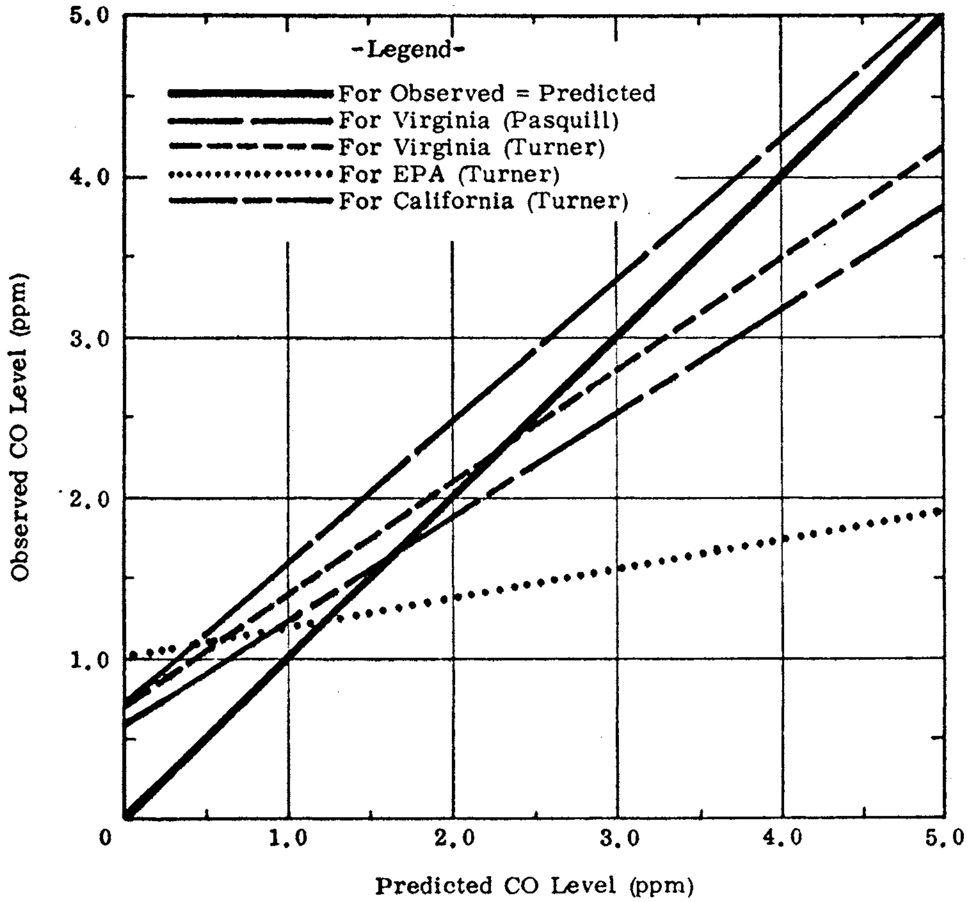
Figure 12. Downwind predictive performance for road/wind angles, $\alpha \leq 30^{\circ}$.



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	90	90	72	90
Probable Error	0.80	0.79	0.71	2.54
% Corr. Coeff.	39	47	46	21
Min. Dev.	-4.71	-4.71	-3.03	-3.81
Max. Dev.	1.41	1.41	2.12	20.05
Dev. Range	6.12	6.12	5.15	23.86

Figure 13. Downwind predictive performance for road/wind angles, $30^{\circ} < \alpha \leq 60^{\circ}$.

3372



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	95	95	86	95
Probable Error	0.73	0.74	0.67	1.09
% Corr. Coeff.	39	42	48	27
Min. Dev.	-4.43	-4.43	-3.94	-4.36
Max. Dev.	1.00	0.83	2.17	7.80
Dev. Range	5.43	5.26	6.11	12.16

Figure 14. Downwind predictive performance for road/wind angles, $60^\circ < \alpha \leq 90^\circ$.

Table 12

Summary of Predictive Performances Relative To Wind Angle

Model	Wind/Road Angle	No. of Data Points	Probable Error	Regression Slope	Regression Intercept	Minimum Deviation	Maximum Deviation	Deviation Range
AIRPOL-4 (Turner)	$0^{\circ} \leq \alpha \leq 30^{\circ}$	69	0.75	0.50	0.56	-2.84	3.81	6.65
AIRPOL-4 (Pasquill)		69	0.59	1.06	0.30	-2.84	1.07	3.91
CALAIR		67	2.54	0.17	0.65	-0.65	13.38	14.03
HIWAY		69	1.36	0.29	0.70	-2.01	6.70	8.71
AIRPOL-4 (Turner)	$30^{\circ} < \alpha \leq 60^{\circ}$	90	0.80	0.87	0.39	-4.71	1.41	6.12
AIRPOL-4 (Pasquill)		90	0.79	1.06	0.31	-4.71	1.41	6.12
CALAIR		72	0.71	0.50	0.31	-3.03	2.12	5.15
HIWAY		90	2.54	0.07	1.13	-3.81	20.05	23.86
AIRPOL-4 (Turner)	$60^{\circ} < \alpha \leq 90^{\circ}$	95	0.73	0.70	0.69	-4.43	1.00	5.43
AIRPOL-4 (Pasquill)		95	0.74	0.89	0.66	-4.43	0.83	5.26
CALAIR		86	0.67	0.65	0.59	-3.94	2.17	6.11
HIWAY		95	1.09	0.18	0.96	-4.36	7.80	12.16

Stability Class

Figures 15, 16, 17, and 18 contain the performance results for downwind receptors under stability classes A, B, C, and D, respectively. (No data were collected under either E or F stability as determined by either the basic Pasquill method or Turner's modified method.) Table 13 summarizes the predictive performances of the models relative to stability class. Interesting indirect statistics suggested by these four analyses are the distributions of the Pasquill and Turner stability classes. From a total of 48 one-hour sampling intervals, (A, B, C, D) distributions of (0.10, 0.63, 0.17, 0.10) and (0.06, 0.29, 0.17, 0.48) were observed for the Pasquill and Turner modified techniques, respectively. These distributions demonstrate, as the methods themselves imply, that the Pasquill technique yields a generally lower stability class estimate than does the Turner technique. Thus, it is reasonable that for urban areas, where the atmosphere is generally turbulent, the Pasquill technique should yield better estimates of atmospheric stability than the Turner technique. This is the principal reason for the superiority of AIRPOL-4 (Pasquill) to AIRPOL-4 (Turner).

Analysis of the results shown in Figure 15 does not, regrettably, yield much information due to the small sample sizes involved, which cause the results to be somewhat unrepresentative. (The results in Figures 16, 17 and 18 do not suffer from this malady.) However, this analysis does show that AIRPOL-4 (Pasquill) and HIWAY are statistically equivalent with respect to probable errors and 100% error ranges and that HIWAY is significantly superior to AIRPOL-4 (Turner) and CALAIR with respect to these error statistics. This analysis furthermore shows that HIWAY is significantly superior to all the other models with respect to average performance characteristics.

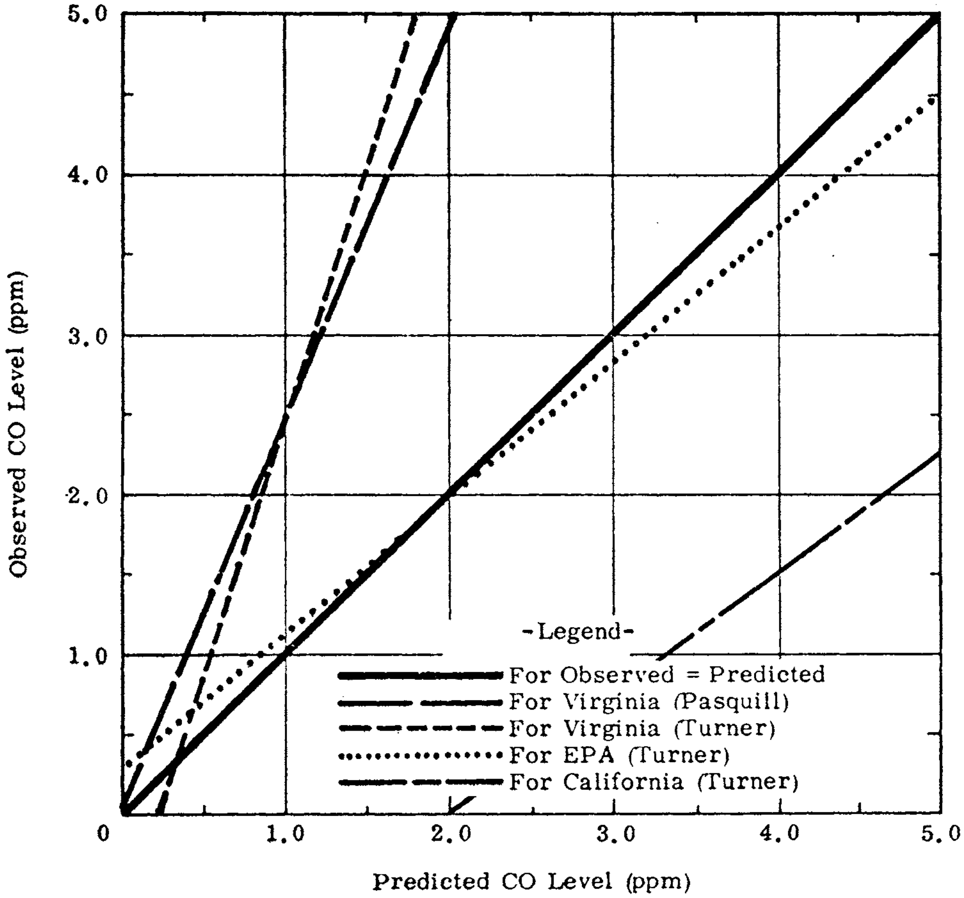
Analysis of the results for stability class B, Figure 16, shows that AIRPOL-4 (Turner), AIRPOL-4 (Pasquill), and CALAIR are statistically equivalent with respect to probable errors and 100% error ranges and that they are all significantly superior to HIWAY with respect to these statistics. Furthermore, these results show that only the two versions of the Virginia model have regression slopes statistically identical to 1. However, as has been the case previously, these results must be tempered by the fact that more than 24% of the Turner class observations were determined at wind speeds < 2.0 mph (0.9 m/s). Thus, the HIWAY results may have been overburdened by the model's poor performance at low wind speeds, while CALAIR failed to make any predictions for nearly one-quarter of the observations.

Figure 17 presents the prediction results for stability class C. Analysis of these results shows that the two versions of AIRPOL-4 are statistically equivalent with respect to probable error and 100% error range and are significantly superior to CALAIR and HIWAY with respect to these statistics. The regression slopes of all four models for stability class C are significantly different from 1 and are all less than 1. However, the slopes for CALAIR, 0.29, and HIWAY, 0.43, are significantly different from those for the Virginia (Turner), 0.74, and (Pasquill), 0.76, models.

Analysis of the results for stability class D, Figure 18, shows that AIRPOL-4 (Pasquill) is significantly superior to all three other models with respect to probable error and 100% error range. However, none of the four models have slopes statistically identical to 1, although AIRPOL-4 (Pasquill) has the slope, 1.48, closest to 1.

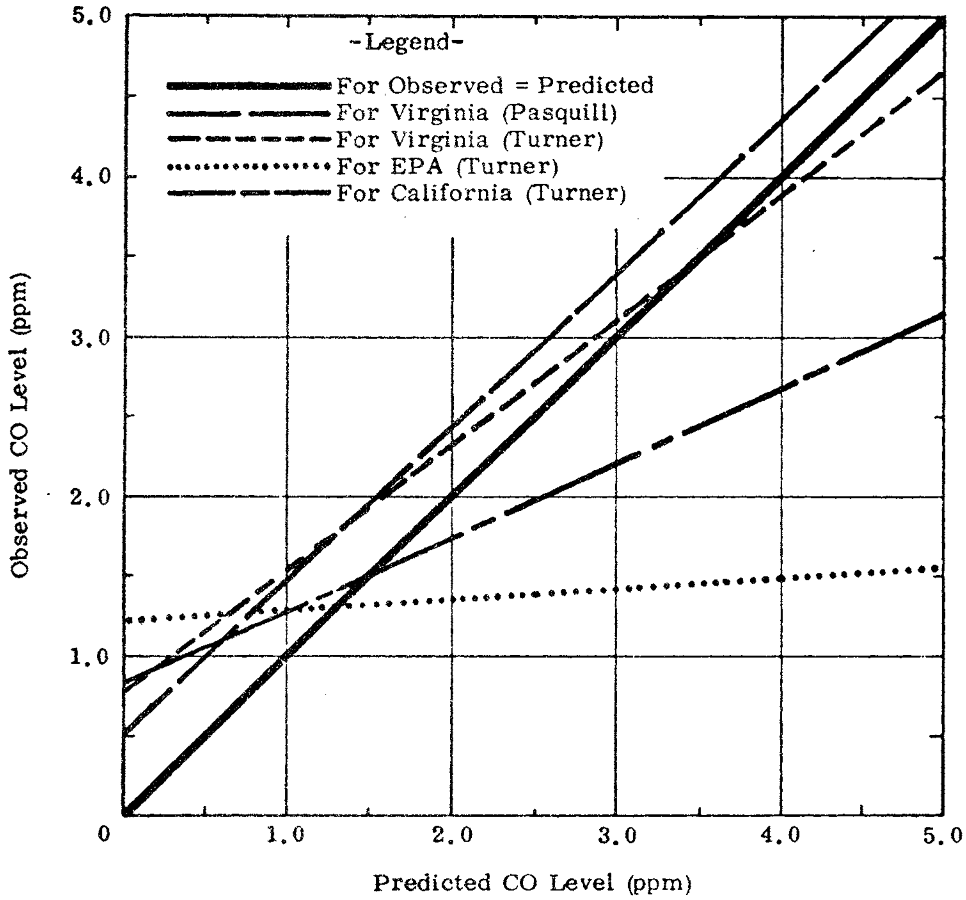
Figures 19 and 20 conclude the analyses relative to meteorological variables by displaying performance results for the cases where the Turner and Pasquill methods for predicting stability class produce identical classes (Figure 19) and nonidentical classes (Figure 20). From these results it can easily be seen that application of the Pasquill technique produces better air quality predictions than does application of the Turner technique.

3376



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	13	25	4	13
Probable Error	1.44	1.14	1.55	0.77
% Corr. Coeff.	88	81	84	82
Min. Dev.	-4.71	-4.71	1.86	-2.45
Max. Dev.	0.16	1.03	3.01	2.18
Dev. Range	4.87	5.74	1.15	4.63

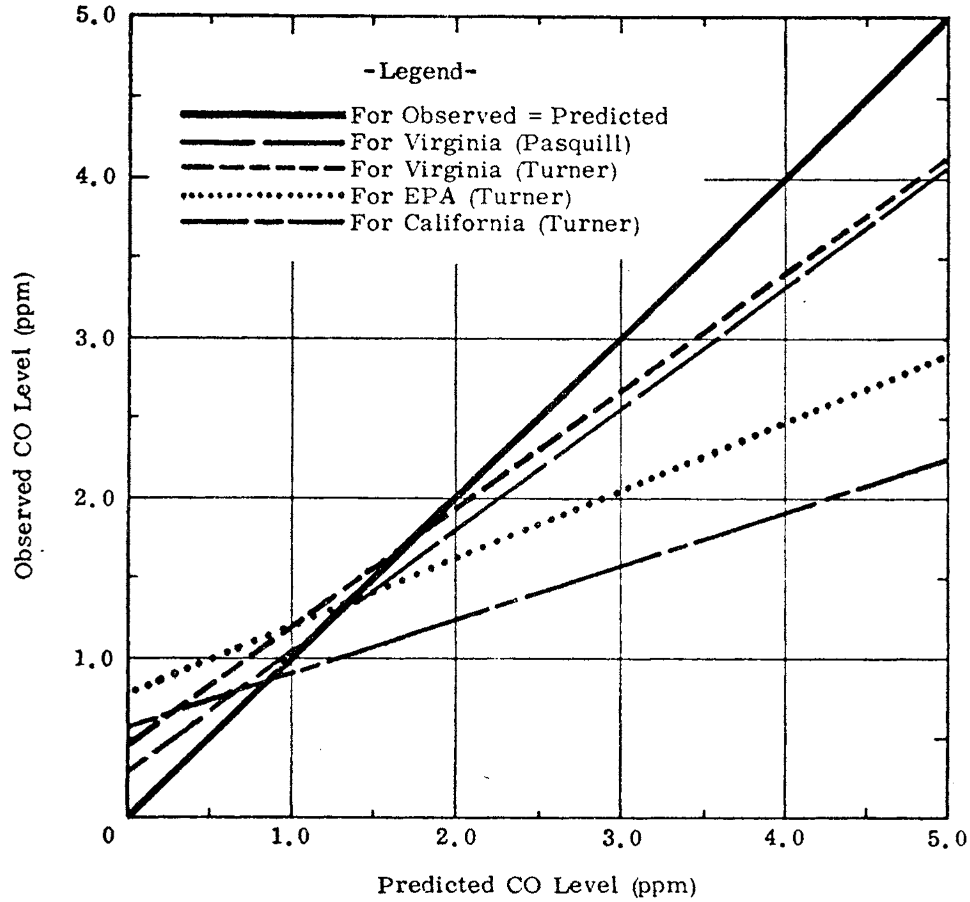
Figure 15. Downwind predictive performance for stability class A.



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	70	154	53	70
Probable Error	0.83	0.75	0.83	3.08
% Corr. Coeff.	47	52	48	25
Min. Dev.	-4.43	-4.43	-3.94	-4.36
Max. Dev.	1.41	1.41	2.44	20.05
Dev. Range	5.84	5.84	6.38	24.41

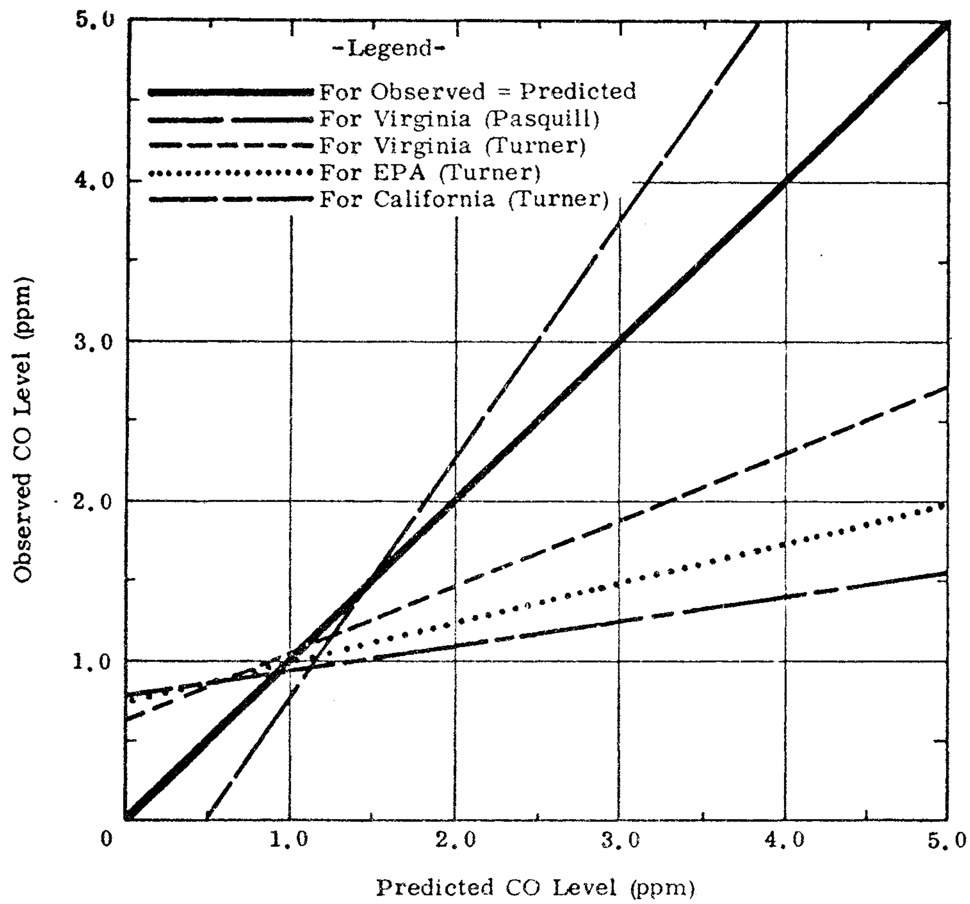
Figure 16. Downwind predictive performance for stability class B.

3378



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	46	46	43	46
Probable Error	0.47	0.43	0.94	0.60
% Corr. Coeff.	62	66	54	38
Min. Dev.	-2.14	-1.62	-1.75	-2.08
Max. Dev.	1.07	1.07	4.64	1.91
Dev. Range	3.21	2.69	6.39	3.99

Figure 17. Downwind predictive performance for stability class C.



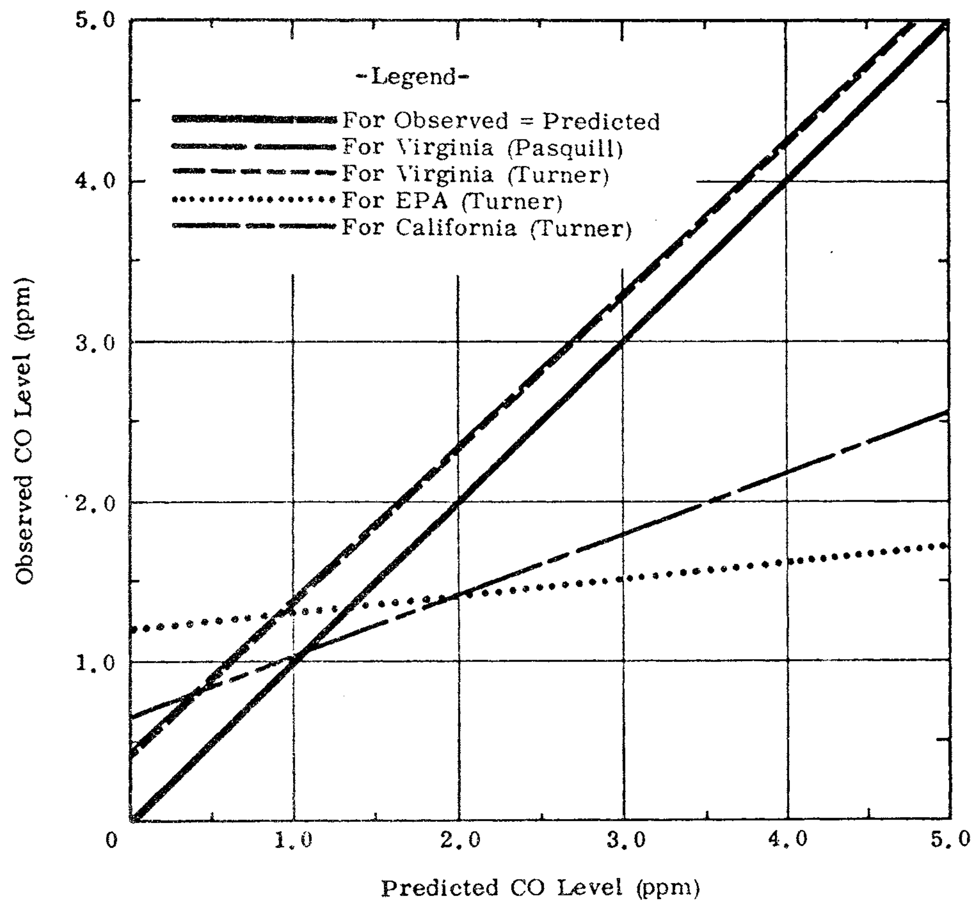
Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	125	29	125	125
Probable Error	0.70	0.43	1.84	1.03
% Corr. Coeff.	45	62	43	38
Min. Dev.	-4.07	-1.92	-3.03	-3.81
Max. Dev.	3.81	1.23	13.38	6.70
Dev. Range	7.88	3.15	16.41	10.51

Figure 18. Downwind predictive performance for stability class D.

Table 13

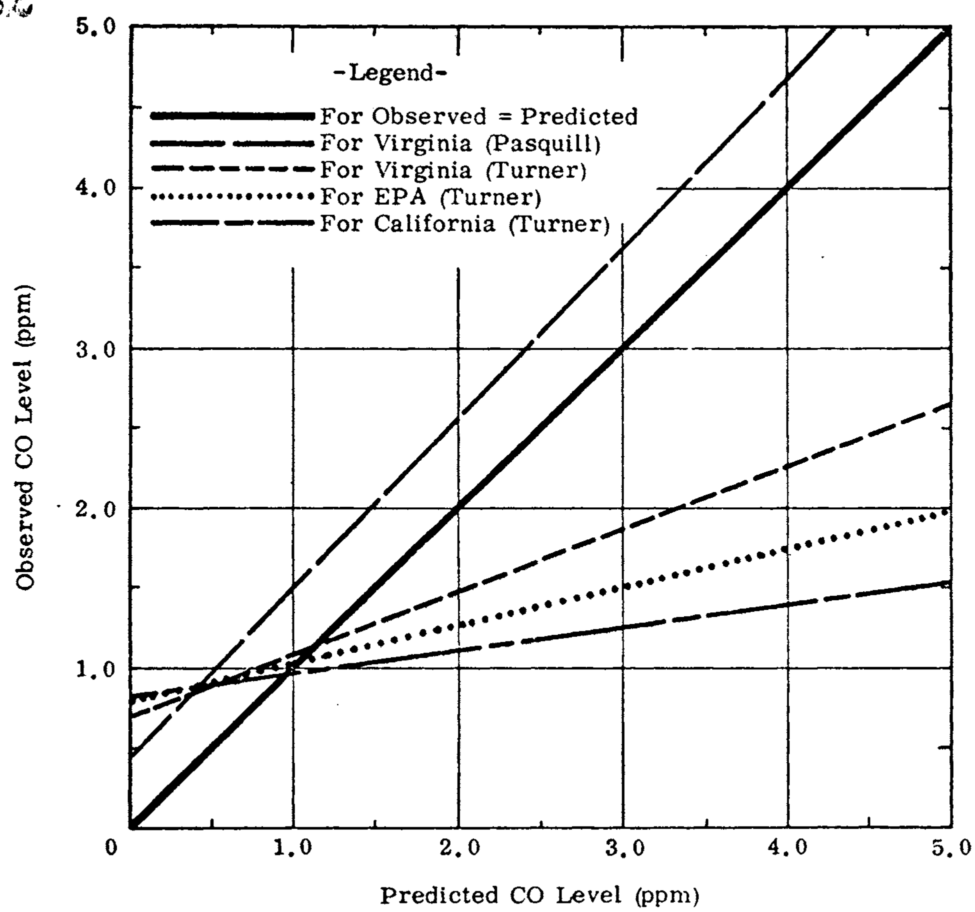
Summary of Predictive Performances Relative to Atmospheric Stability Class

Model	Stability Class	No. of Data Points	Probable Error	Regression Slope	Regression Intercept	Minimum Deviation	Maximum Deviation	Deviation Range
AIRPOL-4 (Turner)	A	13	1.44	3.25	-0.80	-4.71	0.16	4.87
AIRPOL-4 (Pasquill)		25	1.14	2.49	0.01	-4.71	1.03	5.74
CALAIR		4	1.55	0.76	-1.50	1.86	3.01	1.15
HIWAY		13	0.77	0.84	0.31	-2.45	2.18	4.63
AIRPOL-4 (Turner)	B	70	0.83	0.79	0.70	-4.43	1.41	5.84
AIRPOL-4 (Pasquill)		154	0.75	0.96	0.60	-4.43	1.41	5.84
CALAIR		53	0.83	0.48	0.71	-3.94	2.44	6.38
HIWAY		70	3.08	0.07	1.16	-4.36	20.05	24.41
AIRPOL-4 (Turner)	C	46	0.47	0.74	0.45	-2.14	1.07	3.21
AIRPOL-4 (Pasquill)		46	0.43	0.76	0.29	-1.62	1.07	2.69
CALAIR		43	0.94	0.29	0.69	-1.75	4.64	6.39
HIWAY		46	0.60	0.43	0.74	-2.08	1.91	3.99
AIRPOL-4 (Turner)	D	125	0.70	0.42	0.61	-4.07	3.81	7.88
AIRPOL-4 (Pasquill)		29	0.43	1.48	-0.71	-1.92	1.23	3.15
CALAIR		125	1.84	0.15	0.77	-3.03	13.38	16.41
HIWAY		125	1.03	0.24	0.72	-3.81	6.70	10.51



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	117	117	91	117
Probable Error	0.82	0.82	0.91	2.42
% Corr. Coeff.	48	48	49	27
Min. Dev.	-4.71	-4.71	-3.94	-4.36
Max. Dev.	1.41	1.41	4.64	20.05
Dev. Range	6.12	6.12	8.58	24.41

Figure 19. Downwind predictive performance for Turner class = Pasquill class.



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	137	137	134	137
Probable Error	0.70	0.62	1.80	1.01
% Corr. Coeff.	44	53	41	39
Min. Dev.	-4.07	-4.09	-3.03	-3.81
Max. Dev.	3.81	1.03	13.38	6.70
Dev. Range	7.88	5.12	16.41	10.51

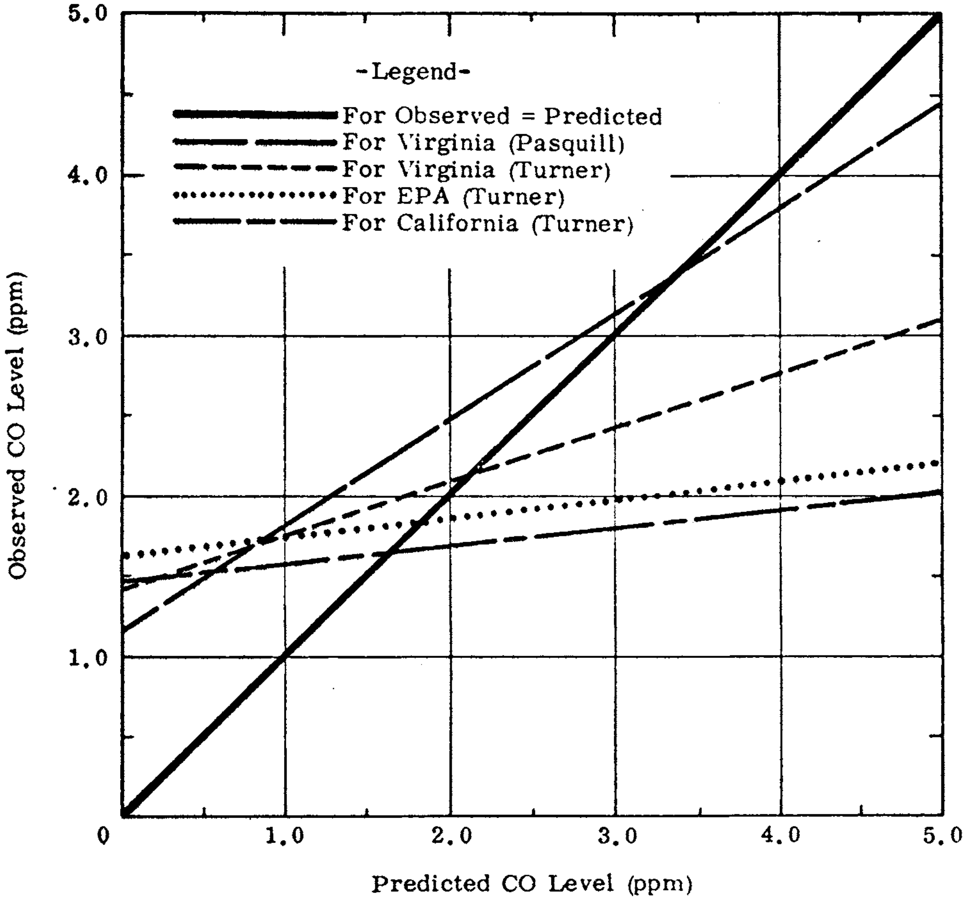
Figure 20. Downwind predictive performance for Turner class ≠ Pasquill class.

Downwind Predictive Predictive Performance Relative to Geometry

Source to Receptor Distance

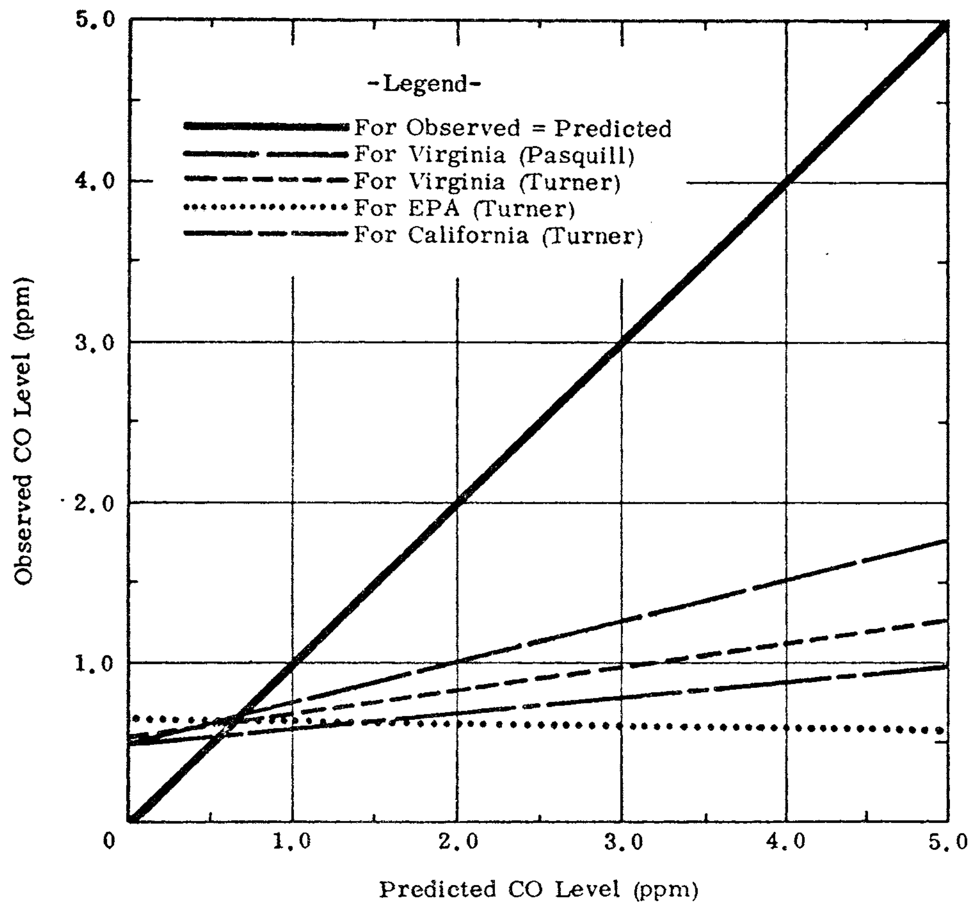
Figures 21 and 22 show the prediction results for source/receptor distances of D $\leq$ 100 feet (30 m) and D > 100 feet, respectively. Table 14 summarizes the predictive performances of the models relative to source/receptor distance. Analysis of these results reveals that for both ranges of D, AIRPOL-4 (Pasquill) is statistically equivalent to AIRPOL-4 (Turner) and that they are both highly superior to CALAIR and HIWAY with respect to probable errors and 100% error bounds. These results also show that for these ranges of D, none of the models are statistically identical to the ideal regression line in their average performance.

3384



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	130	130	113	130
Probable Error	0.98	0.94	1.94	2.21
% Corr. Coeff.	30	36	28	30
Min. Dev.	-4.71	-4.71	-3.94	-4.36
Max. Dev.	3.81	1.41	13.38	20.05
Dev. Range	8.52	6.12	17.32	24.41

Figure 21. Downwind predictive performance for source/receptor distance, D $\leq$ 100 feet (30 m).



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	124	124	112	124
Probable Error	0.42	0.38	0.87	1.24
% Corr. Coeff.	13	16	25	-2
Min. Dev.	-1.71	-1.71	-1.19	-1.60
Max. Dev.	1.74	1.34	6.02	12.26
Dev. Range	3.45	3.05	7.21	13.86

Figure 22. Downwind predictive performance for source/receptor distance, D > 100 feet (30 m).

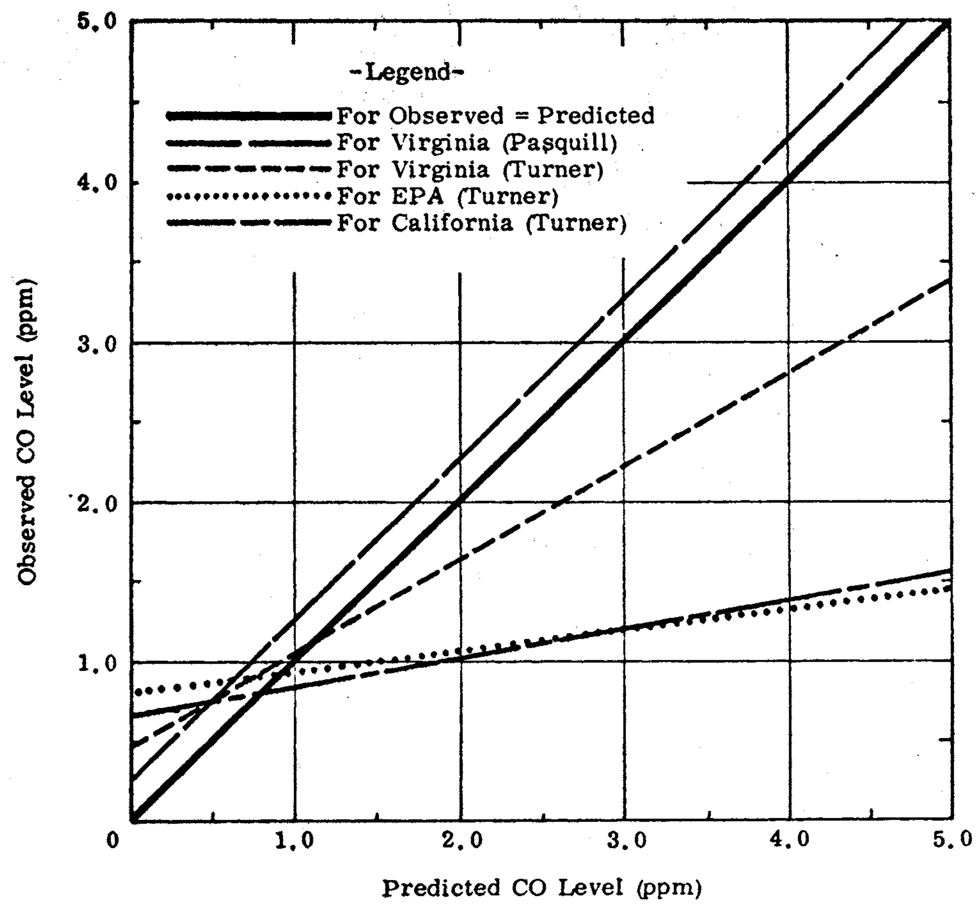
Table 14

Summary of Predictive Performances Relative to Source to Receptor Distance

Model	Source/Receptor Distance	No. of Data Points	Probable Error	Regression Slope	Regression Intercept	Minimum Deviation	Maximum Deviation	Deviation Range
AIRPOL-4 (Turner)	D ≤ 100 ft. (30 m)	130	0.98	0.35	1.39	-4.71	3.81	8.52
AIRPOL-4 (Pasquill)		130	0.94	0.67	1.13	-4.71	1.41	6.12
CALAIR		113	1.94	0.11	1.43	-3.94	13.38	17.32
HIWAY		130	2.21	0.11	1.61	-4.36	20.05	24.41
AIRPOL-4 (Turner)	D > 100 ft. (30 m)	124	0.42	0.15	0.51	-1.71	1.74	3.45
AIRPOL-4 (Pasquill)		124	0.38	0.26	0.49	-1.71	1.34	3.05
CALAIR		112	0.87	0.10	0.48	-1.19	6.02	7.21
HIWAY		124	1.24	-0.01	0.62	-1.60	12.26	13.86

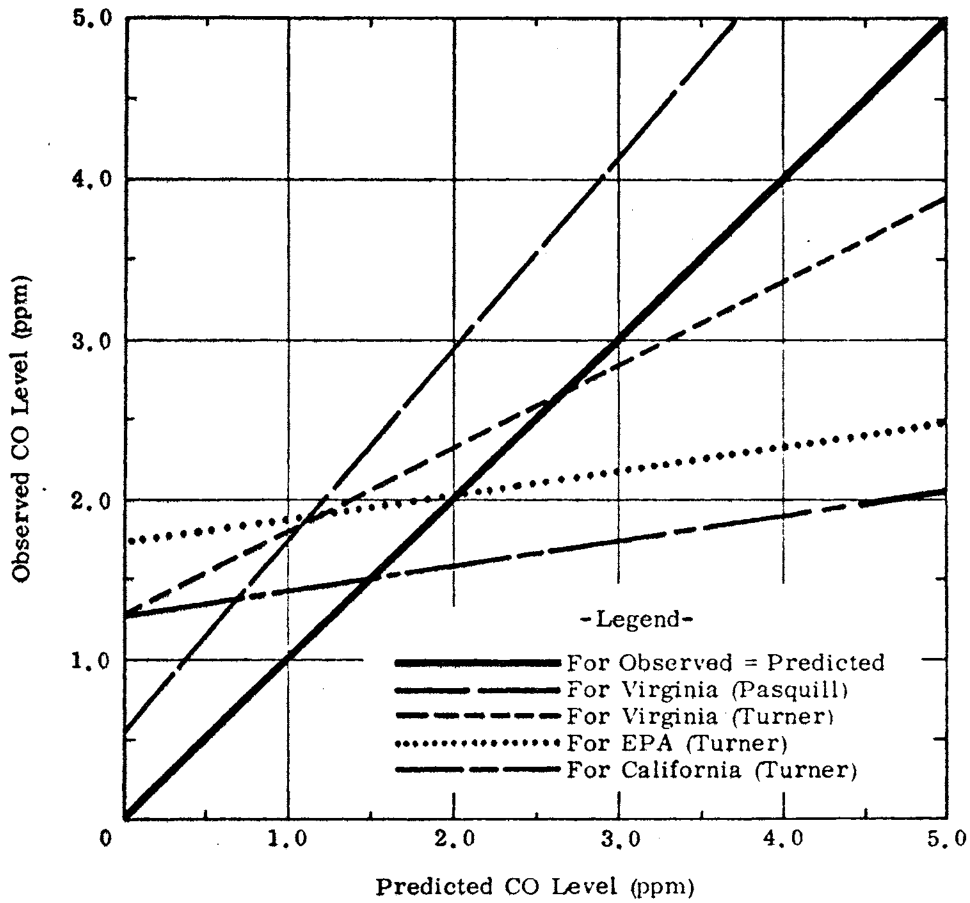
Receptor Elevation

Figures 23 and 24 present the prediction results for receptor heights of 5 feet (1.5 m) and 10 feet (3.0 m), respectively, and Table 15 summarizes the predictive performances of the models relative to receptor elevation. Analysis of the data for receptor heights of 5 feet (1.5 m), Figure 23, demonstrates that AIRPOL-4 (Pasquill) is significantly superior to the other three models with respect to all performance measures. Analysis of the results for receptor heights of 10 feet (3.0 m), Figure 24, also shows that AIRPOL-4 (Pasquill) is superior to the other models.



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	207	207	184	207
Probable Error	0.59	0.53	1.42	1.71
% Corr. Coeff.	53	62	46	35
Min. Dev.	-3.44	-3.44	-2.03	-2.38
Max. Dev.	3.81	1.41	13.38	20.05
Dev. Range	7.25	4.85	15.41	22.43

Figure 23. Downwind predictive performance for receptor elevation, RH = 5 feet (1.5 m).



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	34	34	28	34
Probable Error	0.97	0.96	1.99	2.30
% Corr. Coeff.	40	52	49	40
Min. Dev.	-4.71	-4.71	-0.91	-2.45
Max. Dev.	2.37	1.07	10.36	16.55
Dev. Range	7.08	5.78	11.27	19.00

Figure 24. Downwind predictive performance for receptor elevation, RH = 10 feet (3.0 m).

Table 15

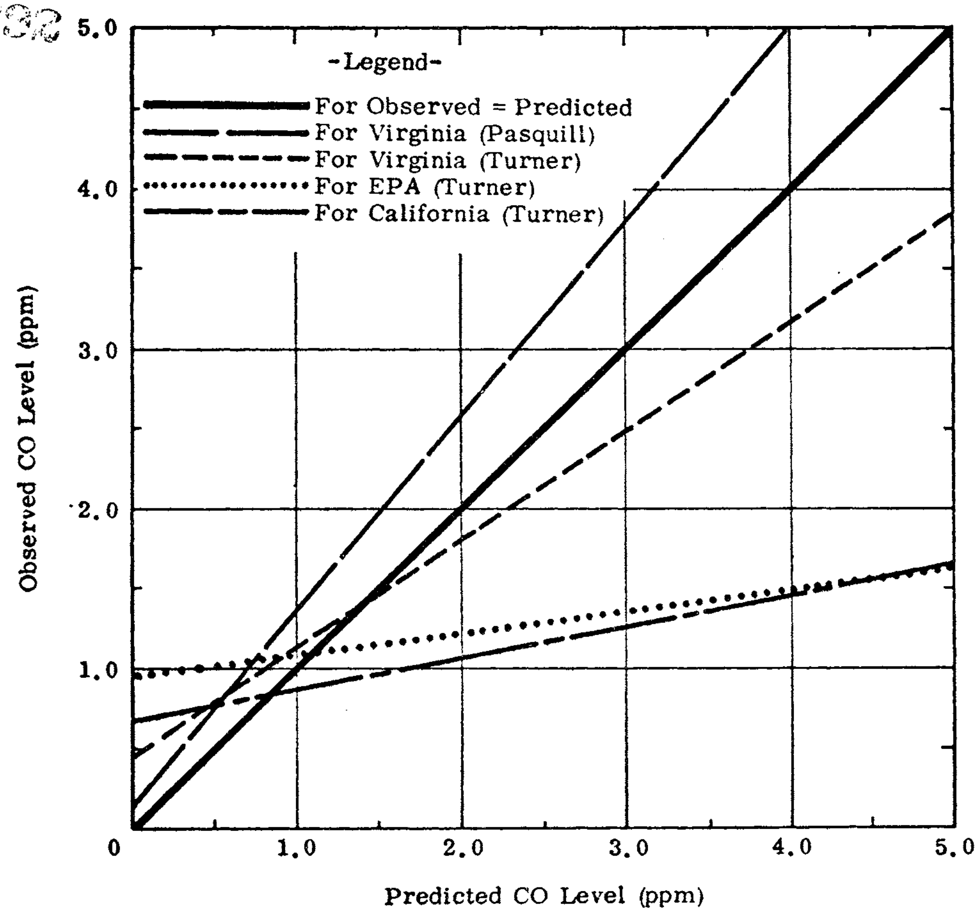
Summary of Predictive Performances Relative to Receptor Elevation

Model	Receptor Elevation	No. of Data Points	Probable Error	Regression Slope	Regression Intercept	Minimum Deviation	Maximum Deviation	Deviation Range
AIRPOL-4 (Turner)	RH = 5 ft. (1.5 m)	207	0.59	0.59	0.44	-3.44	3.81	7.25
AIRPOL-4 (Pasquill)		207	0.53	1.00	0.27	-3.44	1.41	4.85
CALAIR		184	1.42	0.18	0.63	-2.03	13.38	15.41
HIWAY		207	1.71	0.13	0.80	-2.38	20.05	22.43
AIRPOL-4 (Turner)	RH = 10 ft. (3.0 m)	34	0.97	0.52	1.28	-4.71	2.37	7.08
AIRPOL-4 (Pasquill)		34	0.96	1.19	0.57	-4.71	1.07	5.78
CALAIR		28	1.99	0.16	1.26	-0.91	10.36	11.27
HIWAY		34	2.30	0.15	1.70	-2.45	16.55	19.00

Source Elevation

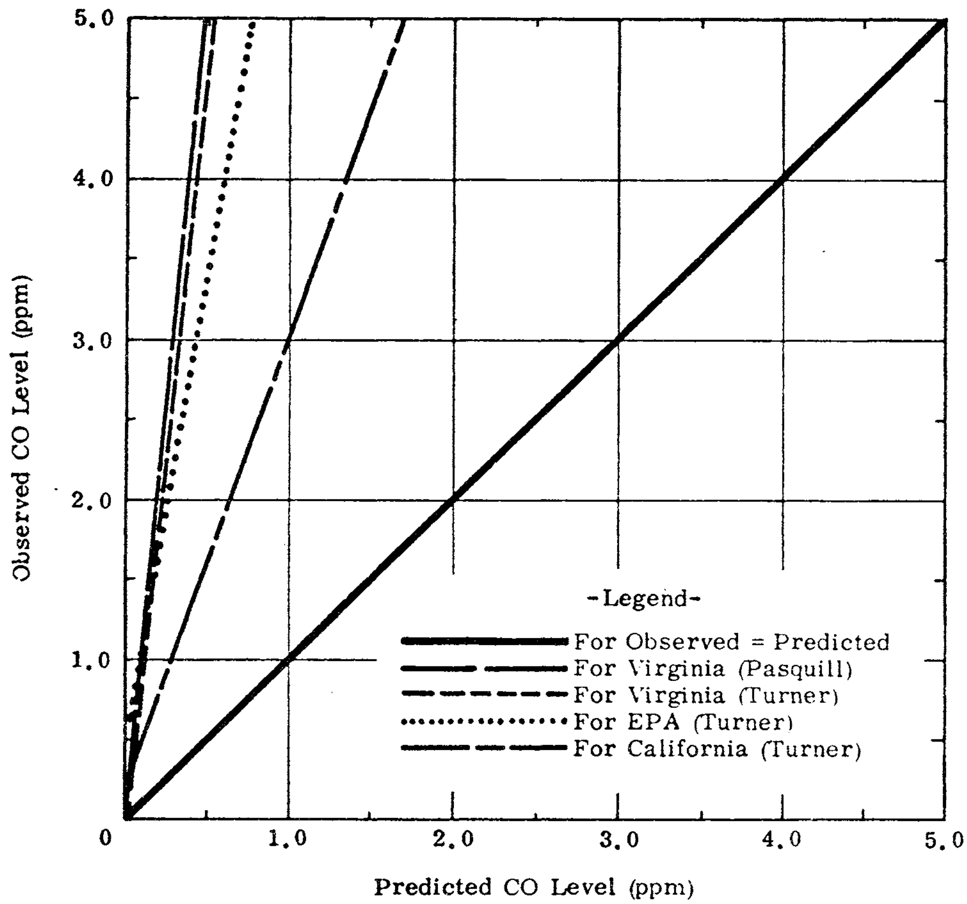
Figures 25 and 26 illustrate the performance results for at-grade and elevated roadways, respectively, and Table 16 summarizes the predictive performances of the models relative to source elevation. Analysis of the results for at-grade roadways, Figure 25, demonstrates that AIRPOL-4 (Pasquill) is significantly superior to the other three models with respect to probable errors and 100% error ranges. However, none of the models are statistically equivalent to the ideal regression line.

Analysis of the performance results for elevated roadways, Figure 26, shows that all four models are statistically equivalent with respect to probable errors and 100% error ranges and that none of the models are statistically equivalent to the ideal regression line. Furthermore, examination of the actual predictions and observations for this data set revealed that all of the models severely underpredicted CO levels, and that the primary reason they produced acceptable probable errors was that the range of observed levels was very limited. These results were expected[4] since the Gaussian theory of dispersion is not truly applicable for highway fill geometries. The authors suggest that for predictions involving highway fill sections, the user generate upper and lower bounds on CO levels by analyzing such highways as both at-grade and elevated sources. This technique is the only reasonable approach available to the user in light of the inapplicability of the Gaussian formulation to highway fill sections.



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	214	214	185	214
Probable Error	0.66	0.61	1.60	1.90
% Corr. Coeff.	54	66	50	37
Min. Dev.	-4.71	-4.71	-1.61	-2.45
Max. Dev.	3.81	1.41	13.38	20.05
Dev. Range	8.52	6.12	14.99	22.50

Figure 25. Downwind predictive performance for at-grade sources.



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	40	40	40	40
Probable Error	1.15	1.15	0.92	1.13
% Corr. Coeff.	62	63	75	59
Min. Dev.	-4.43	-4.43	-3.94	-4.36
Max. Dev.	0.13	0.14	0.25	0.15
Dev. Range	4.56	4.57	4.19	4.51

Figure 26. Downwind predictive performance for elevated sources.

Table 16

Summary of Predictive Performances Relative to Source Elevation

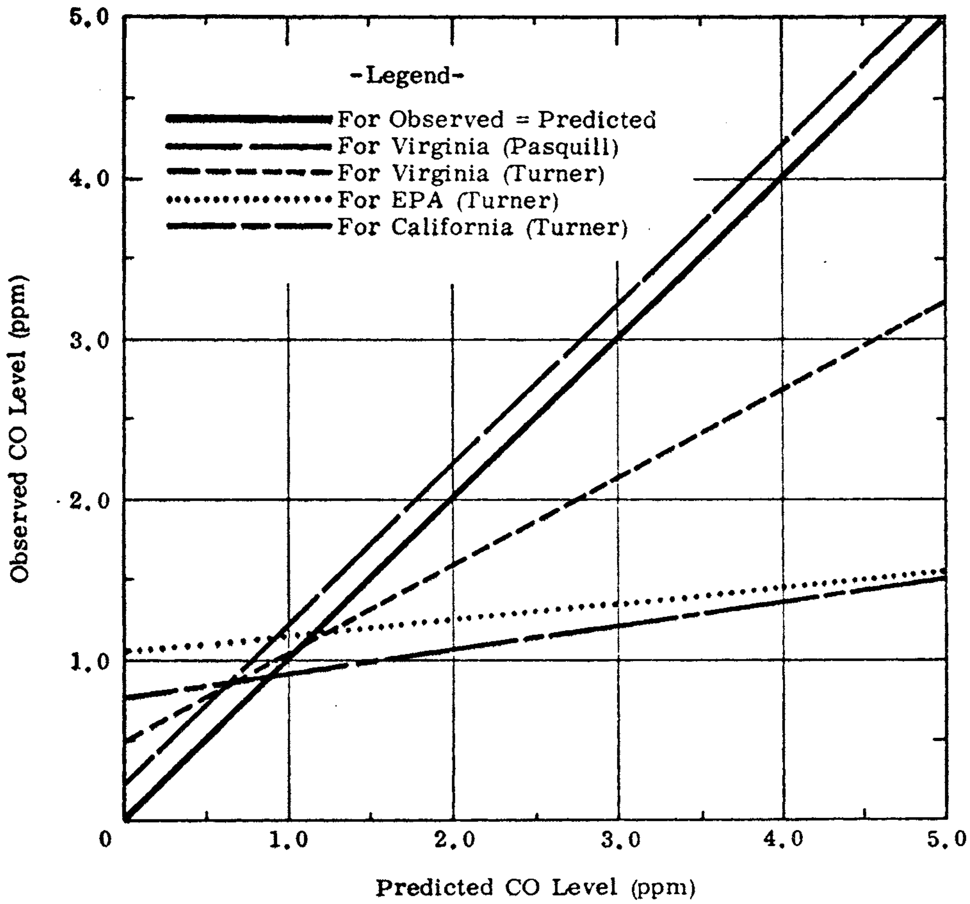
Model	Source Elevation	No. of Data Points	Probable Error	Regression Slope	Regression Intercept	Minimum Deviation	Maximum Deviation	Deviation Range
AIRPOL-4 (Turner)	at-grade	214	0.66	0.69	0.40	-4.71	3.81	8.52
AIRPOL-4 (Pasquill)		214	0.61	1.24	0.09	-4.71	1.41	6.12
CALAIR		185	1.60	0.20	0.66	-1.61	13.38	14.99
HIWAY		214	1.90	0.14	0.92	-2.45	20.05	22.50
AIRPOL-4 (Turner)	elevated	40	1.15	9.52	-0.04	-4.43	0.13	4.56
AIRPOL-4 (Pasquill)		40	1.15	10.45	-0.29	-4.43	0.14	4.57
CALAIR		40	0.92	2.84	0.11	-3.94	0.25	4.19
HIWAY		40	1.13	5.39	0.53	-4.36	0.15	4.51

Downwind Predictive Performance Relative to Individual Sites

Site 1

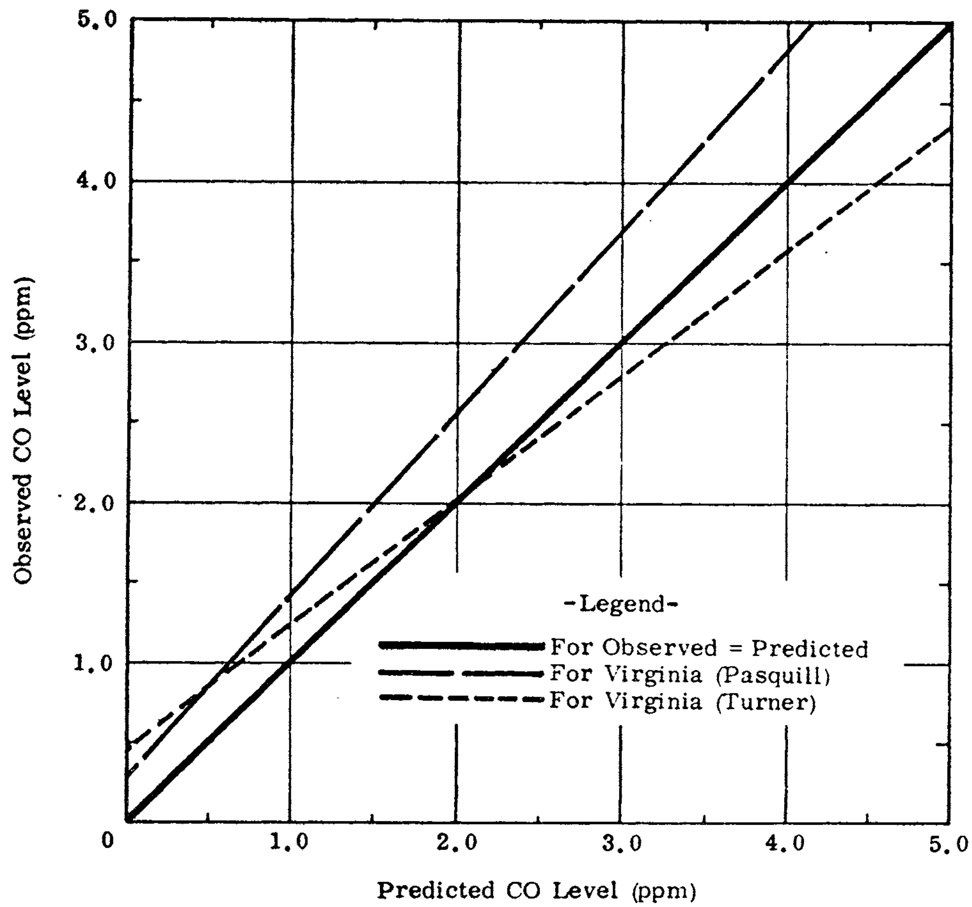
Figures 27, 28, and 29 show the performance results for the downwind, upwind, and upwind-downwind cases,respectively, for site 1. Analysis of these results shows that AIRPOL-4 is statistically superior to the three other models with respect to all performance measures. Figures 30, 31, and 32 show three typical sets of observed and predicted CO-level profiles for site 1. The differences between Figures 30 and 31 illustrate the ability of AIRPOL-4 (Pasquill) to maintain prediction integrity as wind speeds decrease. Comparison of Figures 31 and 32 demonstrates the ability of AIRPOL-4 (Pasquill) to perform satisfactorily for both small and large road/wind angles.

0386



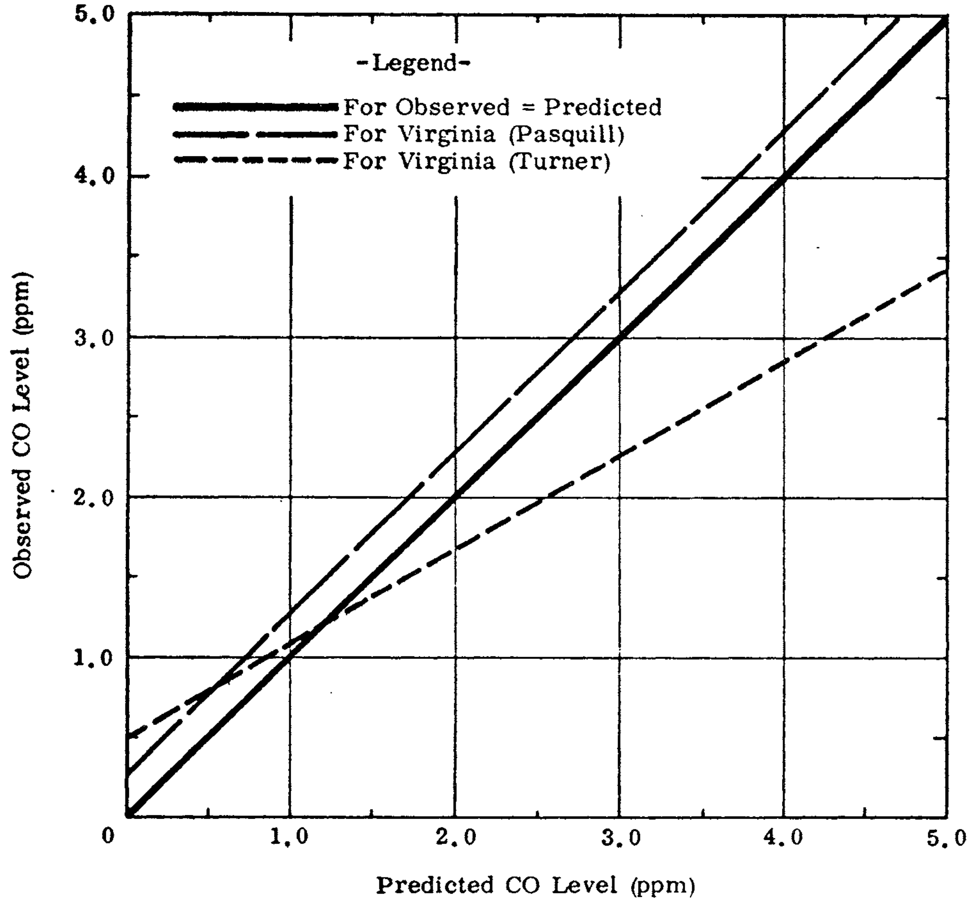
Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	117	117	104	117
Probable Error	0.69	0.60	2.04	2.41
% Corr. Coeff.	53	60	50	32
Min. Dev.	-4.71	-4.71	-1.61	-2.45
Max. Dev.	3.81	1.41	13.38	20.05
Dev. Range	8.52	6.12	14.99	22.50

Figure 27. Downwind predictive performance for site 1.



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	78	78	——	——
Probable Error	0.67	0.62		
% Corr. Coeff.	56	66		
Min. Dev.	-3.94	-3.94		
Max. Dev.	3.15	1.19		
Dev. Range	7.09	5.13		

Figure 28. Upwind predictive performance for site 1.



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	195	195	——	——
Probable Error	0.68	0.60		
% Corr. Coeff.	56	64		
Min. Dev.	-4.71	-4.71		
Max. Dev.	3.81	1.41		
Dev. Range	8.52	6.12		

Figure 29. Upwind and downwind predictive performance for site 1.

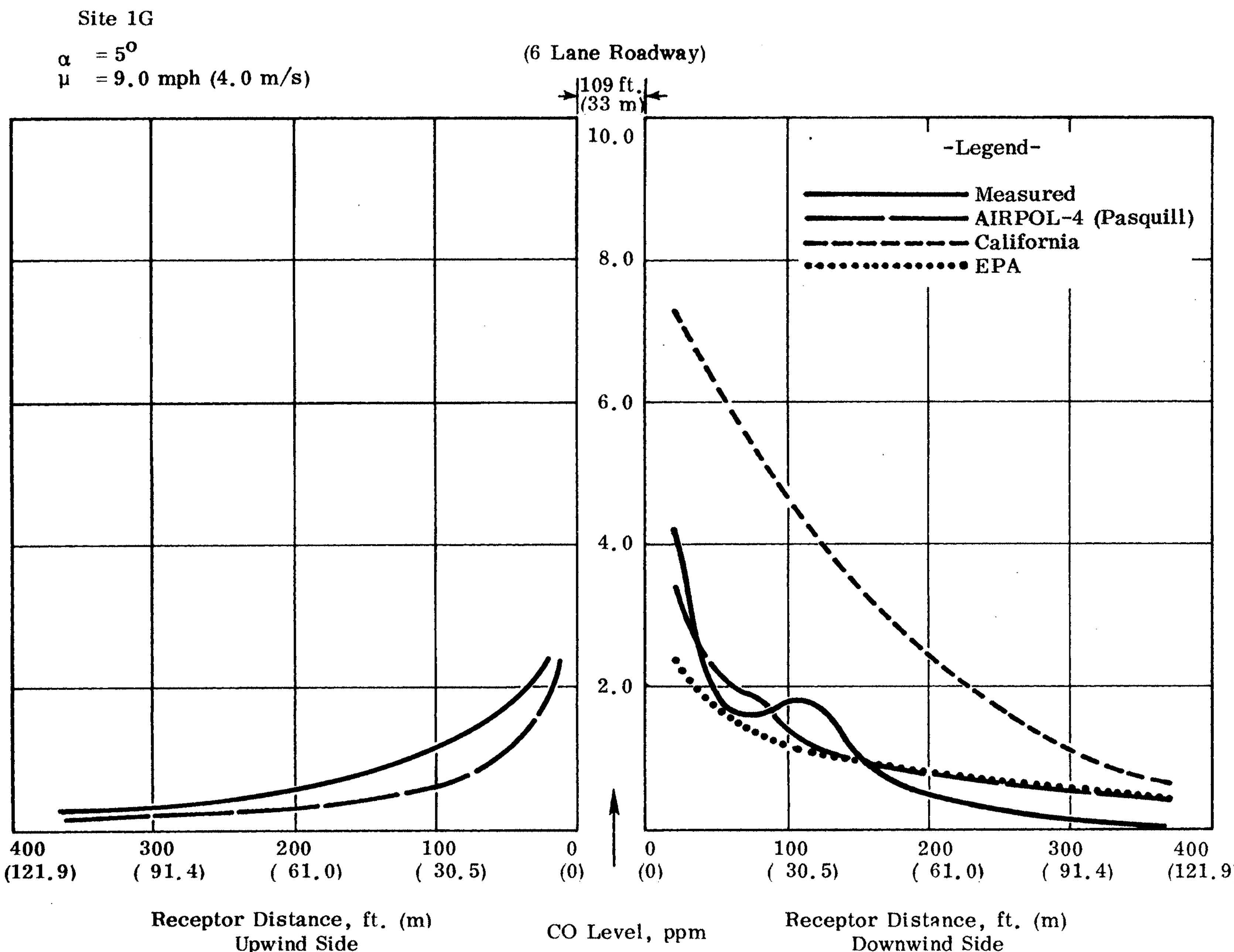


Figure 30. Typical observed and predicted CO profiles for site 1.

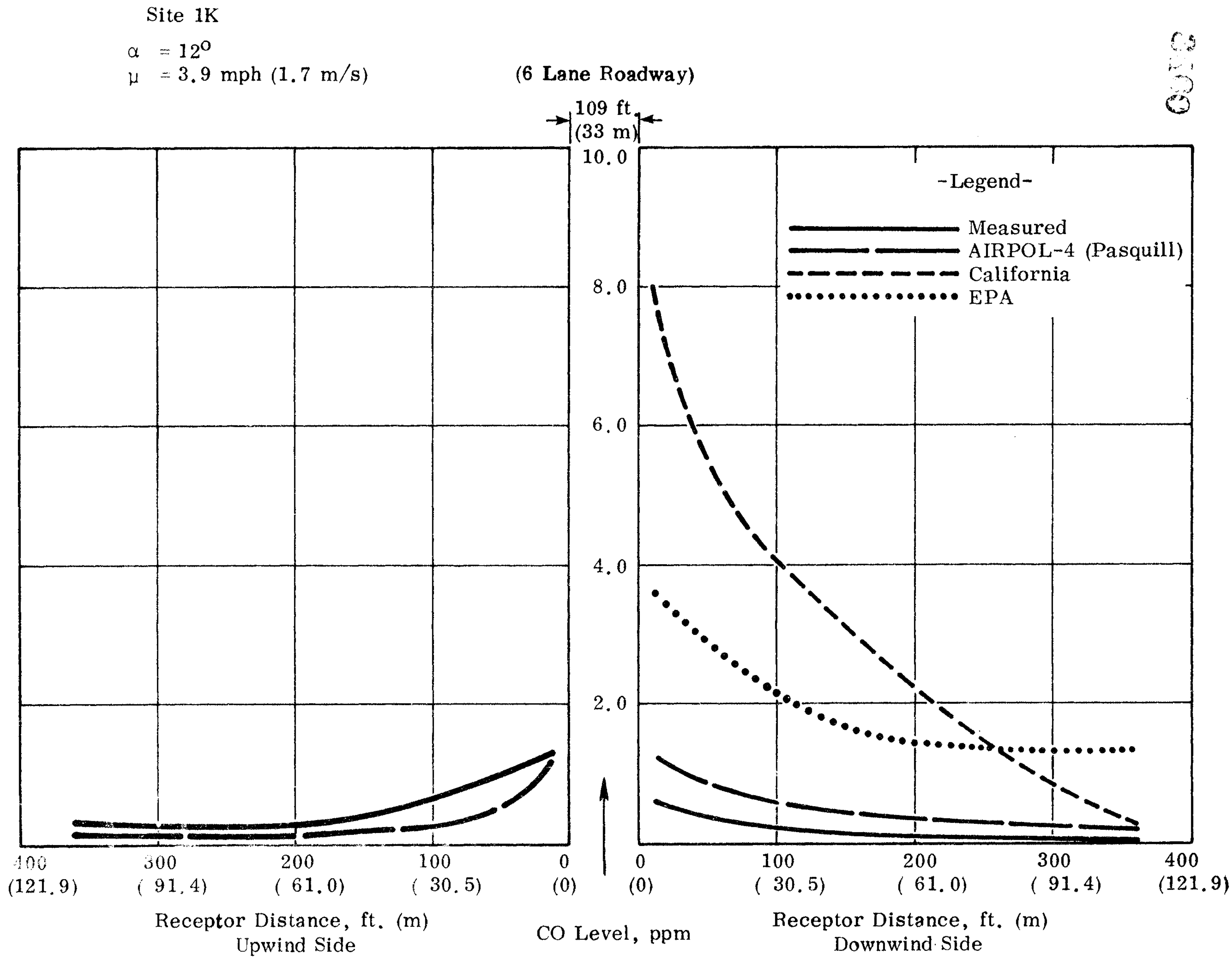


Figure 31. Typical observed and predicted CO profiles for site 1.

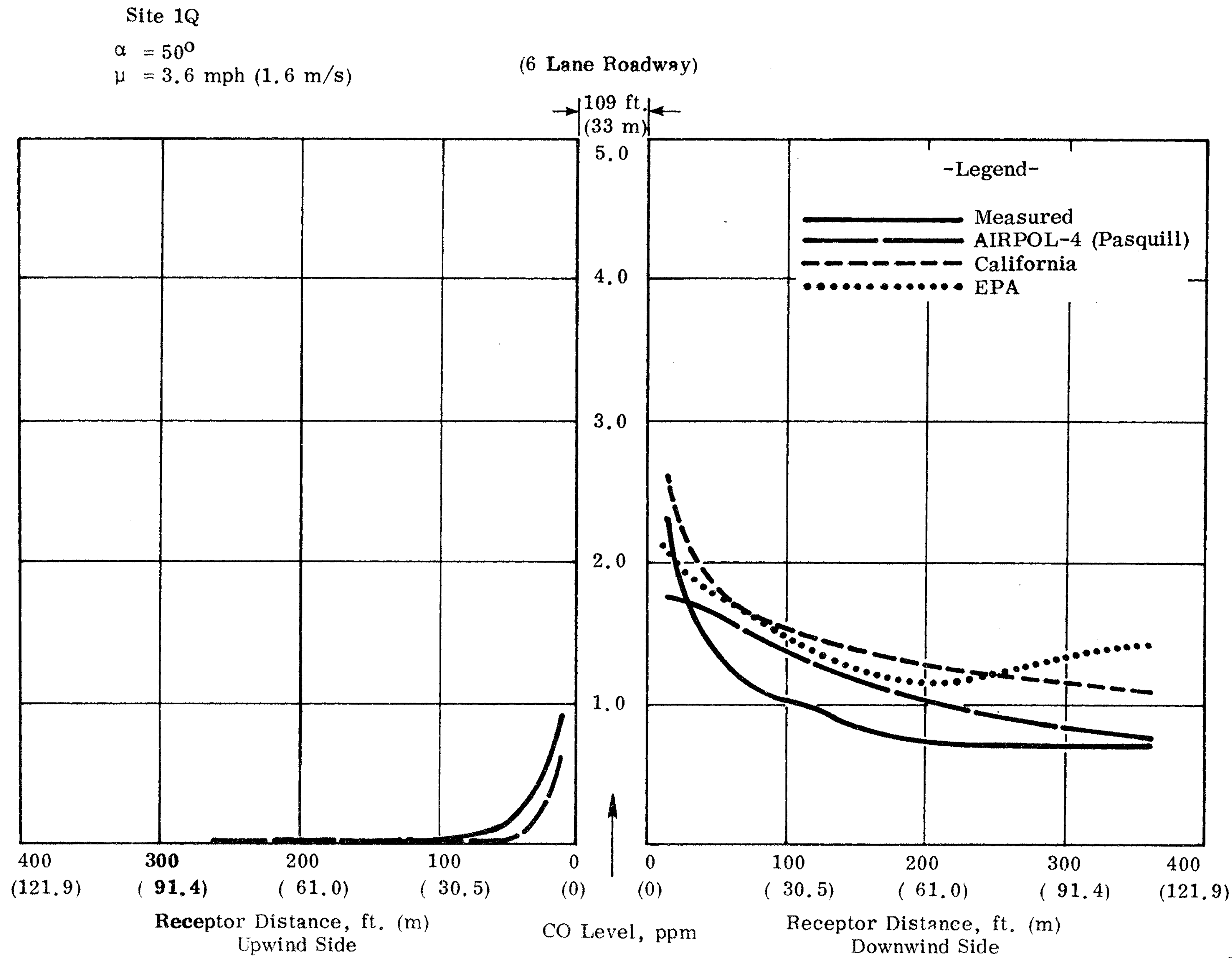
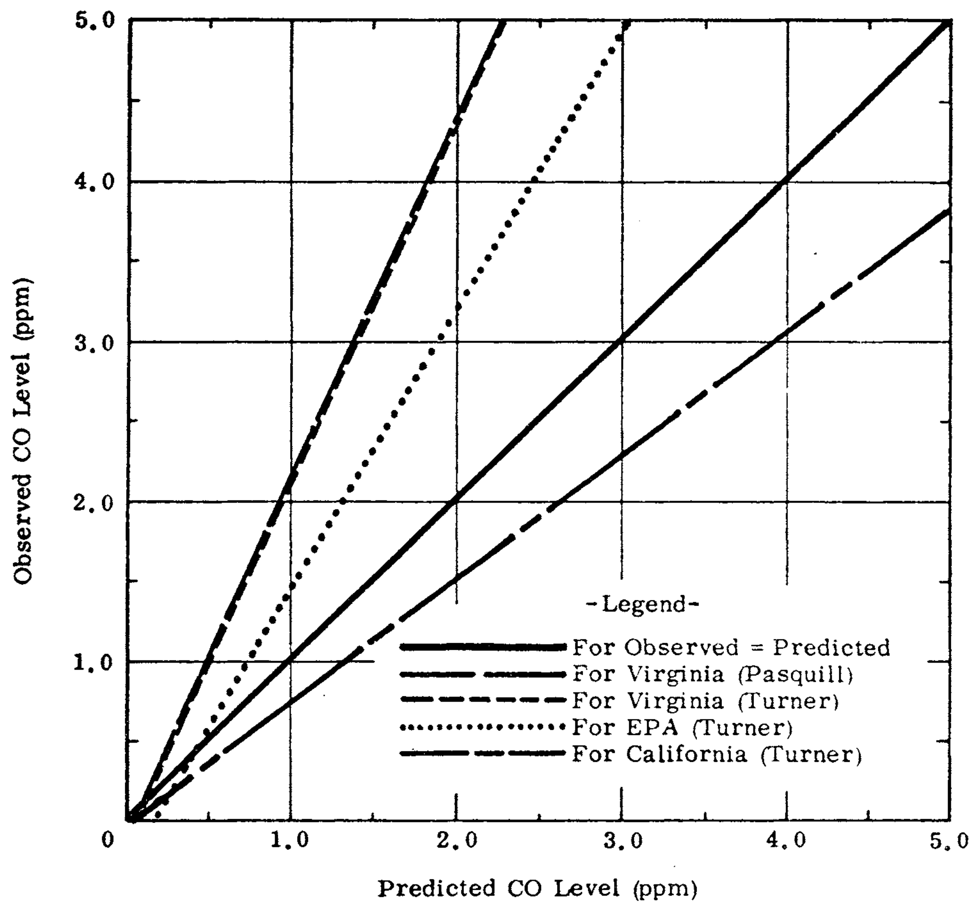


Figure 32. Typical observed and predicted CO profiles for site 1.

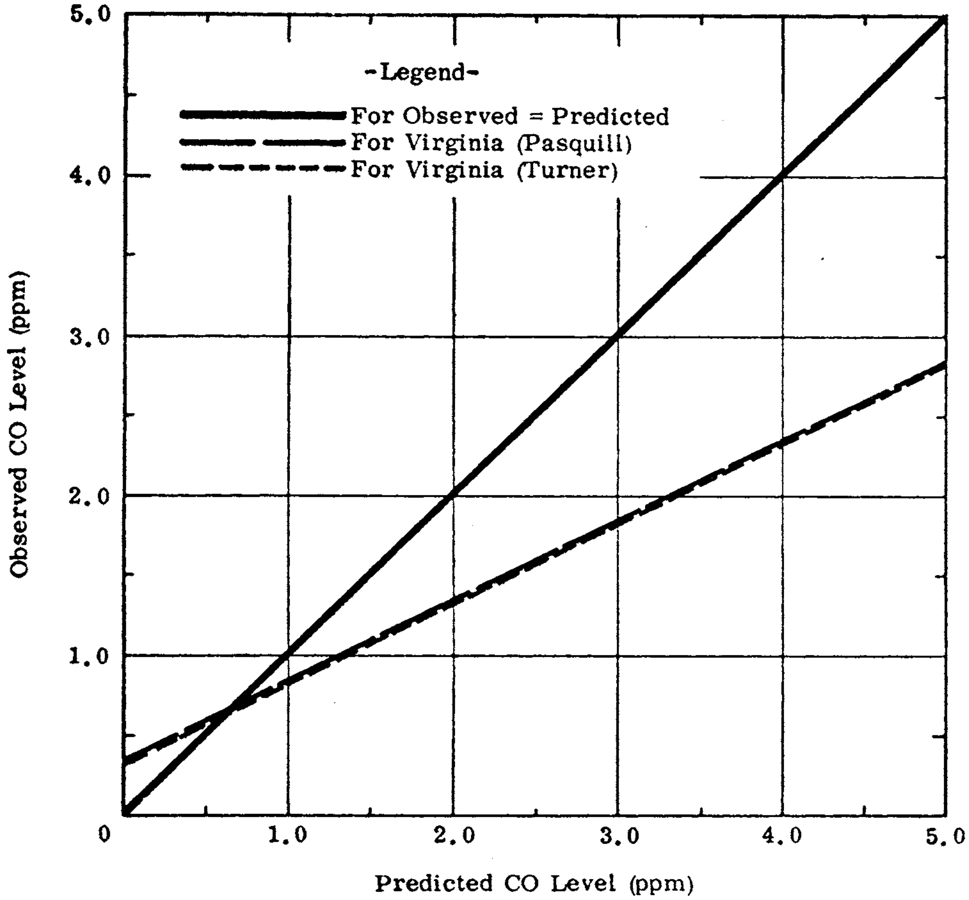
Site 2

Figures 33, 34, and 35 show the performance results for site 2 for the downwind, upwind, and total cases, respectively. Analysis of these results shows that the models are all statistically equivalent; although the small sample sizes involved render the statistical analyses somewhat useless. Figure 36 illustrates a typical set of actual and predicted CO profiles for site 2. Notice that none of the models performed very well in this instance.



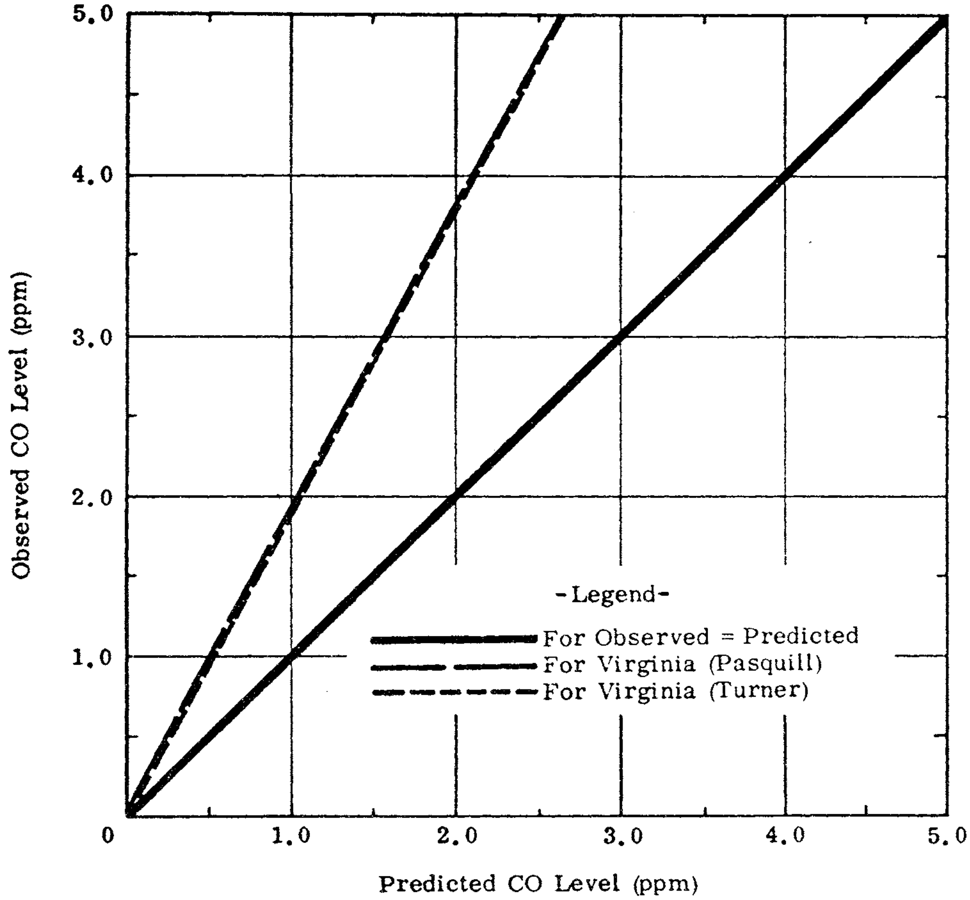
Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	9	9	9	9
Probable Error	0.99	0.99	0.67	0.73
% Corr. Coeff.	67	67	83	80
Min. Dev.	-2.84	-2.84	-0.65	-2.01
Max. Dev.	0.54	0.54	2.12	0.62
Dev. Range	3.38	3.38	2.77	2.63

Figure 33. Downwind predictive performance for site 2.



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	10	10	——	——
Probable Error	0.23	0.23		
% Corr. Coeff.	56	56		
Min. Dev.	-0.59	-0.59		
Max. Dev.	0.39	0.39		
Dev. Range	0.98	0.98		

Figure 34. Upwind predictive performance for site 2.



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	19	19	——	——
Probable Error	0.70	0.70		
% Corr. Coeff.	75	75		
Min. Dev.	-2.84	-2.84		
Max. Dev.	0.54	0.54		
Dev. Range	3.38	3.38		

Figure 35. Upwind and downwind predictive performance for site 2.

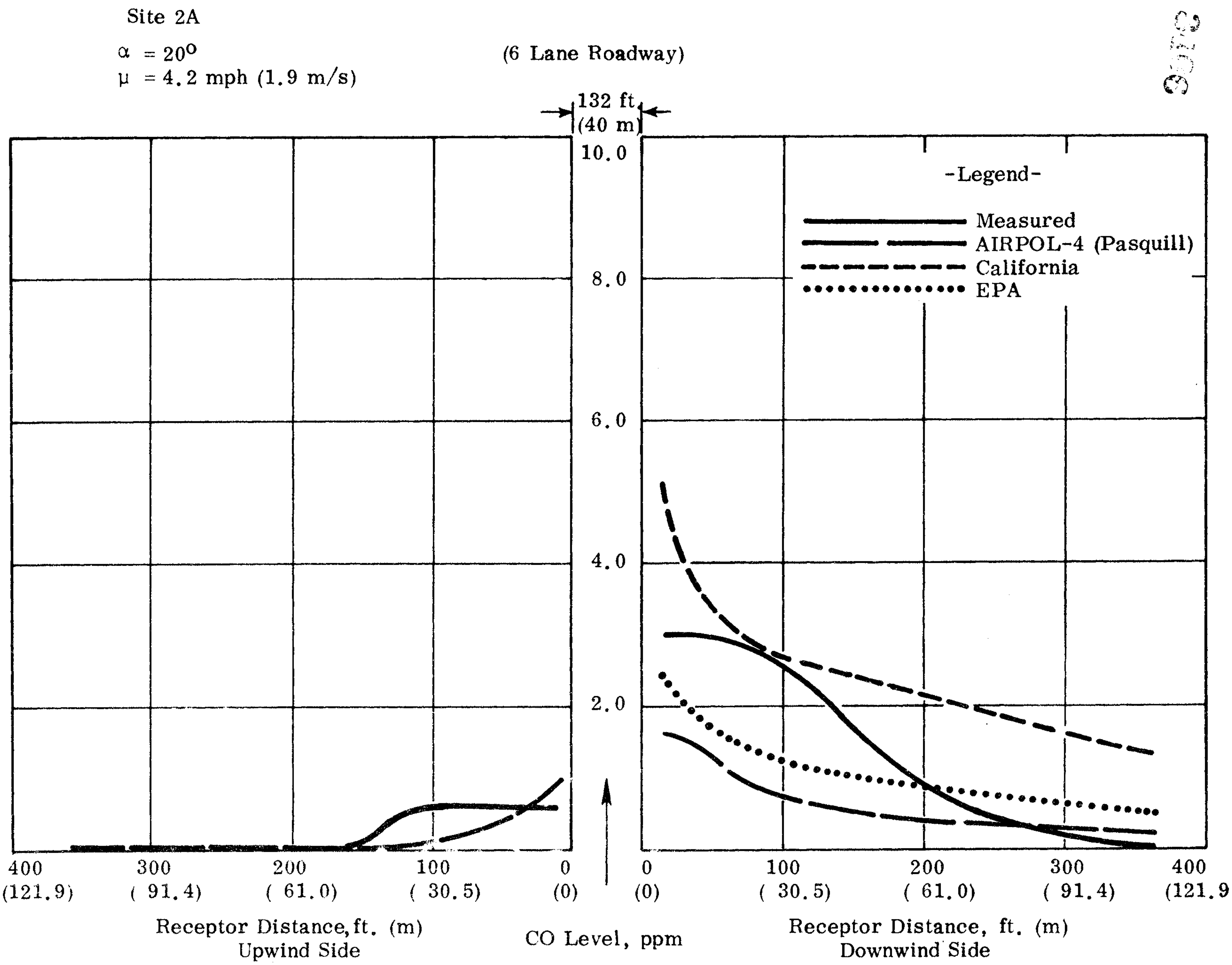
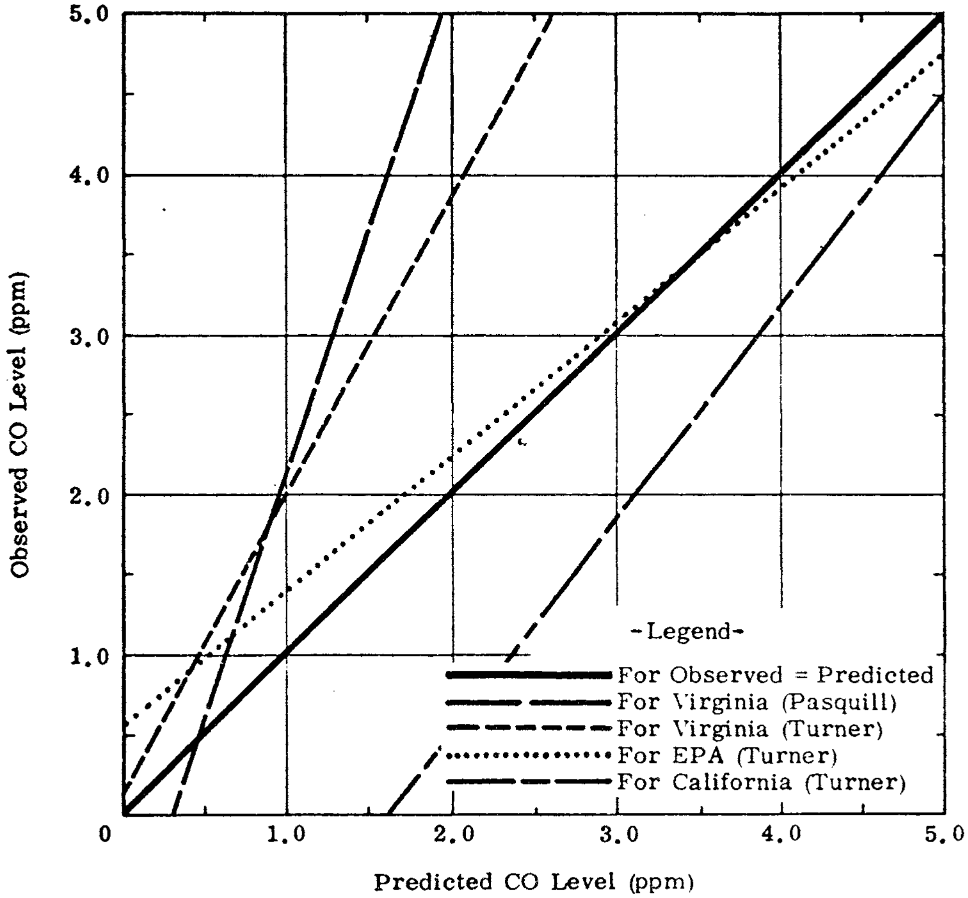


Figure 36. Typical observed and predicted CO profiles for site 2.

3407

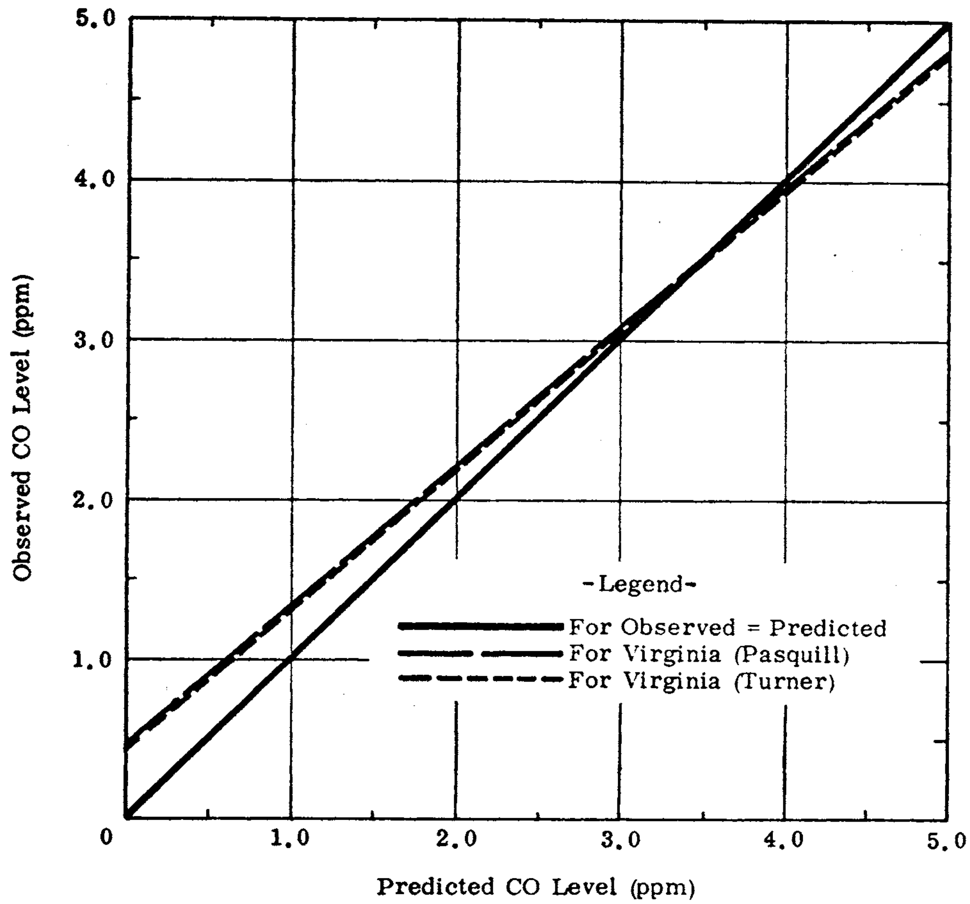
Site 3

Figures 37, 38, and 39 illustrate the results of the analyses for site 3 for the downwind, upwind, and total cases, respectively. Here again, as was the case for site 2, the data sets are fairly small. Analysis of the downwind data set, Figure 37, shows that HIWAY is statistically superior to both Virginia models and equivalent to CALAIR with respect to all statistical measures. Analysis of the upwind data set, Figure 38, which is a larger data set than the downwind set, shows that the Virginia models perform very well. Similarly, the performances of the two versions of the Virginia model relative to the total data set for site 3, Figure 39, are quite acceptable. Figure 40 illustrates a typical set of actual and predicted CO profiles for site 3.



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	12	12	8	12
Probable Error	1.29	1.37	1.16	0.69
% Corr. Coeff.	75	93	63	85
Min. Dev.	-3.66	-3.66	-1.16	-2.06
Max. Dev.	0.58	0.16	3.01	1.75
Dev. Range	4.24	3.82	4.17	3.81

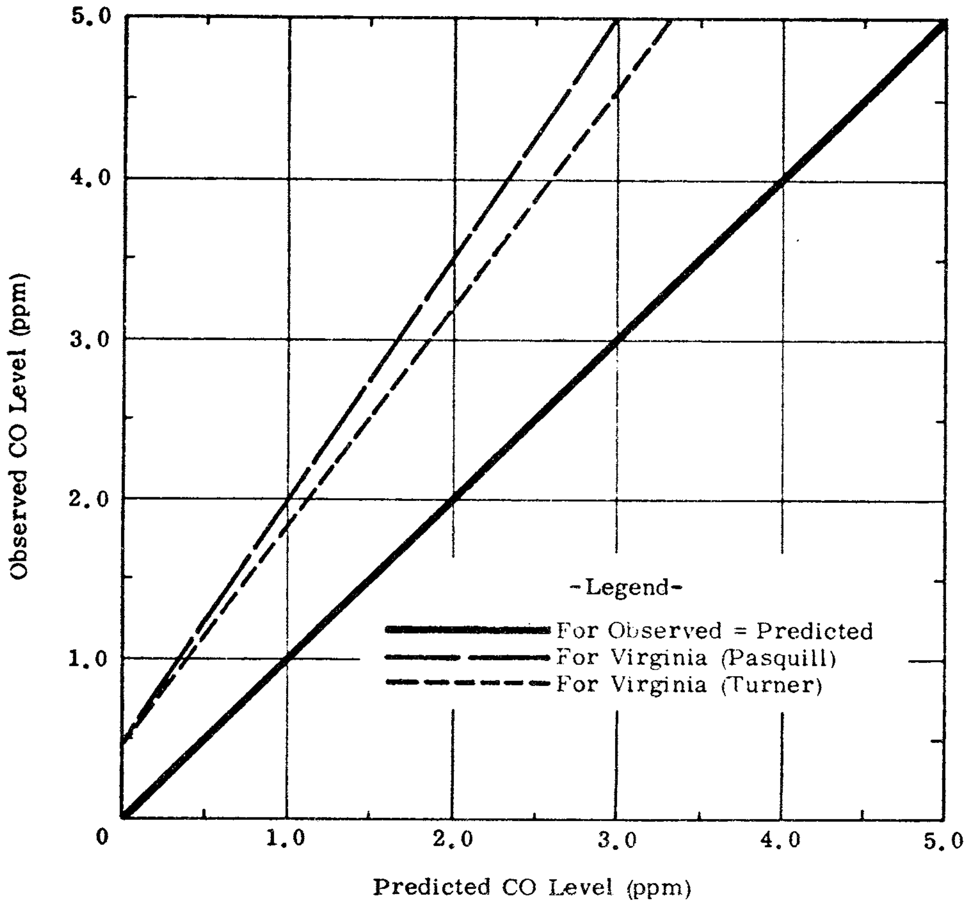
Figure 37. Downwind predictive performance for site 3.



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	18	18	——	——
Probable Error	0.47	0.47		
% Corr. Coeff.	81	81		
Min. Dev.	-1.51	-1.51		
Max. Dev.	1.20	1.20		
Dev. Range	2.71	2.71		

Figure 38. Upwind predictive performance for site 3.

3419



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	30	30	—	—
Probable Error	0.90	0.94		
% Corr. Coeff.	78	79		
Min. Dev.	-3.66	-3.66		
Max. Dev.	1.20	1.20		
Dev. Range	4.86	4.86		

Figure 39. Upwind and downwind predictive performance for site 3.

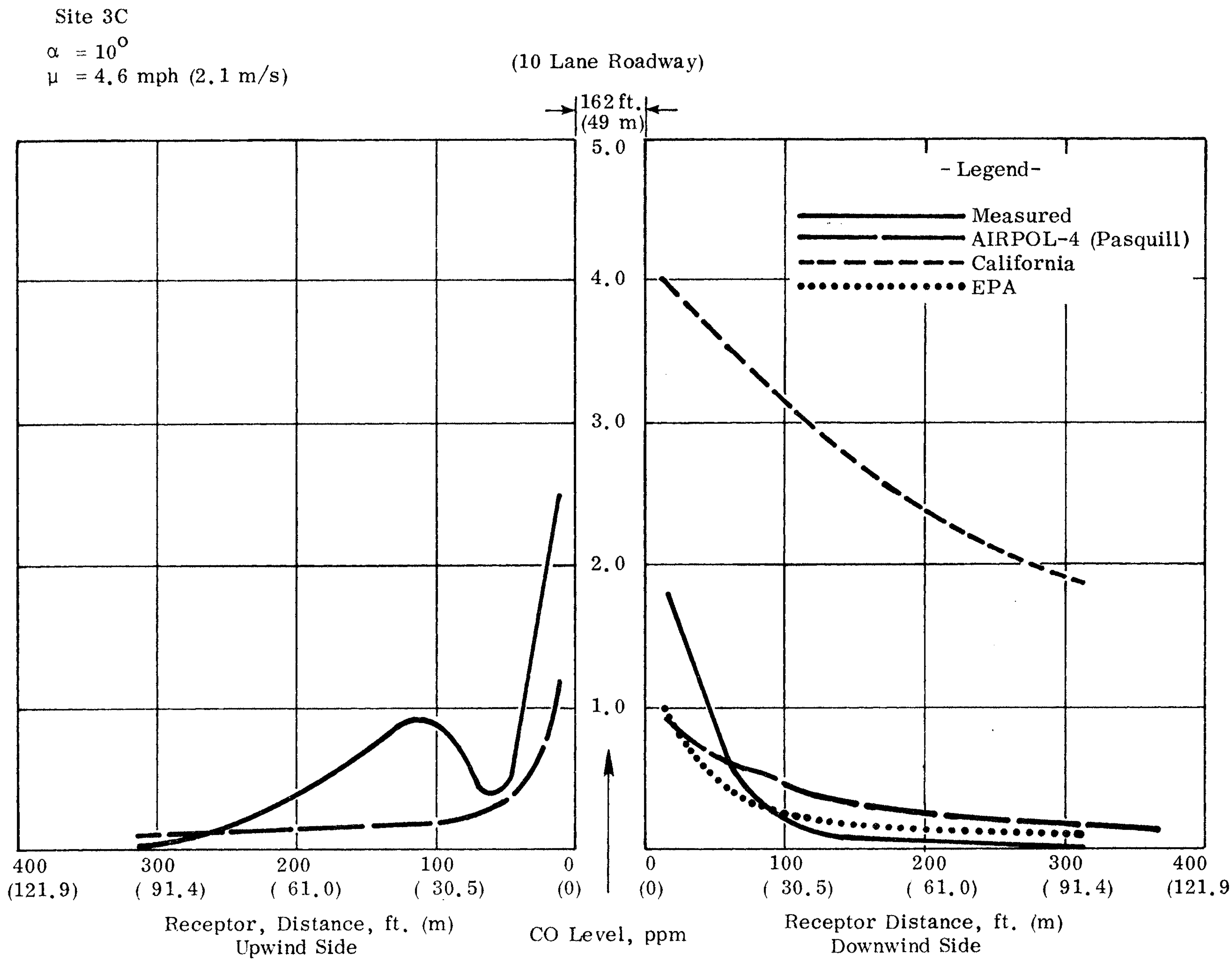
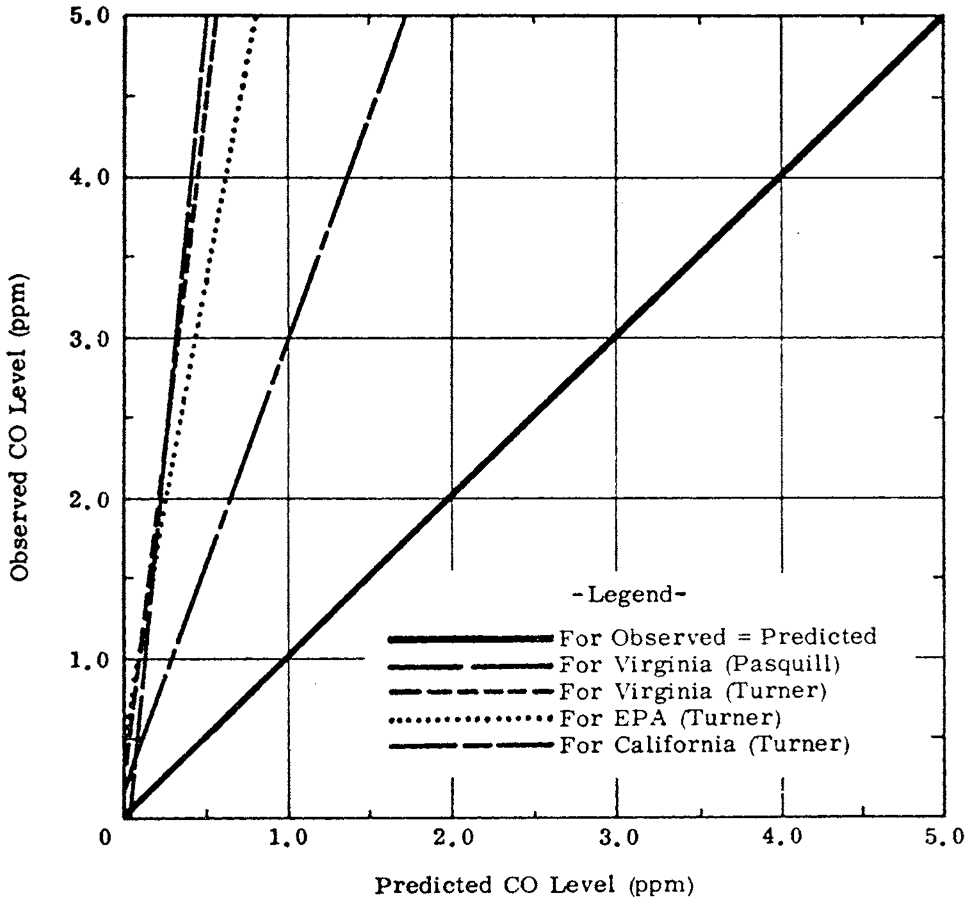


Figure 40. Typical observed and predicted CO profiles for site 3.

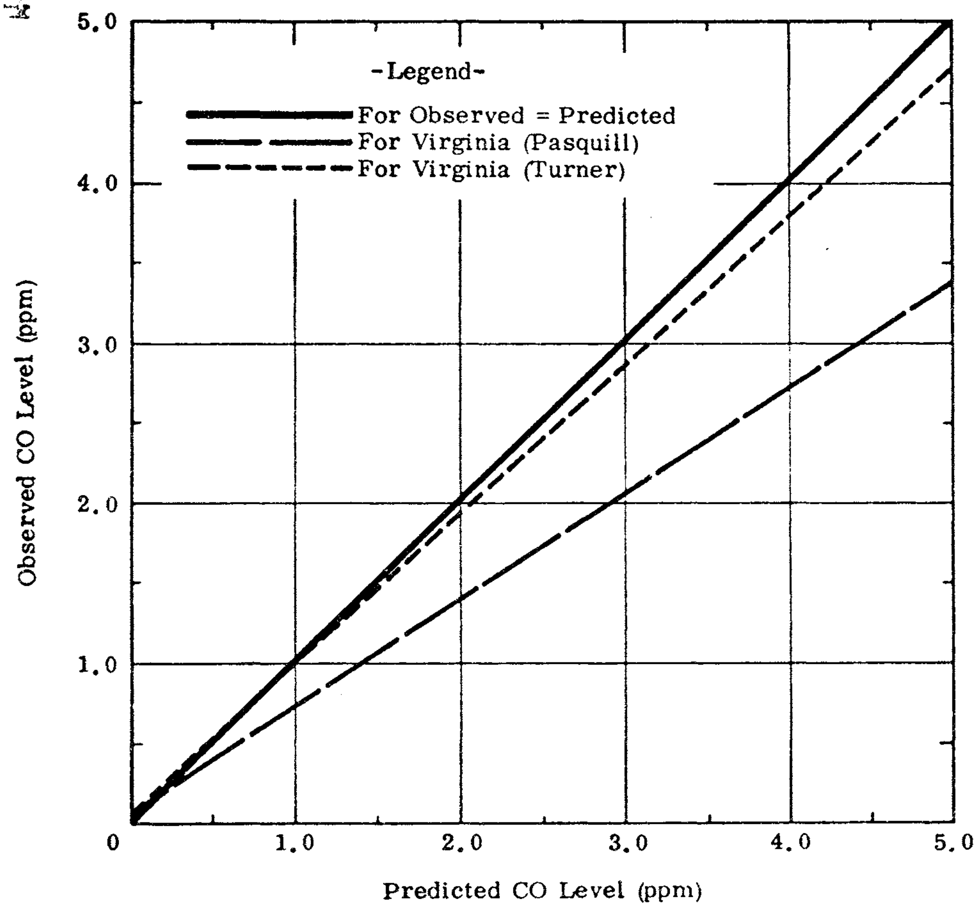
Site 4

Figures 41, 42, and 43 show the performance results for site 4, the elevated site, for the downwind, upwind, and total cases, respectively. For the downwind analysis, Figure 41, all four models were statistically equivalent with respect to all performance measures, and their performances were all relatively poor. Figure 44 illustrates a typical set of actual and predicted CO profiles for site 4. Notice that none of the models perform satisfactorily in this instance and that the Virginia (Pasquill) model demonstrates the poorest level of performance.



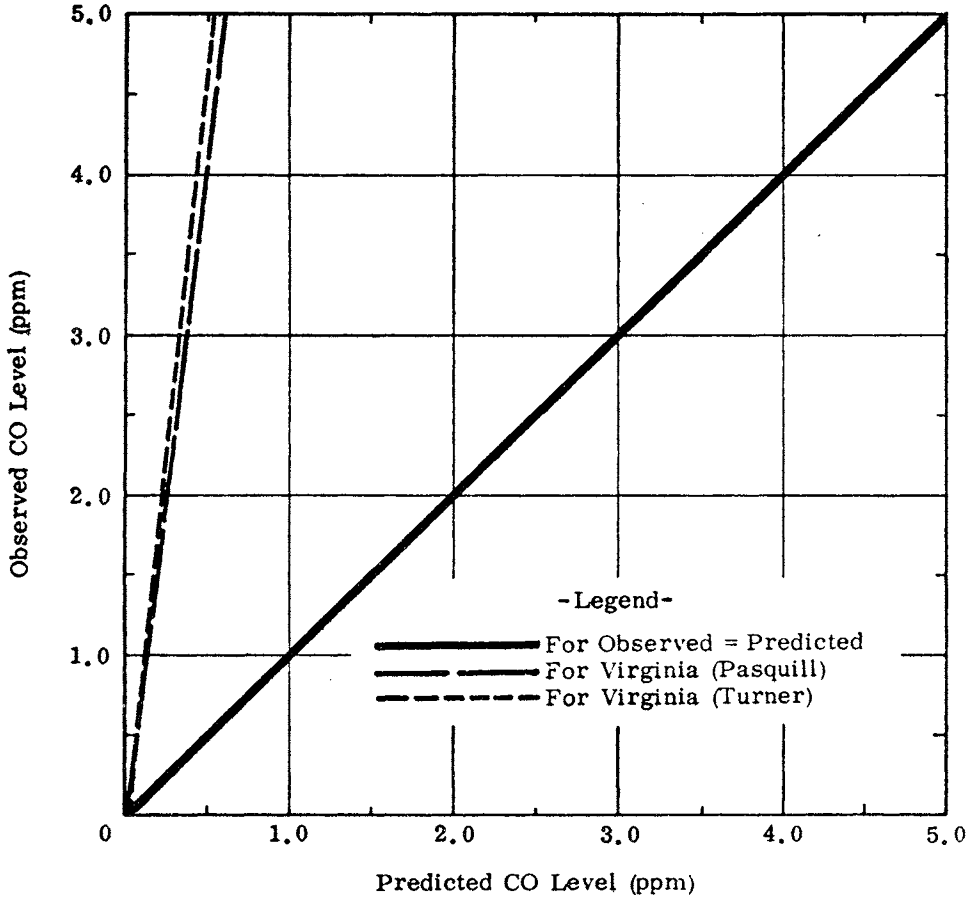
Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	40	40	40	40
Probable Error	1.15	1.15	0.92	1.13
% Corr. Coeff.	62	63	75	59
Min. Dev.	-4.43	-4.43	-3.94	-4.36
Max. Dev.	0.13	0.14	0.25	0.15
Dev. Range	4.56	4.57	4.19	4.51

Figure 41. Downwind predictive performance for site 4.



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	19	19	——	——
Probable Error	0.11	0.10		
% Corr. Coeff.	31	30		
Min. Dev.	-0.50	-0.50		
Max. Dev.	0.07	0.13		
Dev. Range	0.57	0.63		

Figure 42. Upwind predictive performance for site 4.



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	59	59	——	——
Probable Error	0.95	0.94		
% Corr. Coeff.	71	70		
Min. Dev.	-4.43	-4.43		
Max. Dev.	0.13	0.14		
Dev. Range	4.56	4.57		

Figure 43. Upwind and downwind predictive performance for site 4.

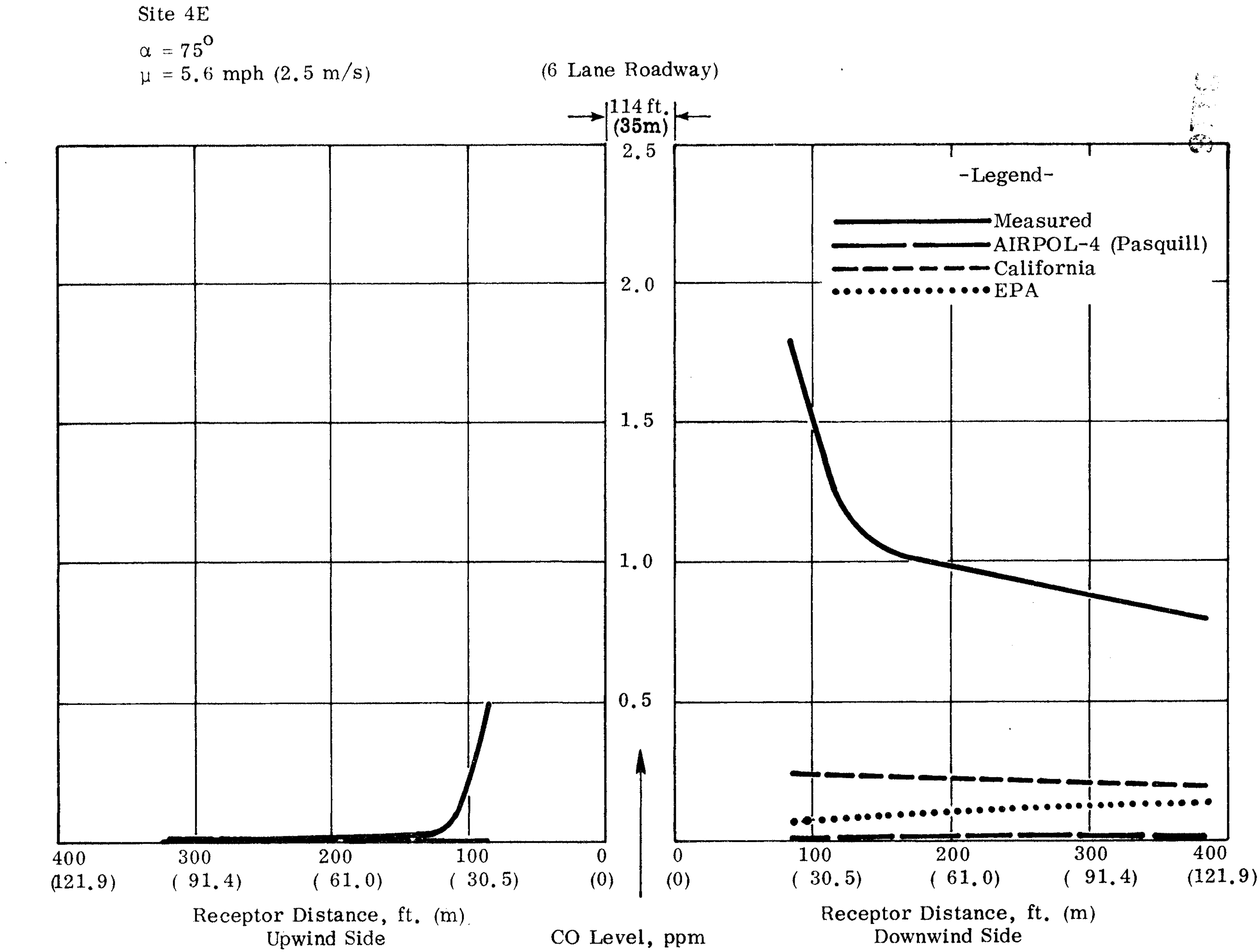
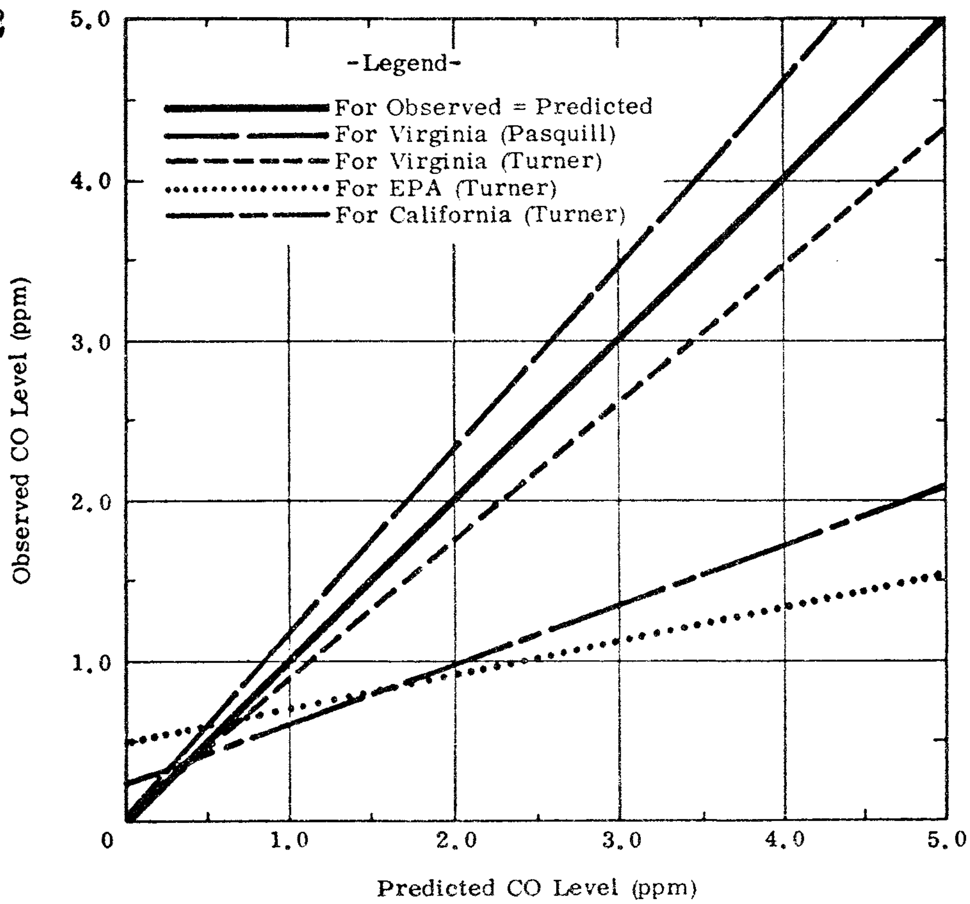


Figure 44. Typical observed and predicted CO profiles for site 4.

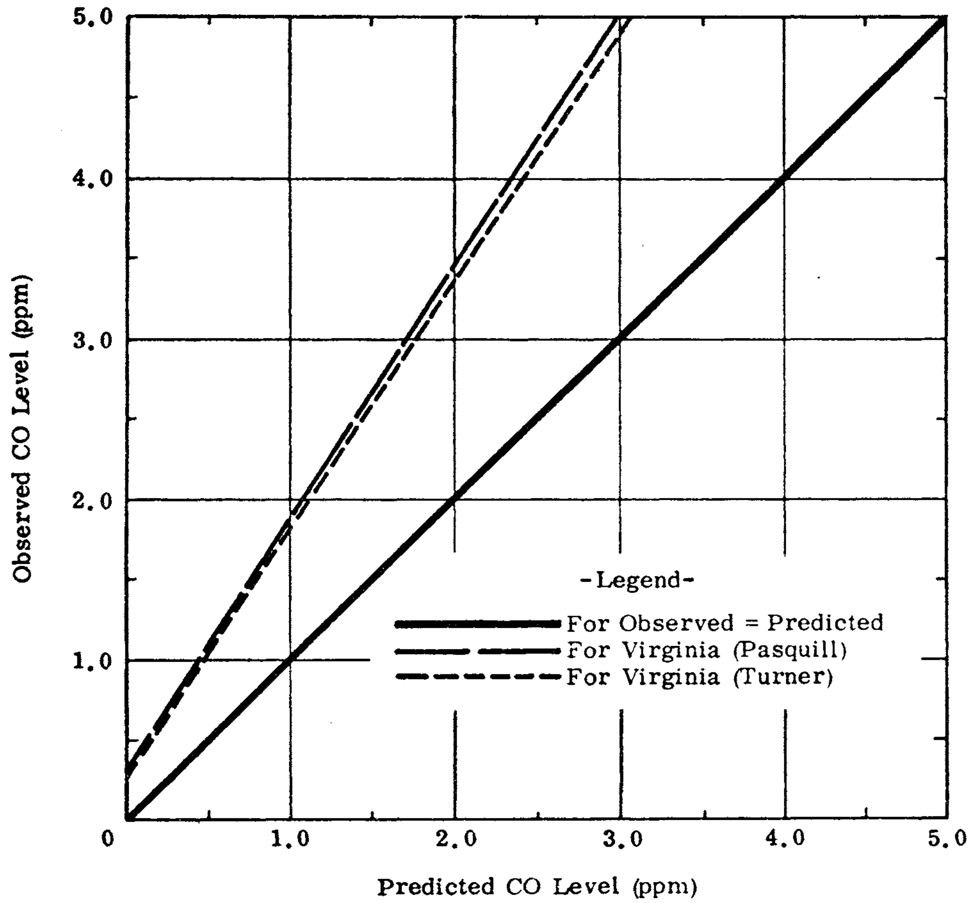
Site 5

Figures 45, 46, and 47 illustrate the performance results for the downwind, upwind, and total cases, respectively, for site 5. The downwind results, Figure 45, show that the two versions of the Virginia model are statistically equivalent to each other and superior to CALAIR and HIWAY with respect to all statistical measures of performance. Figure 46, which contains the results of the upwind analysis, shows no statistical difference in the performance levels of the Virginia models, which are both respectable. Similarly, Figure 47 shows that both versions of the Virginia model perform satisfactorily for the combined upwind and downwind data set. Figures 48 and 49 illustrate two typical sets of actual and predicted CO profiles for site 5. Both of these figures are excellent examples of the ability of AIRPOL-4 (Pasquill) to yield accurate predictions at low wind speeds.



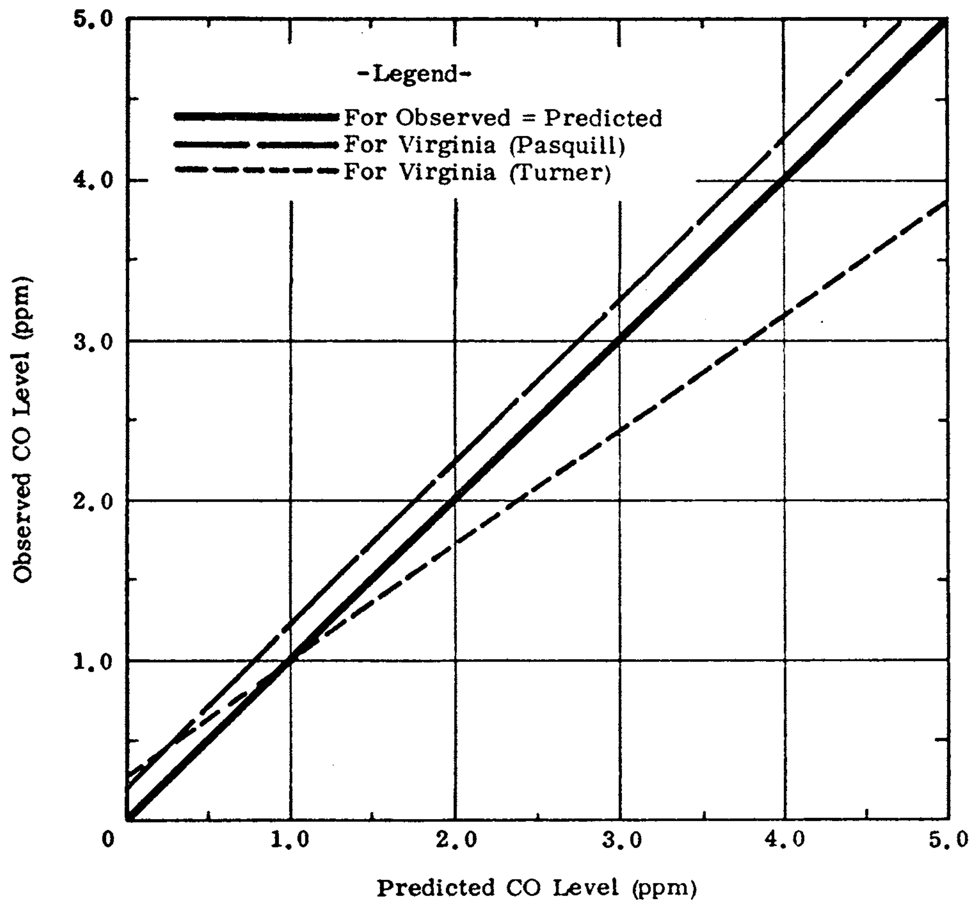
Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	76	76	64	76
Probable Error	0.33	0.29	0.61	1.04
% Corr. Coeff.	65	77	55	55
Min. Dev.	-1.36	-1.36	-1.21	-1.61
Max. Dev.	1.08	0.83	2.17	7.80
Dev. Range	2.44	2.19	3.38	9.41

Figure 45. Downwind predictive performance for site 5.



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	57	57	—	—
Probable Error	0.36	0.34		
% Corr. Coeff.	40	49		
Min. Dev.	-1.30	-1.30		
Max. Dev.	0.27	0.27		
Dev. Range	1.57	1.57		

Figure 46. Upwind predictive performance for site 5.



Statistic	Virginia (Turner)	Virginia (Pasquill)	California (Turner)	EPA (Turner)
Data Points	133	133	——	——
Probable Error	0.34	0.32		
% Corr. Coeff.	63	72		
Min. Dev.	-1.36	-1.36		
Max. Dev.	1.08	0.83		
Dev. Range	2.44	2.19		

Figure 47. Upwind and downwind predictive performance for site 5.

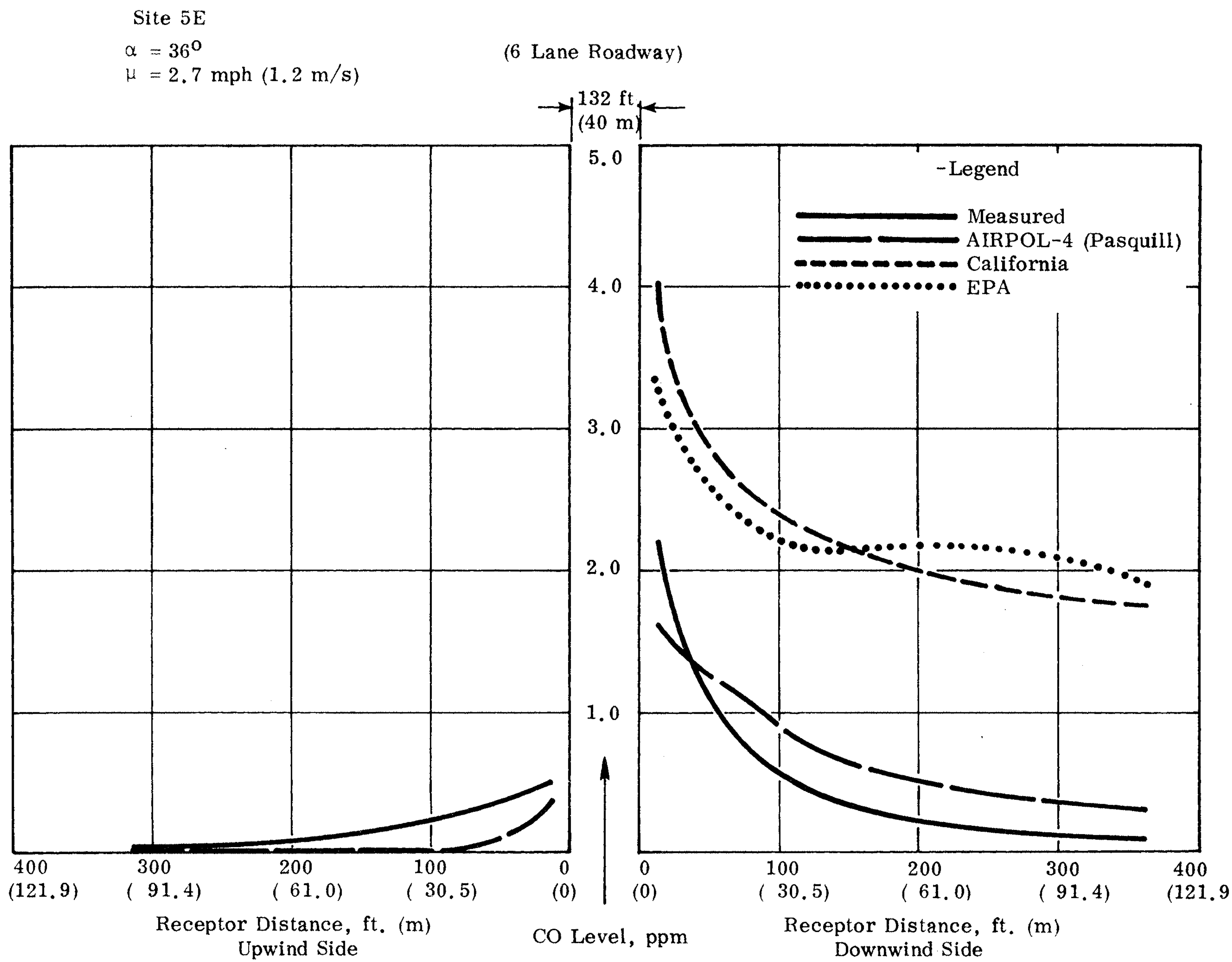


Figure 48. Typical observed and predicted CO profiles for site 5.

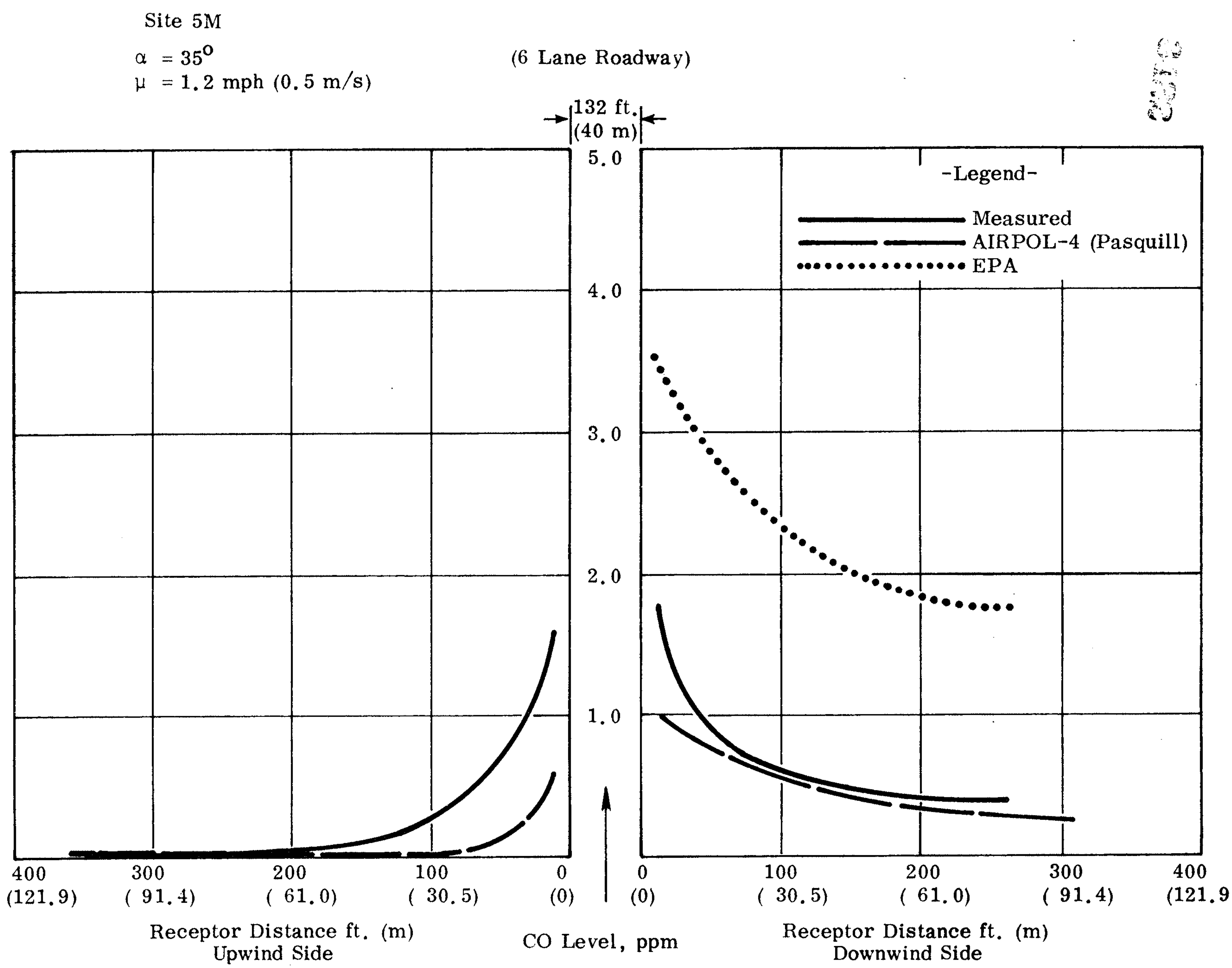


Figure 49. Typical observed and predicted CO profiles for site 5.