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ESTIMATING AIR POLLUTION FROM ROAD TRAFFIC: A GRAPHICAL SCREENING METHOD

by

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ABSTRACT

A simple graphical method is presented for the estimation of the annual maximum 8-hour concentration of carbon monoxide arising from traffic at a location near to a road network. The method was derived from information from a computer model and it is intended to be used to indicate whether air pollution from traffic around a particular road system requires more detailed study.

1. INTRODUCTION

In recent years, there has been a continuous increase in road traffic and, consequently, in the pollution of the air by exhaust gases. To counteract the increase, exhaust emissions have been subject to certain controls. For example, new cars must comply with ECE Regulation 15[1] which sets limits for some exhaust constituents and there has been a phased reduction in the maximum permitted lead content of petrol, with a further reduction intended by 1985[2]. Nevertheless, road traffic is still a major contributor to urban air pollution.

In 1977, the Advisory Committee on Trunk Road Assessment, chaired by Sir George Leitch, concluded in its report[3] that a special air quality report should be prepared where air pollution is likely to be a problem. For these reasons, and because of possible future recommendations or legislation on air pollution concentrations, it is necessary that highway engineers consider carefully any changes in air pollution that will result from road construction and modification.

A computer method has been developed at the Laboratory which provides a detailed forecast of air pollution around road networks[4]. However, there is a requirement for a simpler, initial test to establish whether the scheme needs the more detailed examination. This report provides a simple method of estimating maximum levels of pollution in a road network involving straight roads, junctions and roundabouts. The method is intended to indicate those areas where pollution is likely to cause concern. It is an initial guide and does not provide the basis of an air quality report but merely aims to indicate whether further investigation is necessary.

The method uses a set of graphs constructed from results obtained from the computer model and takes into account vehicle flow, vehicle speed and the distance of the receptor from the roads. Meteorological and other variables, which also have a large effect on pollutant concentrations, are not considered independently because this method provides an estimate of the maximum concentration likely to occur. The result chosen is the highest probable value from a distribution of 8-hour average concentrations which is based on the average hourly value. Thus, all variations in concentration which result from factors other than traffic conditions and position are implicitly included as those which lead to the highest concentration.

2. DESCRIPTION AND DEVELOPMENT OF THE GRAPH SET

The method makes use of the set of four graphs shown in Figures 1–4. Graphs 1 and 2 show the concentration of carbon monoxide as a function of the distance between the road and receptor (graph 1 for a straight road and graph 2 for a roundabout). These graphs were produced from the computer program for certain traffic and weather conditions and give the 1-hour average concentration expected for 1000 vehicles per hour travelling at 100 km/h. Graph 3 shows a correction factor which is applied to compensate for differences between the actual vehicle speed and the standard value and graph 4 can be used to predict the probable maximum 8-hour concentration from the hourly average value determined from the other graphs. Equations that fit the curves have been derived and they are shown in Figures 1–4. Using these equations, it is possible to program a calculator or computer to work out the concentration estimates. Each of the graphs, and the way in which the data were calculated are described in more detail below.

2.1 *Graph 1*

This graph shows carbon monoxide concentration as a function of the distance between the receptor and the centre of a very long, straight road. Four different road types, a B-road, an A-road, a four-lane dual carriageway and a six-lane motorway were used in the production of this graph. The curves showing the fall of concentration with increasing distance from the road were seen to superimpose if the distance was measured from the centre of each type of road.

The data were calculated for a flow of 1000 vehicles/hour and, because pollutant concentration is directly related to traffic volume, they may be adjusted for any flow by multiplying by the number of thousands of vehicles per hour expected at the site in question. Because of the way in which the estimated concentrations are evaluated the traffic flow considered should be the expected peak-hour flow (see Section 2.4). A correction for vehicle speed should also be made by use of graph 3.

The meteorological data used in the calculations were a relatively low wind-speed of 2 m/s and a set of eight wind directions, at 45° intervals, whose resulting concentrations were averaged for the final figure. These values were chosen to represent typical average conditions, and thus the result is an estimate of the average concentration to be expected at the time of peak traffic flow.

Carbon monoxide concentrations were calculated for distances up to 200m away from the centre of the road. Beyond this distance the contribution from vehicles to the carbon monoxide levels becomes negligible.

2.2 *Graph 2*

This graph is similar to graph 1 except that it shows the concentration of carbon monoxide near roundabouts. The graph was compiled using roundabouts with a range of diameters and once again the curves were superimposed when distances were measured from the centre of the carriageway.

Problems arise in assessing the gradation of road junctions through simple intersections, mini-roundabouts to small and large roundabouts. It is suggested, for the purposes of this exercise, that roundabouts with central islands larger in diameter than 10m be treated as roundabouts using graph 2; for smaller diameter central islands the roads should be treated in the way outlined under graph 1 and the roundabout ignored.

2.3 *Graph 3*

Motor vehicles travelling at slow speeds emit more carbon monoxide than those which are travelling faster. Graph 3 shows a correction factor as a function of vehicle speed which is used to adjust from the standard value used in the calculation of the graphs (100 km/h) to the actual speed likely on the road under consideration.

The correction factor is the ratio of the emission rate at that speed to the emission rate at 100 km/h. All emission rates were calculated using a relationship determined from measurements of carbon monoxide emissions from British cars[5] and from American data showing the variations of emissions with vehicle speed[6].

2.4 *Graph 4*

As there is no UK recommendation on limits for exposure to ambient levels of carbon monoxide, standards set by other countries and international bodies have had to be considered in the interpretation of the estimates. The United States Federal Air Quality Standards[7] specify concentrations of carbon monoxide of 35 and 9 ppm which should not be exceeded more than once a year for exposure periods of one and eight hours respectively. Data from our surveys of air pollution near roads have shown that the eight-hour standard is more difficult to meet than the one-hour standard. (If the concentration exceeds 35 ppm for one hour, it will almost certainly exceed 9 ppm for eight hours. The reverse is not necessarily true.) Therefore, since this method is intended as an initial test, the more stringent, eight-hour standard was chosen to indicate where an investigation of likely air pollution levels should be considered.

Graph 4 provides the means of estimating the 8-hour average concentration which is likely to be exceeded once a year (0.01 per cent probability) from the 1-hour average value derived from the other graphs. The graph was constructed by a method based on data from observed distributions of carbon monoxide concentrations which forms part of the more detailed model[3]. The base value is the average peak 1-hour concentration, that is, the average concentration likely during periods of peak traffic flow. Therefore, peak hourly traffic flow data should be used for the initial estimates from graphs 1 and 2.

3. DESIGNATION OF ROADS

The data shown in graph 1 were calculated using very long straight roads. Therefore the road network should be divided into as few continuous roads as possible to avoid overestimation by including contributions separately from different parts of the same road. In the calculation it is necessary to consider only the section nearest to the receptor.

This is true even when a road is not straight or is interrupted by a roundabout, crossroad or other feature. Errors introduced because of such departures from the idealised conditions assumed in the production of the graphs will be less than if contributors are duplicated. There will be situations where a short section of road is not part of a longer continuous road and it must be considered as a separate contributor.

This concept is illustrated in Figure 5 which shows the apportionment of four simple road networks. Figure 5(a) shows a roundabout with 4 exits. The traffic flows, the road centres, the road designations, and the distances from the nearest point on each road to the receptor are marked. Although they are separated by the roundabout, the different branches of the roads are considered as continuous, so the network reduces to two roads, marked A and B, and the roundabout. Figure 5(b) is similar to 5(a) except that the continuous roads are not straight and there is a fifth exit from the roundabout. In this case two roads are made up of branches carrying similar traffic flows. The fifth branch must be considered as a separate contributor. Figure 5(c) shows a motorway with two slip roads. The motorway is obviously one road, and, because the two slip roads have similar traffic flows they can also be treated as one road although they are not in a straight line. Finally, Figure 5(d) shows a simple 3-way junction. Because most of the traffic takes the route marked A, this is regarded as a single road rather than the physically continuous section, AB. The contribution from B is included separately.

4. METHOD OF USE OF THE GRAPHS

1) Divide up the network of roads as described in Section 3. Then carry out steps 2–6 for each road and roundabout.
2) Measure the shortest distance between the receptor and the centre of the carriageway of the road.
3) From graph 1 (2 if the road is a roundabout) read the expected concentration per 1000 vehicles, or calculate it from the equation of the curve.
4) Multiply by the expected peak-hour traffic flow, in thousands. If peak-hourly traffic data are not available then 10 per cent of the daily flow can be taken as peak-hour flow.
5) Estimate the speed of the traffic at the point on the road nearest to the receptor.
6) Use graph 3 or its equation to find the correction factor for that speed and multiply the answer from step 4 by the factor.
7) When steps 2–6 have been carried out for each road and roundabout, add together all the values to give the hourly average concentration at times of peak traffic flow at the receptor.
8) This result can be used to find the eight-hour concentration that is likely to be exceeded once a year by using graph 4 or its equation.
9) If the result is greater than 9 ppm it is recommended that a more thorough assessment should be made by using the computer model.

5. EXAMPLE SHOWING THE METHOD OF USE

A map of the roads considered in this example is shown in Figure 6. The road network has a roundabout with a dual carriageway running E-W and a minor road running N-S. There is also another minor road crossing the dual carriageway approximately 100m east of the roundabout. The network has been divided into three long continuous roads; A, B and C and one roundabout; D. The peak-hour traffic flows and the speed at the point on each road nearest to the receptor are shown in Table 1. The traffic on the roundabout (D) has been estimated from the flows on roads A and B assuming that vehicles travel, on average, half-way around the roundabout.

All the steps from the method of use have been carried out and the results are shown in Table 2.

This example gives an eight-hour concentration likely to be exceeded once a year of 12.4 ppm.

This value exceeds 9 ppm and, therefore, the site needs to be studied in greater detail.

TABLE 1

Traffic flows and speeds

Road	Traffic (veh/h)	Speed (km/h)
A	1000	30
B	3000	40
C	1000	50
D	2000	30

TABLE 2

Results for the example

Road	Shortest distance between receptor and road (m)	CO concentration for 1000 veh/h at 100 km/h (ppm)	Peak traffic flow (veh/h)	CO concentration for specific traffic flow at 100 km/h (ppm)	Traffic speed (km/h)	Speed correction factor	CO concentration for specific traffic flow and speed (ppm)
A	48	0.42	1000	0.42	30	2.6	1.09
B	48	0.42	3000	1.26	40	2.05	2.58
C	90	0.16	1000	0.16	50	1.74	0.28
D	43	0.34	2000	0.68	30	2.6	1.77
Total average peak-hour level of CO							5.72
Corresponding eight-hour concentration likely to be exceeded once a year							12.4

6. VALIDATION OF THE GRAPHICAL METHOD

The results of a validation test have been included which compares the results obtained using the computer program and the graphical method for the simple road system shown in Figure 7.

The computer program was used to predict levels at each of the receptors marked in Figure 7 under the meteorological conditions for which the graphs were developed. The 1-hour average concentrations given by the program can be compared directly with results from the graphical method when it has been worked up to and including step 7 in the 'method of use' (Section 4).

Figure 7 shows the road system used (only the centre of the roads are marked) with the appropriate traffic volume on each road. As the graphs were compiled using very long, continuous roads, this system can be seen as one main road with a slip road. The main road carries 3000 veh/h on one side of the junction and 2000 veh/h on the other, the traffic flow considered depends on the point of shortest distance to the receptor. The concentrations were calculated, therefore, as the sum of a contribution from each of these roads.

The results are shown in Table 3. There is good correlation between the two sets of results which are plotted in Figure 8. There are some discrepancies but as the results from the initial graphical guide tend to be higher than those from the computer model, it is unlikely that an area subject to high pollution levels will be missed using this preliminary estimate.

TABLE 3

Results of the validation exercise

	ROAD 1				ROAD 2					
Receptor	Distance (m)	Traffic (veh/h)	Speed (km/h)	Graphical method CO concentration (ppm)	Distance	Traffic	Speed	Graphical method	Total conc. graphical method	Computer model conc.
A	64	3000	60	1.28					0.79	1.25
B	58	3000	60	1.44					0.95	1.45
C	43	3000	60	2.21	196	1000	20	0.11	2.32	1.69
D	47	3000	60	1.98	168	1000	20	0.14	2.12	2.00
E	57	3000	60	1.49	154	1000	20	0.27	1.76	1.57
F	50	3000	60	1.80	126	1000	20	0.32	2.12	1.96
G	60	3000	60	1.40	114	1000	20	0.40	1.80	1.62
H	68	3000	60	1.17	106	1000	20	0.47	1.64	1.39
I	60	3000	40	1.89	78	1000	20	0.76	2.65	1.82
J	50	3000	40	2.44	56	1000	20	1.22	3.66	2.50
K	56	2000	50	1.19	58	1000	20	1.17	2.36	2.17
L	58	2000	50	1.14	68	1000	20	0.94	2.08	1.95
M	60	2000	50	1.09	76	1000	20	0.79	1.88	1.80
N	56	2000	60	1.02	85	1000	20	0.65	1.67	1.69
O	52	2000	60	1.14	94	1000	20	0.54	1.68	1.62
P	49	2000	60	1.23	100	1000	30	0.36	1.59	1.60
Q	66	2000	60	0.81	125	1000	30	0.23	1.04	1.00
R	62	2000	60	0.90	130	1000	30	0.21	1.11	0.99
S	58	2000	60	0.98	136	1000	30	0.18	1.16	0.97
T	52	2000	60	1.14	142	1000	30	0.18	1.32	0.94
a	20	3000	60	4.28					4.28	4.30
b	14	3000	60	4.95					4.95	5.00
c	8	3000	60	5.67	182	1000	20	0.11	5.78	5.70
d	19	3000	60	4.41	170	1000	20	0.14	4.55	4.35
e	12	3000	60	5.18	142	1000	20	0.25	5.43	5.14
f	22	3000	60	4.05	126	1000	20	0.32	4.37	4.09
g	14	3000	60	4.95	98	1000	20	0.52	5.47	5.30
h	22	3000	60	4.05	82	1000	20	0.68	4.73	4.38
i	15	3000	40	6.64	54	1000	20	1.30	7.94	6.26
j	23	3000	40	5.41	42	1000	20	1.80	7.21	5.19
k	14	3000	40	6.77	16	1000	20	3.78	10.55	7.34
l	16	3000	40	6.46	23	1000	20	3.17	9.63	6.46
m	18	2000	50	3.50	32	1000	20	2.45	5.95	5.75
n	20	2000	50	3.33	39	1000	20	1.98	5.31	5.21
o	17	2000	50	3.61	48	1000	20	1.55	5.16	4.81
p	14	2000	60	3.30	56	1000	30	0.88	4.18	4.63
q	10	2000	60	3.60	62	1000	30	0.78	4.38	4.62
r	26	2000	60	2.43	88	1000	30	0.44	2.87	2.83
s	24	2000	60	2.55	94	1000	30	0.39	2.99	2.94
t	19	2000	60	2.94	100	1000	30	0.36	3.30	3.07
u	14	2000	60	3.30	103	1000	30	0.34	3.64	3.21

7. ACKNOWLEDGEMENTS

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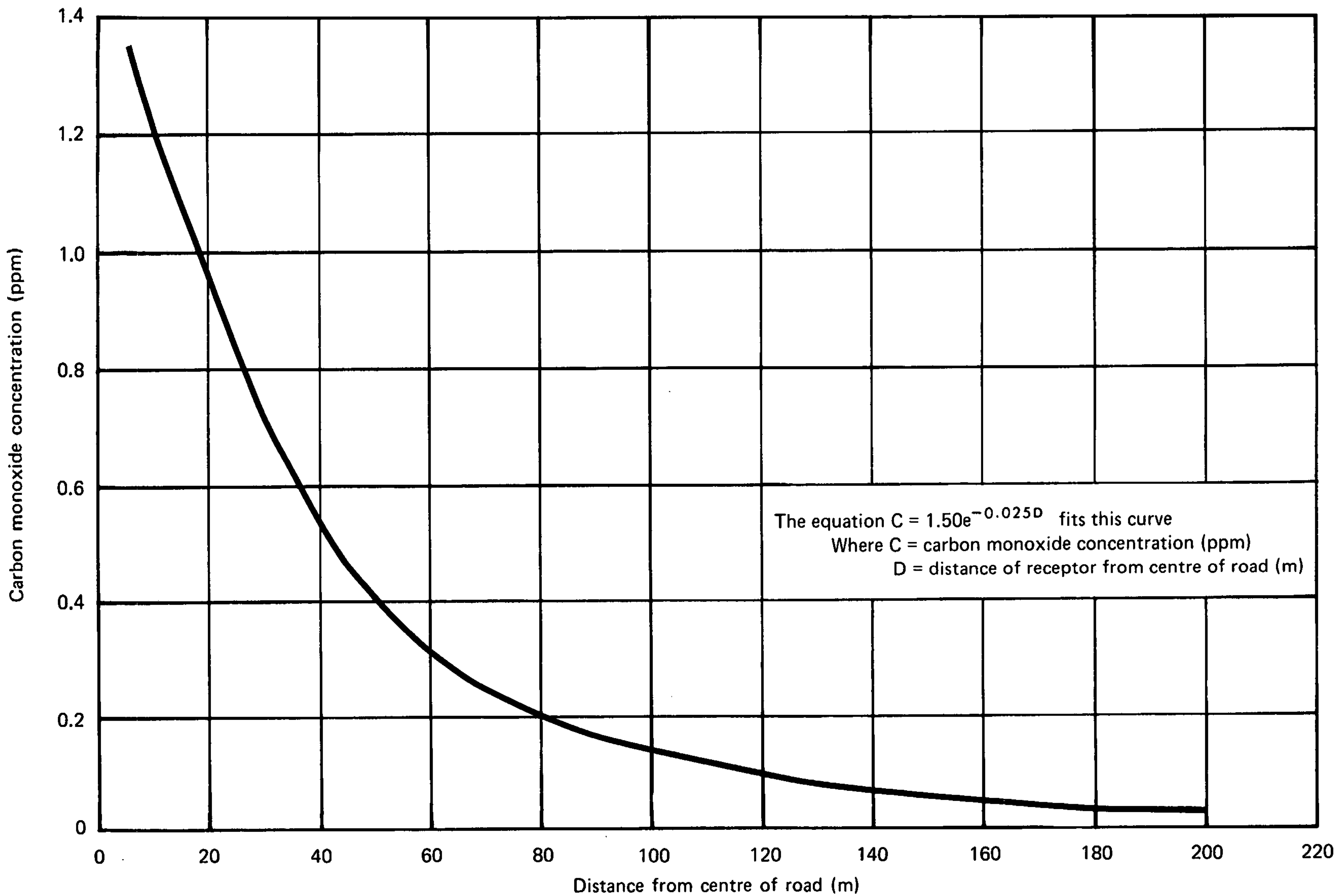


Fig. 1 Carbon monoxide concentration as a function of distance from centre of roads carrying 1000 vehicles/h at 100km/h

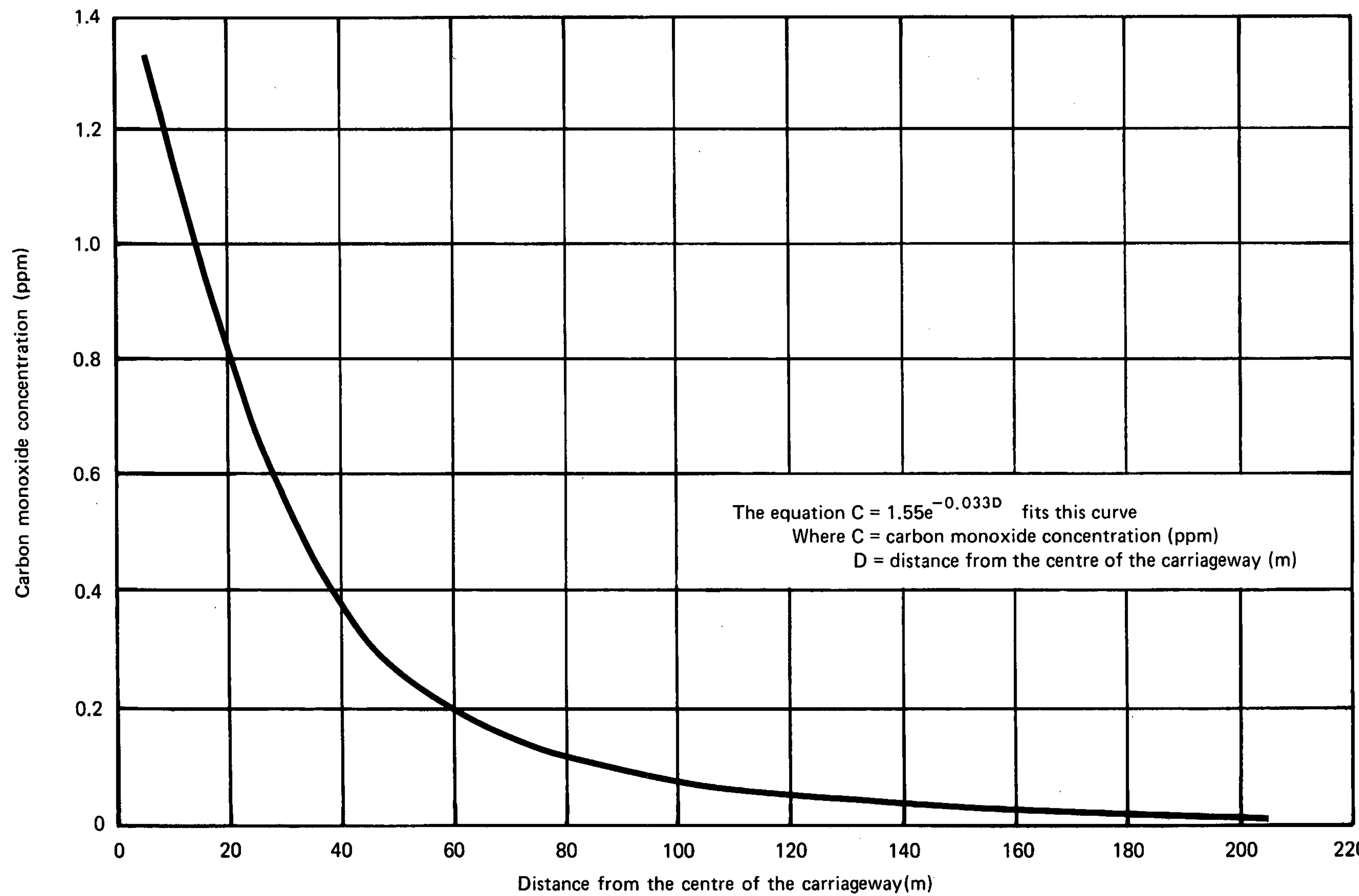


Fig.2 Carbon monoxide concentration as a function of distance from roundabouts carrying 1000 vehicles/h at 100km/h

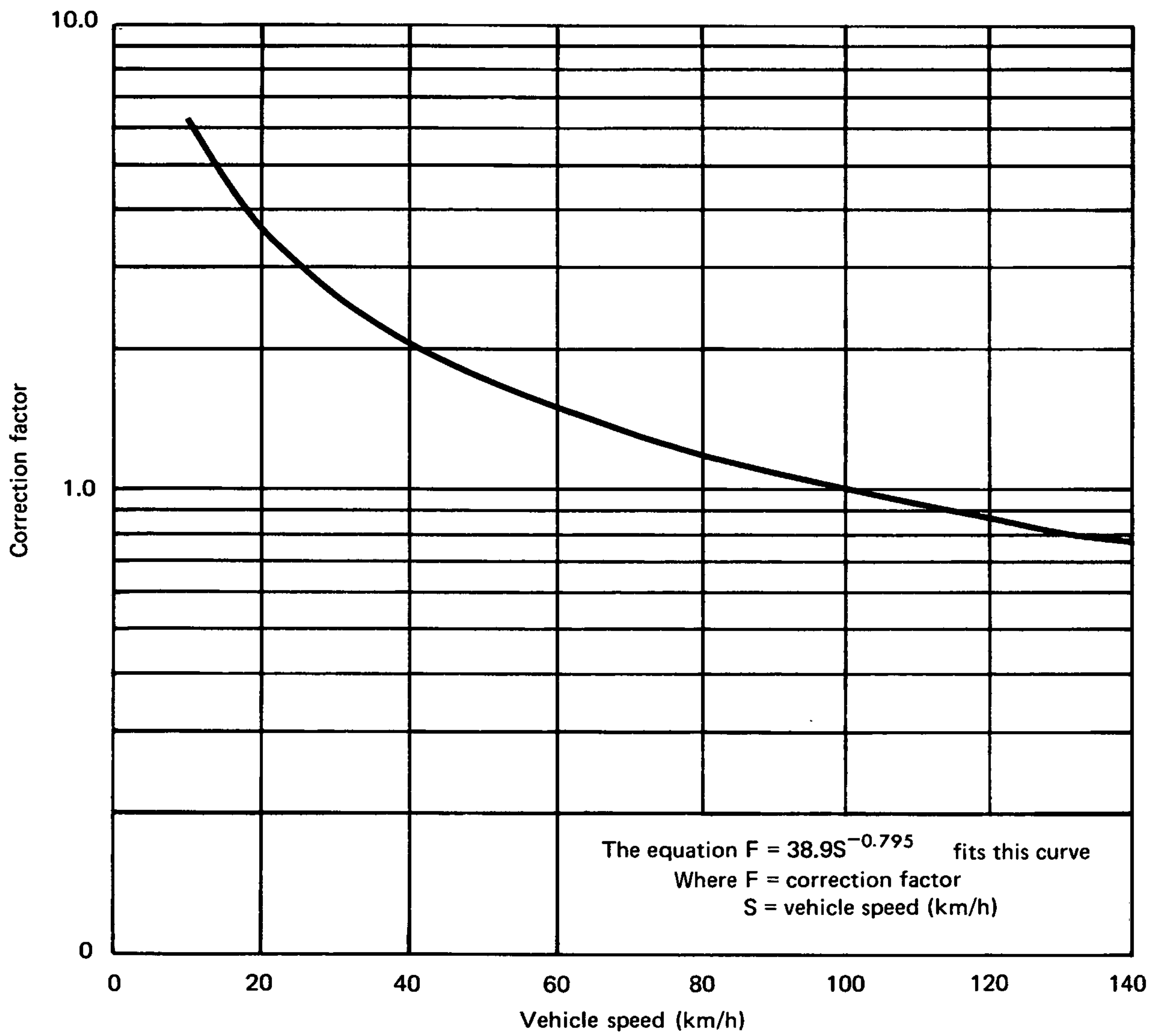


Fig.3 Speed correction factor

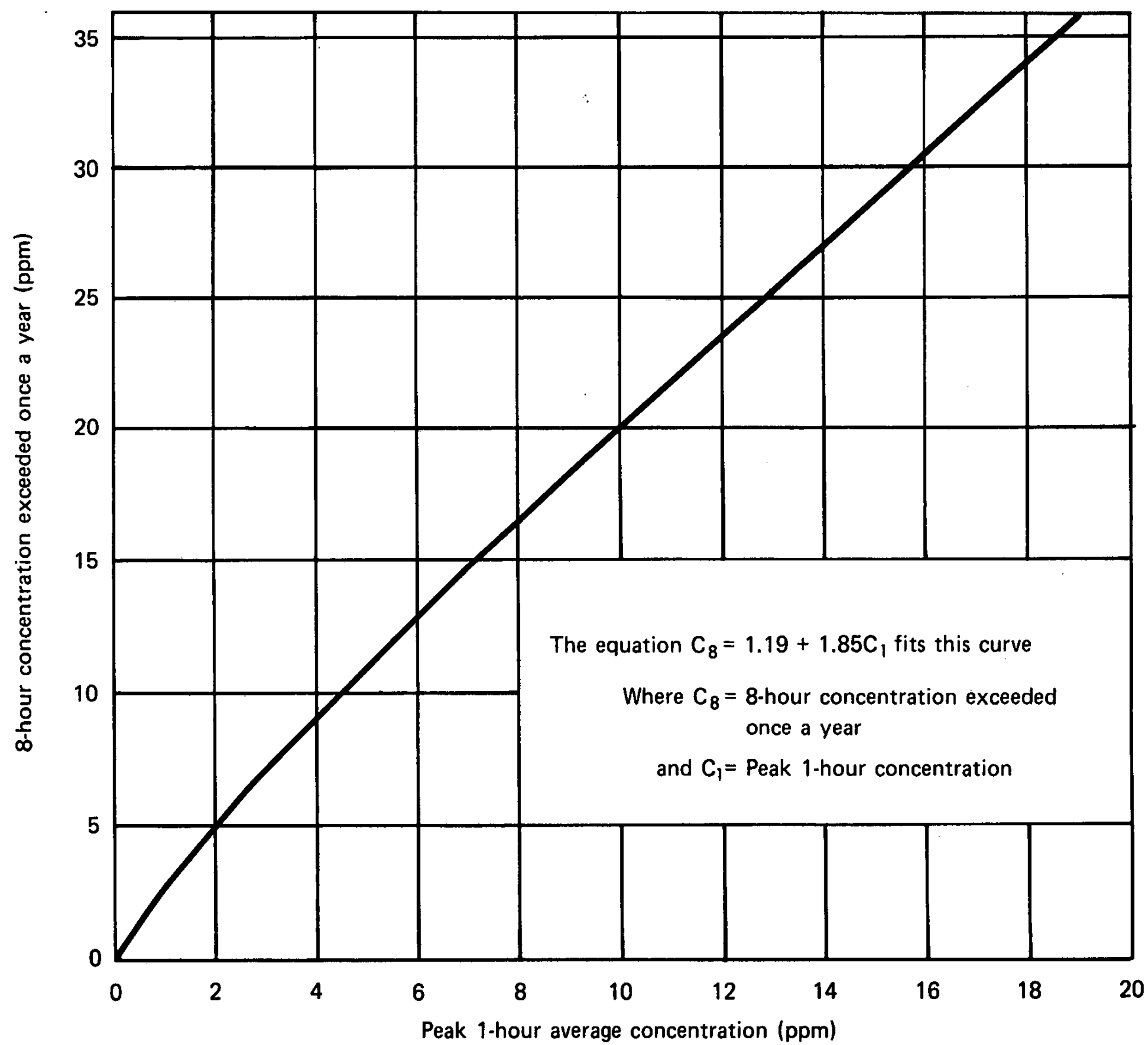


Fig.4 8-hour concentration likely to be exceeded once a year for a range of peak 1-hour average concentrations

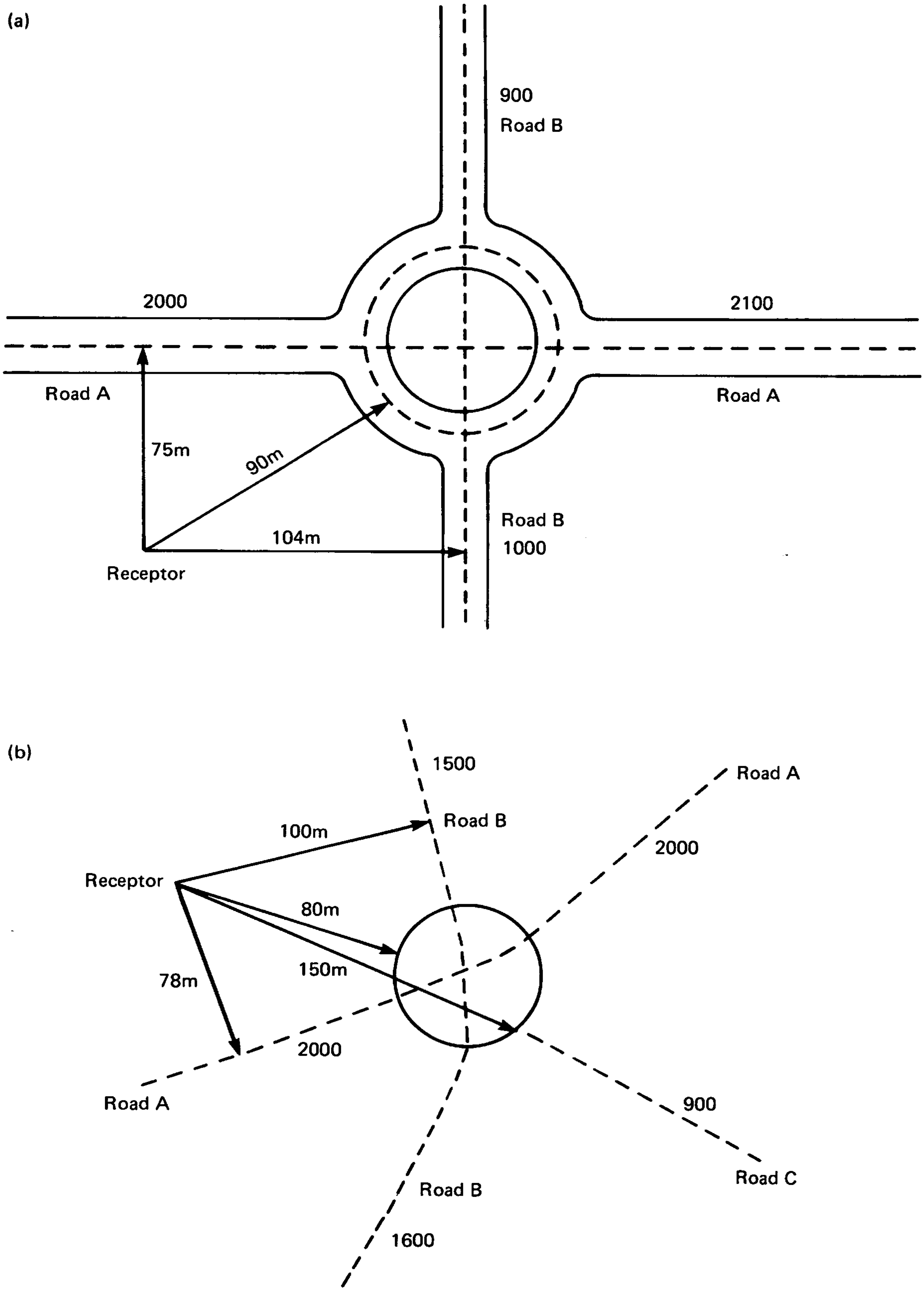
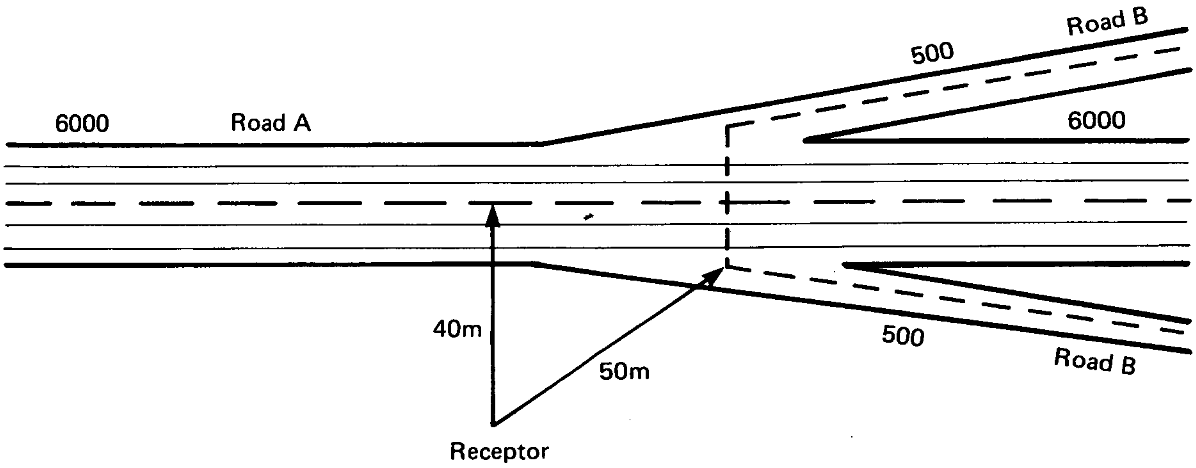


Fig.5 Examples of road designations

(c)



(d)

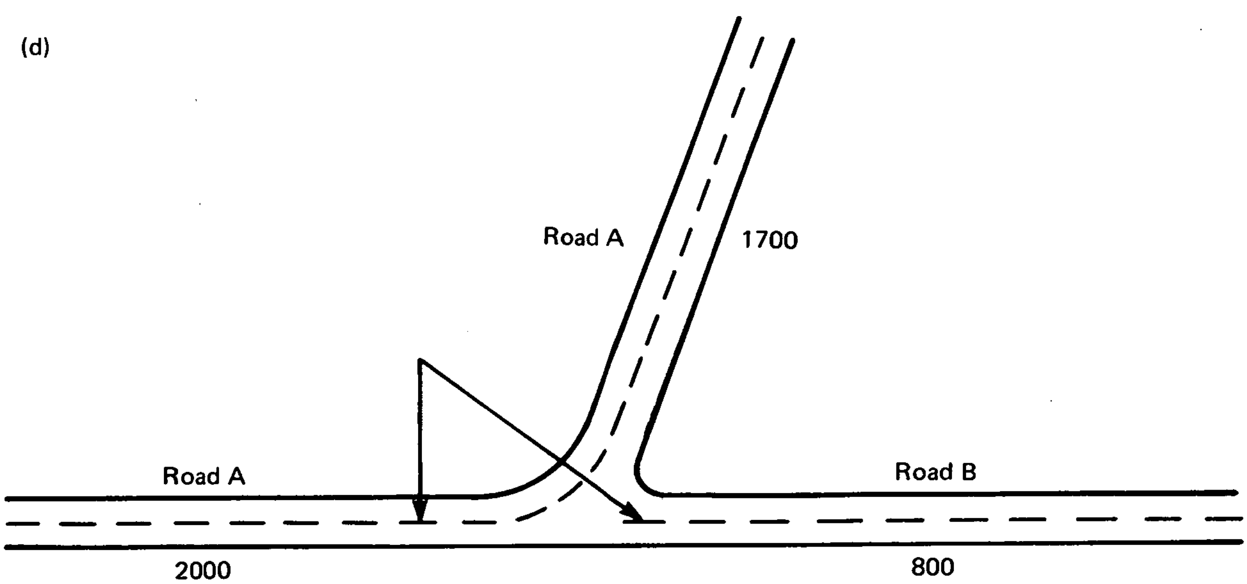


Fig.5 Continued

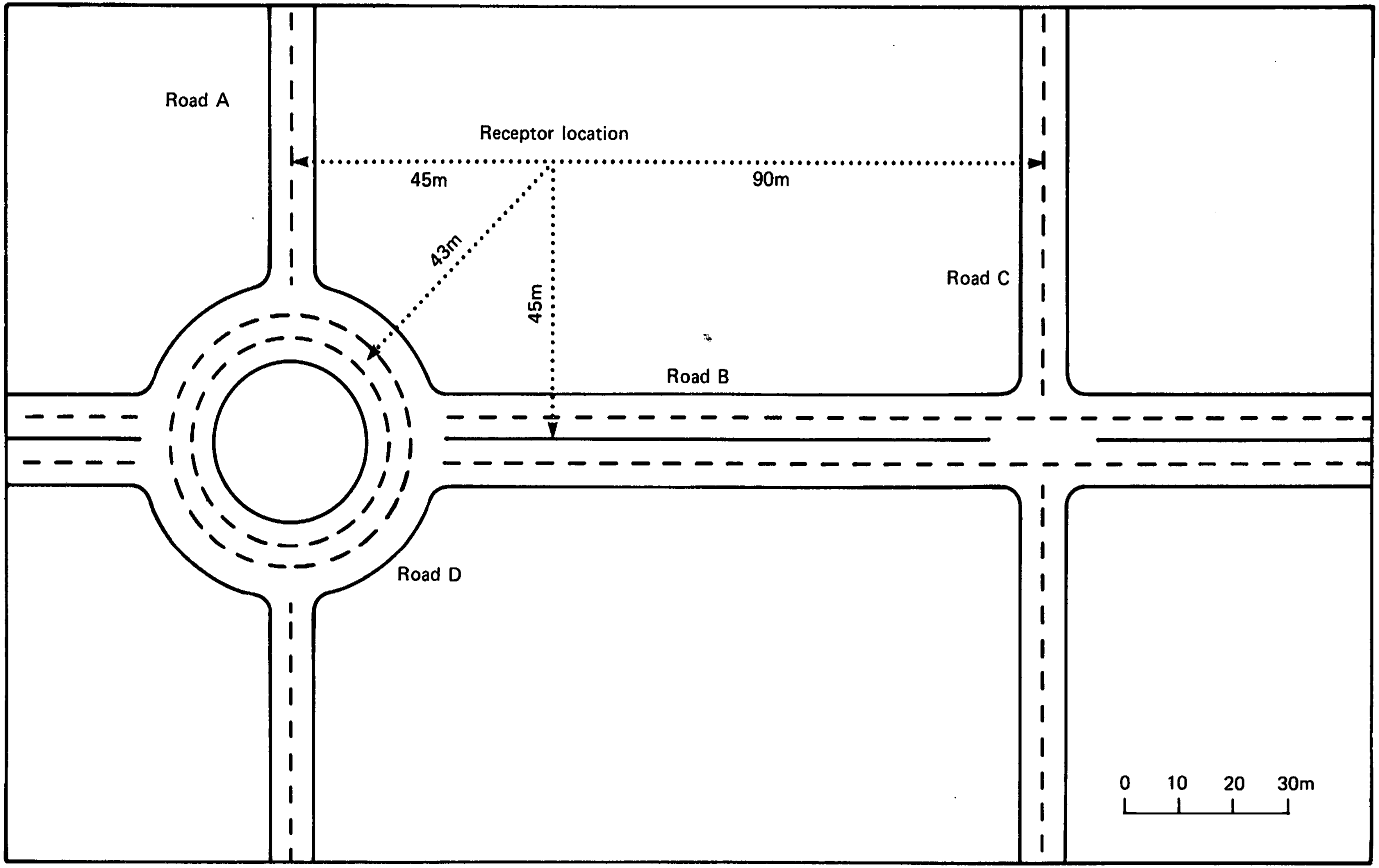


Fig.6 Map of road network for example

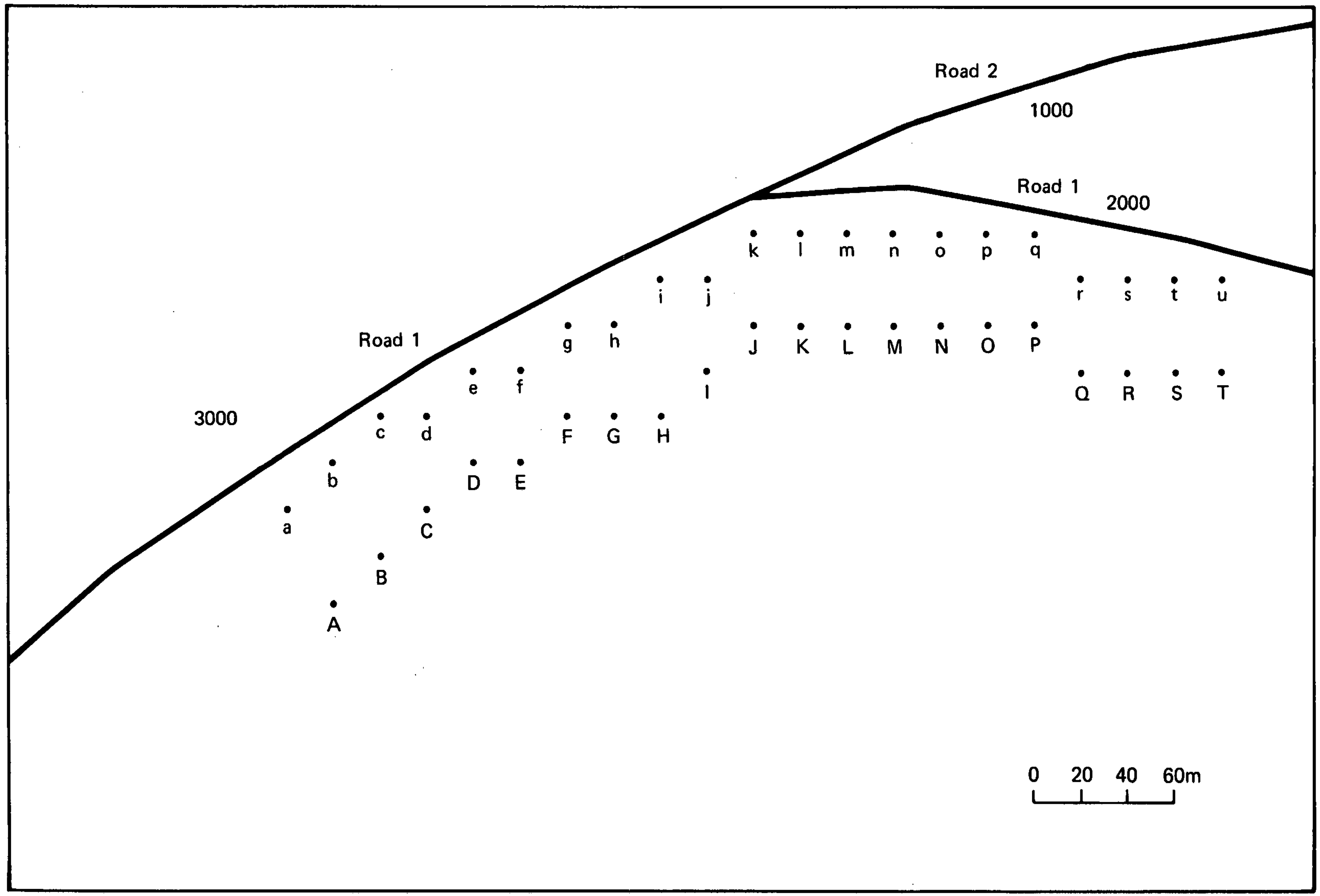


Fig.7 Map of validation exercise for graphical method

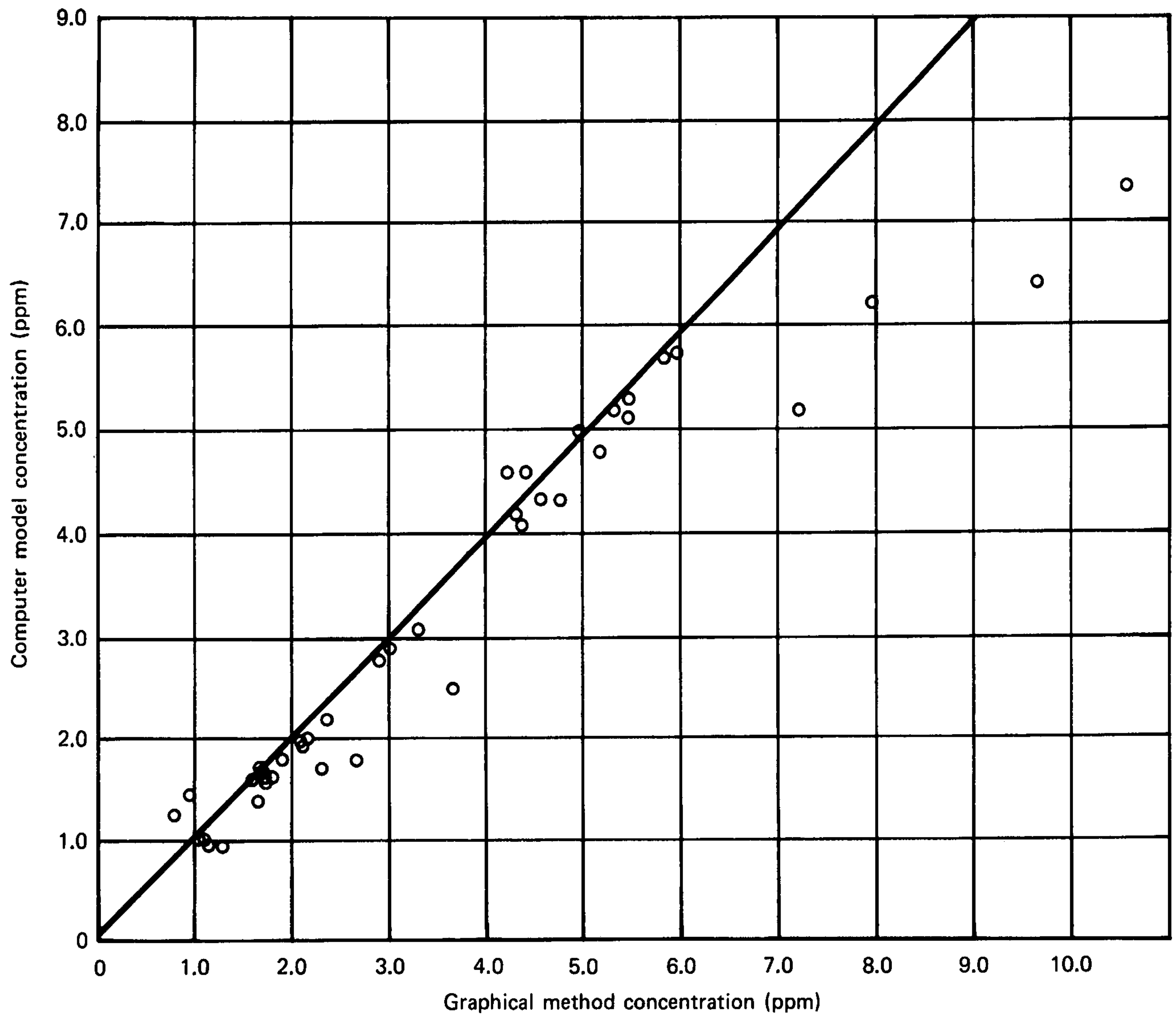


Fig.8 Comparison between results from the graphical method and those from the computer model

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