NILU
OPPDRAGSRAPPORT NR. 6/80
REFERANSE: 21080
DATO: FEBRUAR 1980

COAL FIRED POWER PLANT FECSA/INYPSA
PRELIMINARY SITE STUDY

BY
BJARNE SIVERTSEN

NORWEGIAN INSTITUTE FOR AIR RESEARCH
P.O.BOX 130, N-2001 LILLESTRØM
NORWAY

CONTENTS

COAL FIRED POWER PLAN FECSA/INYPSA
PRELIMINARY SITE STUDY

1 INTRODUCTION

The Norwegian Institute for Air Research (NILU) was asked by Domingo Jiminez Beltran on behalf of FECSA (Fuerzors Electricos de Cataluna S.A.) and INYPSA (an engineering company) to perform preliminary studies of air quality in the surroundings of a planned coal fired power plant in the province of Catalon in Spain. The concentration estimates have been based upon existing data. Evaluations of the meteorological data base and the discussion of alternative sites were also based upon a visit to the area.

The time available for the study has been very short. Detailed discussions of special effects, the impact of toxic metal emissions, secondary pollutants and deposition have thus not been possible.

2 POWER PLANT, EMISSION DATA

2.1 Location

The three alternative power plant sites considered are shown on the map in Figure 1.

Alternative I is located on the coast line about 3 km southeast of L'Ametlla de Mar, 15-20 km north of the Ebro delta. There are no large villages within the nearest 15 km.

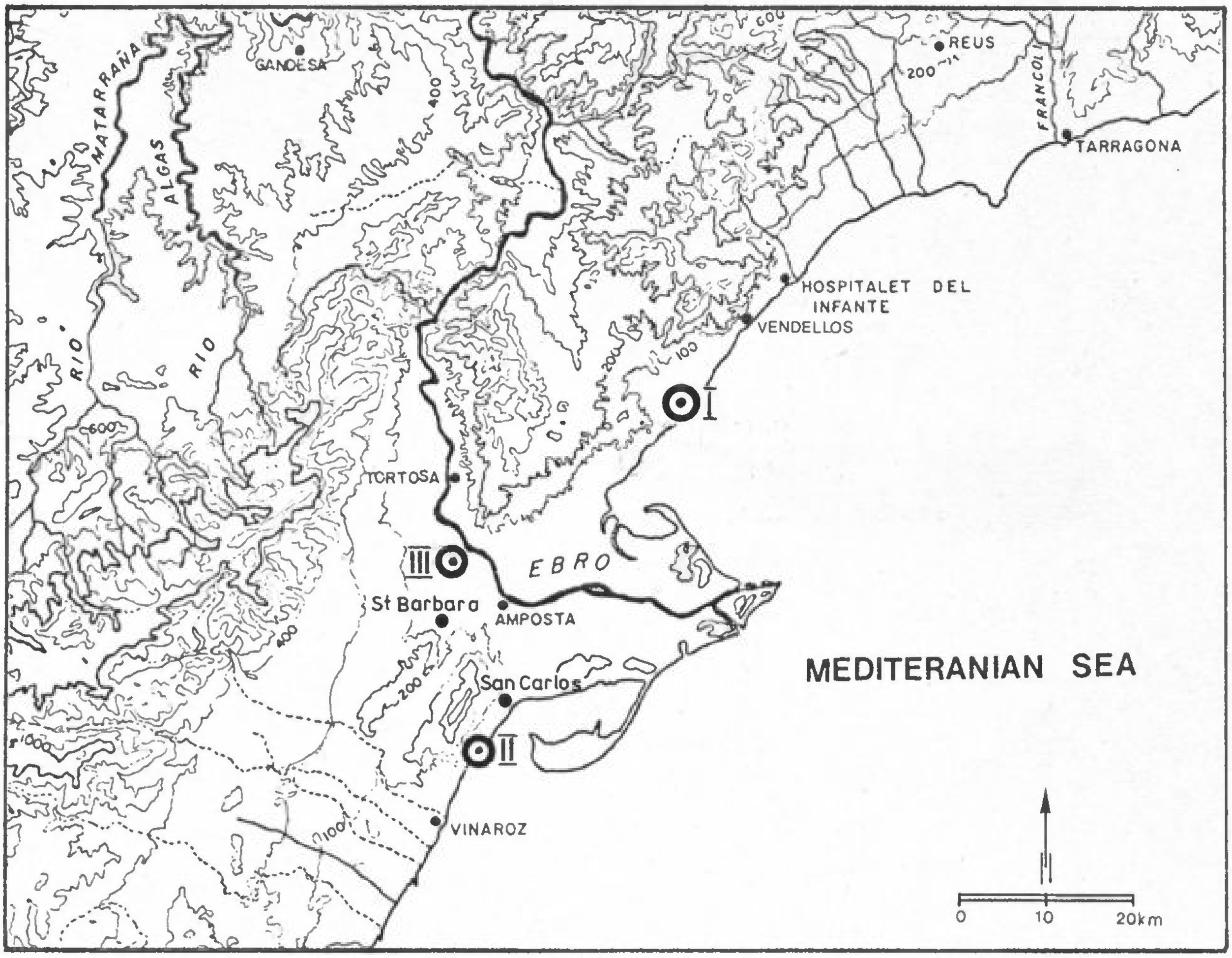


Figure 1: Alternative power plant sites near the Ebro delta.

Alternative II is located south of the delta, about 7 km southeast of San Carlos, and 10 km north-northeast of Vinaroz. The site is located close to a cement plant. It is on the coastline and surrounded by resort areas.

Alternative III is located inland about 10 km east of the delta, 2 km south of the Ebro river. At this site cooling water has to be taken from the river and used in cooling towers. The town of Tortosa (∿40000 inhabitants) is situated 5 km north of this site, and the villages of St.Barbara and Amposta are within 6 km south and southeast of the site.

2.2 Topography at Site I

The influence of topography on the ground level concentrations will probably be more adverse at Site II and Site III, than at Site I. Detailed concentration estimates can, however, not been performed for the Sites II and III during the short time available in this study. Therefore the discussion below only applies to Site I. This site is situated in the south east corner of a fairly large plain. The highest mountains are 600-700 masl about 10 km north and 15 km west of the plant. Figure 2 shows cross sections of the topography in the most important directions from the site.

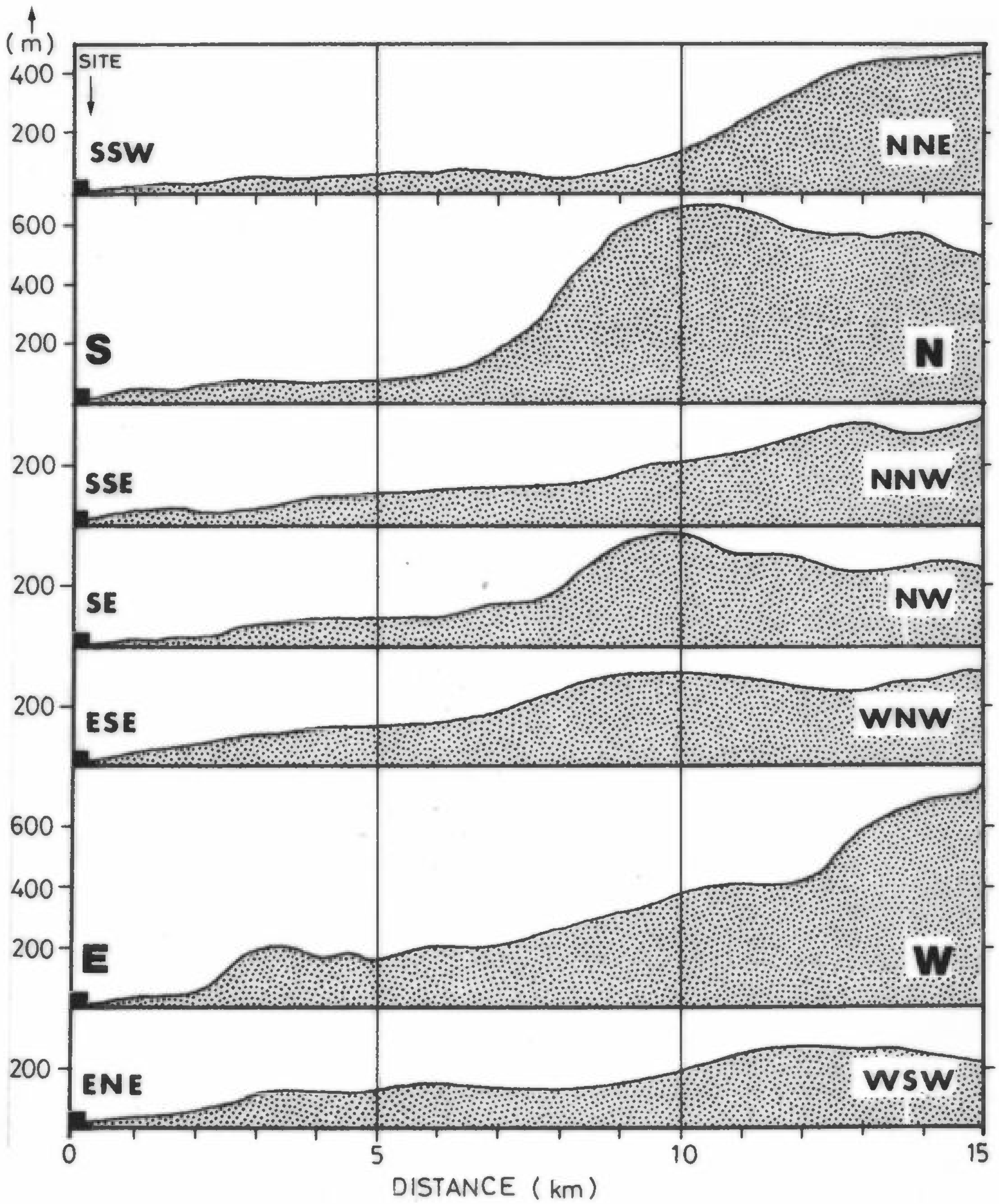


Figure 2: Cross sections of topography in different directions from power plant Site I.

2.3 Emission alternatives

The detailed layout of the power plant has not been finalized. The following basic information was however, provided to perform dispersion estimates. The total capacity of the plant is planned to be 2000 MWe, with four separate units each with a power output of 500 MWe. Imported coal with heat of combustion of 6000 kcal/kg, ash content of 15% and sulphur content of 1% will be used.

The original emission data submitted (1) assumed separate stacks for each unit. The layout sketch indicated a distance of about 100 m between the stacks. Later, one alternative assuming the gas flow from two units into one stack has been included in the concentration estimates.

The emission data from one 500 MWe unit running at 100% load is shown in Table 1.

Table 1: Emission data for one 500 MWe unit.

Gas flow rate:	1,440,000 Nm^3/h
Exit gas temperature:	130 ^oC
SO_2 content:	2,400 mg/Nm^3
Dust content:	150 mg/Nm^3
Gas exit velocity:	25 m/s
Stack diameter:	5.46 m

Calculations have been performed for a power plant consisting of one unit, two units, and four units. A number of alternative stack heights has been included, as shown in Table 2.

Table 2: Alternative power plant size considered in the concentration estimates.

Alternative no.	Number of units	Total power output (MWe)	Number of stacks	Stack height (m)	Total SO_2 emission rate (kg SO_2/h)
1	1	500	1	150	3450
2	1	500	1	200	3450
3	2	1000	2	150	6900
4	2	1000	2	250	6900
5	2	1000	1	200	6900
6	4	2000	4	200	13800
7	4	2000	4	250	13800
8	4	2000	4	300	13800
9	4	2000	2	200	13800

For estimating annual average concentration distributions the power load factor is assumed to be 70% (equivalent 6000 h of operation on full capacity each year).

3 METEOROLOGICAL DATA

Meteorological data were submitted by INYPSA, based upon a study from 1975 (2). It is not clear how these data were collected, or what was the basis for the wind-stability frequency matrix presented in the report. From these data we have, however, developed a frequency matrix applicable to the NILU-type dispersion models. This matrix consist of 16 wind directions (22.5° sectors), four stability classes, and four wind speed classes. The matrix is presented in Appendix A1.

3.1 Surface winds

The total wind direction frequency distribution for the L'Ametlla site (Appendix A) is shown as a wind rose in Figure 3. This wind frequency distribution was suggested to be representative for 8 m above the ground.

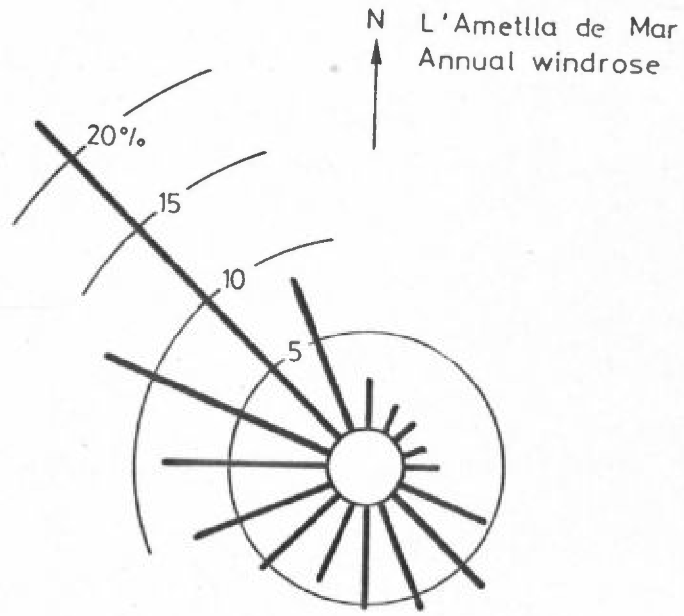


Figure 3: Wind rose for L'Ametlla de Mar as estimated from reference 2. (Annual average.)

The dominant wind direction is from northwest. This wind direction is especially typical during the winter season, and seems to be more prevalent at L'Ametlla de Mar than at weather stations north and south of this area, as shown in Chapter 3.2.

In daytime during the summer season, data from Tortosa (which is situated 22 km east of the site) show that winds from south-east was dominating. Figure 4 shows that these winds, usually associated with seabreeze situations, occurred 50 % of the time observed at 1300 and 1800 hrs during the summers of 1951-60 (3).

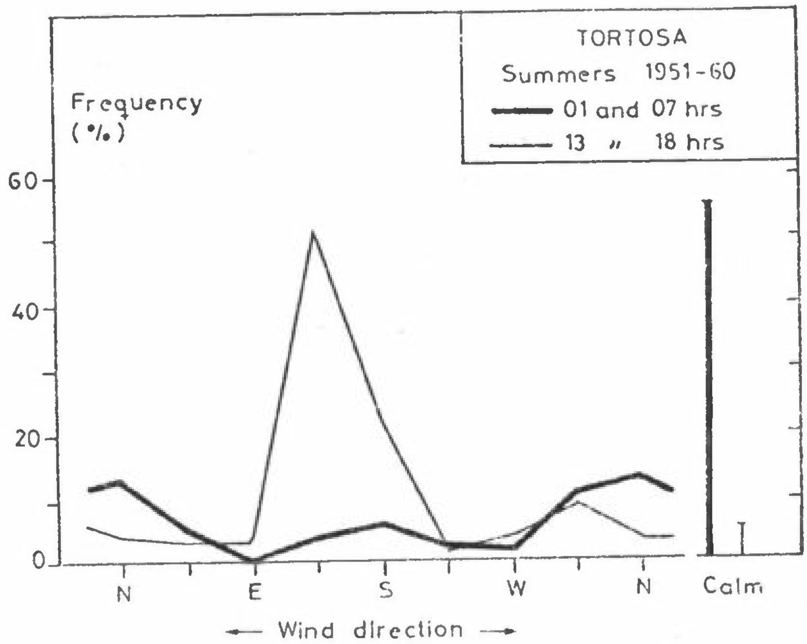


Figure 4: The frequency of wind directions during nighttime hours and daytime hours at Tortosa. (Summers of 1951-60).

On an annual basis, meteorological data from the nuclear power plant at Vandellos during the years of 1969-71 (9) also show a large difference between daytime and nighttime frequency distribution of wind direction (cf. Figure 5).

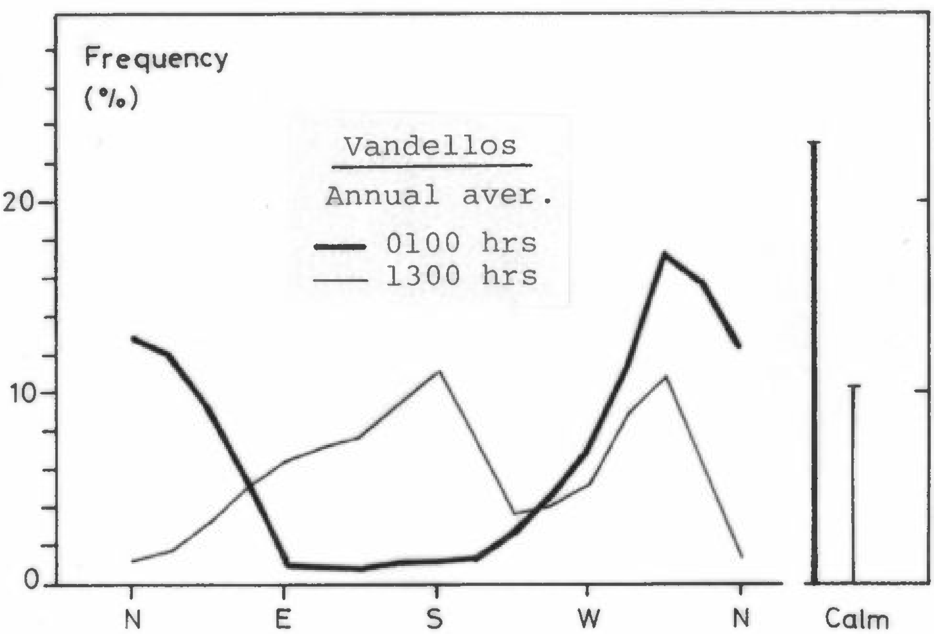


Figure 5: The annual average frequency of wind directions at 0100 hrs and 1300 hrs at Vandellos (data from 1969-71).

The frequency of calm conditions is also much higher at nighttime than during daytime.

The seasonal variation of prevailing wind directions also available from Tarragona observations (4) are presented in Figure 6. They show that north and northwesterly winds are most frequent during the winter season and south and southeasterly winds during the summer.

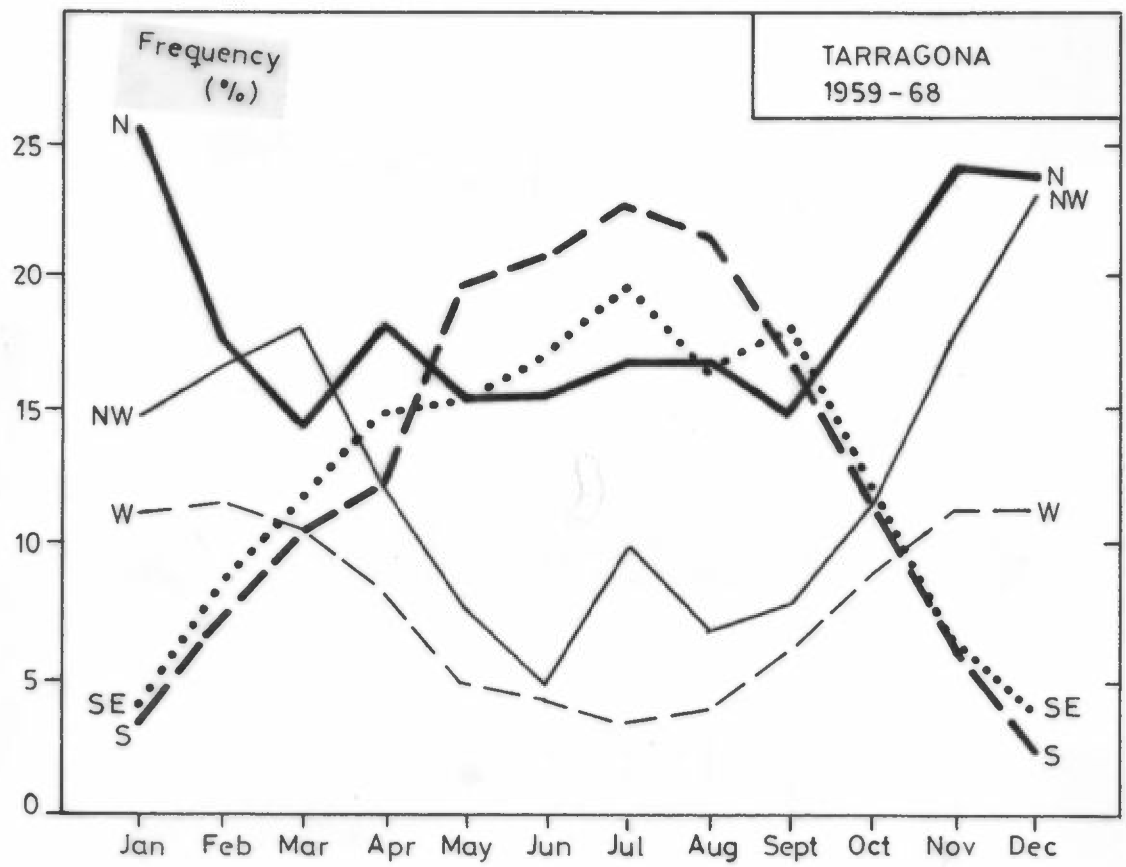


Figure 6: Seasonal variation of the frequency of different wind directions, divided into 8 sectors at Tarragona (1959-68).

On the average the highest wind speeds are observed with winds from northwest and north, as shown for the Tarragona data in Figure 7.

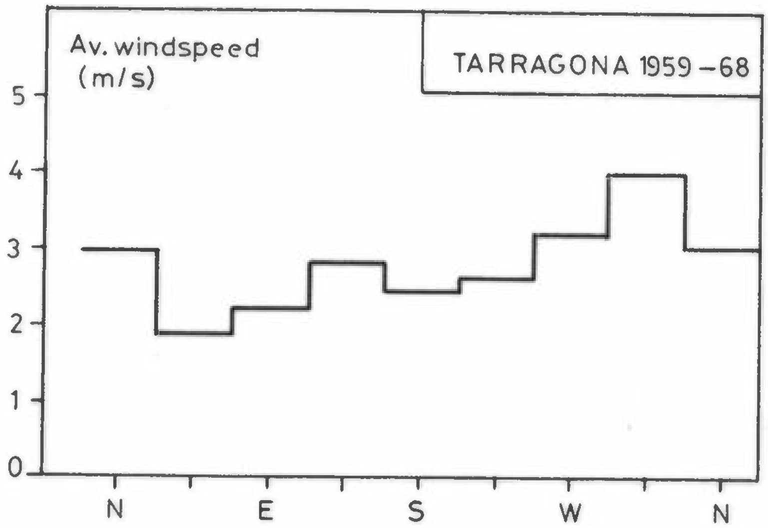


Figure 7: The average wind speed as a function of wind direction at Tarragona. (Annual average.)

This is also the case for the L'Ametlla data, although these data reveal strong winds also from west-northwest and west.

3.2 Upper level winds

Radiosonde and pilot balloon data have been collected at Tortosa since 1924 (3). Wind roses for different altitudes are shown from this study in Appendix B. The wind roses show that above the planetary boundary layer (2000 m level wind), the winds are mainly from west and northwest. At 250 masl there are predominantly northwesterly and northerly winds, with a second maximum from around south east. This is also illustrated in Figure 8 for data from Tortosa collected during 1960 (5).

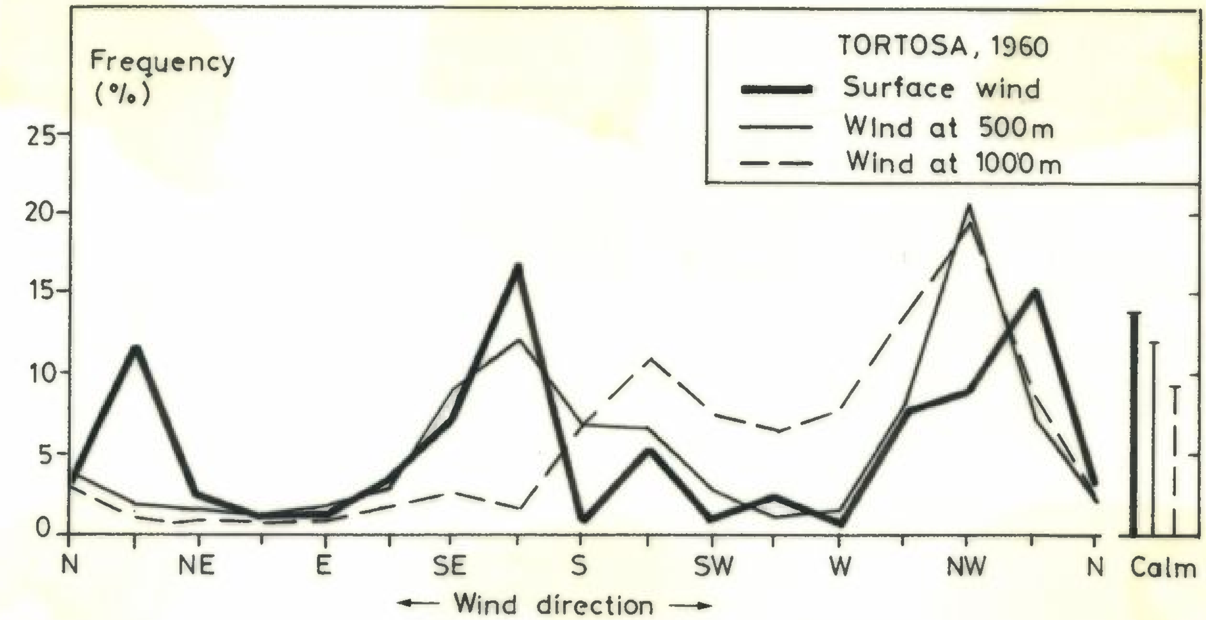


Figure 8: The frequency of wind directions at different levels above the surface at Tortosa.

Figure 8 shows that at the surface the most frequent wind directions were south-southeast, northwest and north-northeast. At 500 masl, winds from southeast still were quite frequent but the dominant wind direction at this level was from northwest. At 1000 masl, winds in the sector from north via east and south appeared very seldom. The most freequent winds were from northwest and from southwesterly directions.

3.3 Representativity of wind data from L'Ametlla de Mar

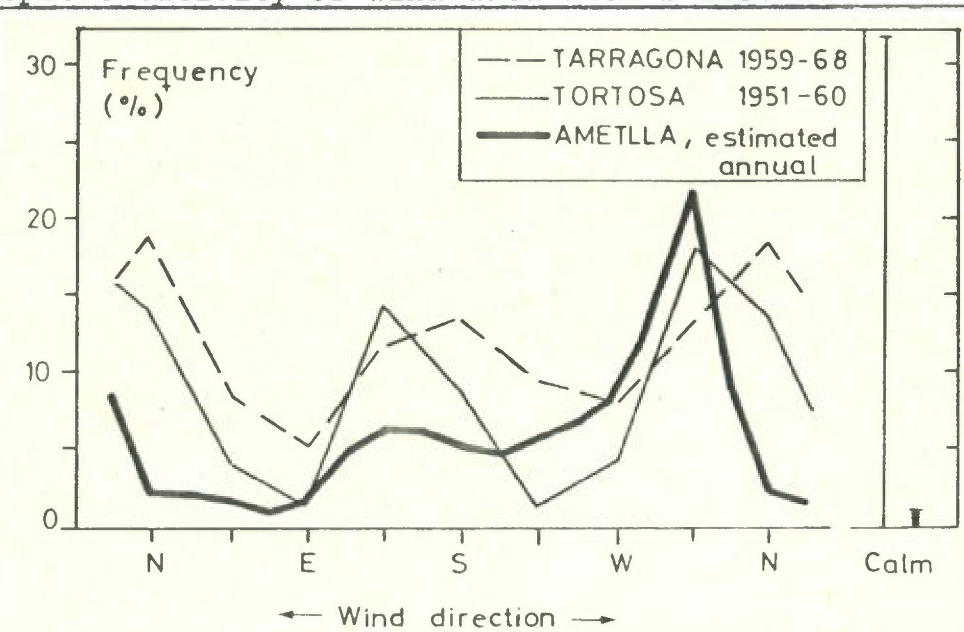


Figure 9: Wind frequency distributions for L'Ametlla and two other sites in the area.

When considering surface winds, it seems from Figure 9 that the frequency of winds from northwest at L'Ametlla was overestimated compared to data from other nearby measuring sites. Both at Tarragona and Tortosa the most frequent winds were from north and northwest,with a second maximum of winds from south and southeast. These south-easterly winds are almost absent in the L'Ametlla data, which would lead to an underestimate of the annual average impact on land compared to what would be brought out over the sea.

When considering the upper level winds in Figure 8 and in Appendix B, it seems that the northwesterly and westerly winds will be dominating at the level of an elevated plume from a large power plant (at 250-500 m). The question remains as to whether the summer season sea breeze regime is deep enough to affect the transport of pollutants at the level of the effective plume height. It is thus a question of the depth of the seabreeze layer in the area, and the channeling of winds from the Ebro valley across the plain northwest of the L'Ametlla site. A thorough discussion of the representativity of the wind data used in the dispersion estimates would require a better knowledge of these phenomena.

3.4 Stability

The stability data in the frequency matrix (Appendix A) used for estimating annual average concentration distributions was based upon Pasquill Gifford stability classification.

Figure 10 presents the frequency of unstable (A, B and C classes) and stable (E and F classes) as a function of wind directions at L'Ametlla.

Unstable cases occur most often when the wind is from northwest, while the stable cases are more evenly distributed among all wind directions, except winds from north and northeast.

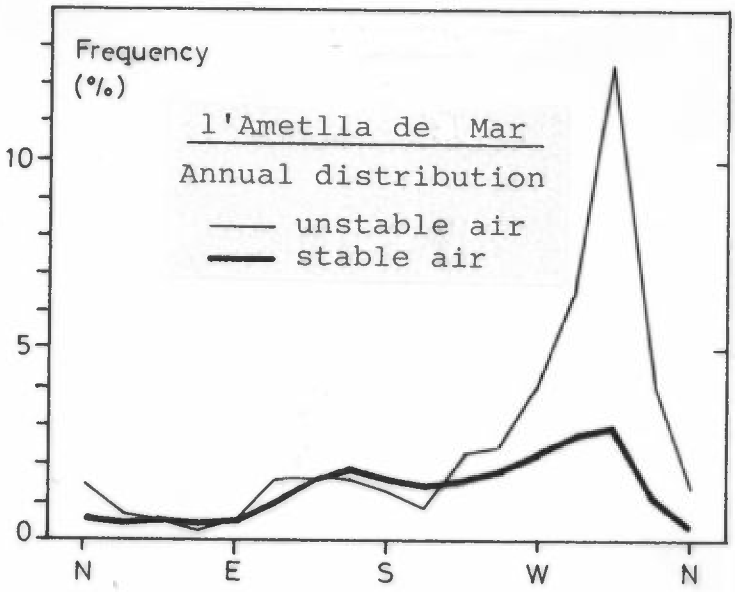


Figure 10: Frequency (in %) of unstable (A,B and C) and stable (E and F) cases as a function of the wind direction at L'Ametlla (annual average distribution).

4 CONCENTRATION ESTIMATES

Calculations of ground level concentrations have been performed using Gaussian type dispersion models. A description of the models is presented in Appendix C.

The dispersion parameters used for the estimates presented here were developed by Singer and Smith (6). These parameters are applicable to tall stack emissions transported and dispersed across flat, homogeneous land with a typical surface roughness length of about 0.3 to 0.5 m. Other dispersion parameters have also been applied. Parameters developed by Vogt (7), also for tall stacks but for larger surface roughness, give somewhat higher maximum ground level concentrations. The average surface roughness of the land surrounding Site I was jugded to be appropriate for applying the Singer and Smith parameters.

For estimating plume rise due to exit gas velocity and heat output, the Briggs formulas for different stabilities were used (8).

4.1 One-hour average concentrations of SO_2

Estimated one-hour average ground level concentrations of SO_2 are presented for the different alternatives in Appendix D. These calculations were based upon assumption of flat, homogeneous terrain. Topographical features or fumigation cases have not been considered.

Table 3 summarizes the results of the calculations presented in Appendix D.

Table 3: Maximum one-hour average ground level concentrations of SO_2, meteorological conditions, and distance to the maxima for different power plant alternatives for the SO_2 emission rates (given in Table 2).

Alt. No.	Number of units	Total power (MWe)	Stack height	Number of stacks	One hour aver. max. gr.level concentration ($\mu g\ SO_2/m^3$)	At distance (km)	Wind speed (m/s)	Stability
1	1	500	150	1	230 180 ≃ 830	1.8 6.3 ≃ 12	6 5 3	unstable neutral sl. stab.*
2	1	500	200	1	140 110	2.6 8-10	5 4-6	unstable neutral
3	2	1000	150	2	460 360	1.8 4-6	6 5	unstable neutral
4	2	1000	250	2	200 150	3 ≃ 10	4-6 3-6	unstable neutral
5	2	1000	200	1	220 180	2-3 7-10	5-9 4-8	unstable neutral
6	4	2000	200	4	560 440 ≃ 300	2-3 8-9 ≃ 15	4-6 4-5 6	unstable neutral sl. stab.*
7	4	2000	250	4	390 300	≃ 3 ≃ 10	≃ 5 4-5	unstable neutral
9	4	2000	200	2	450 350	≃2.5 8-10	6-8 4-7	unstable neutral

* estimates are uncertain at this distance. (sl.stab. = slightly stable conditions)

Based upon the emission data given in Section 2.3, the results of these estimates can also be summarized as follows:

- For one unit of 500 MWe, it is sufficient to build a 150 m high stack to avoid ground level concentrations higher than 200-300 µg SO_2/m^3.
- A power plant of 1000 MWe, with one stack for each unit of 500 MWe, needs 250 m tall stacks to avoid maximum ground level concentrations of more than 200 µg SO_2/m^3.
- For a 1000 MWe power plant with <u>one</u> 200 m tall stack, the maximum ground level concentration is estimated to reach ≃ 200 µg SO_2/m^3.
- A 2000 MWe coal fired power plant, with one 250 m stack for each of 4 units, might lead to ground level concentrations near 400 µg SO_2/m^3.
- Emitting of the warm effluents from two units through one stack will increase the plume rise. This results in a reduction of the ground level concentrations from a 200 m high stack by about 20%. On the other hand, will emissions from two stacks give an initial spread of the plume, which is not considered in the estimates.

The maximum ground level concentrations are likely to occur at distances of between 2 and 10 km for average wind speeds ranging from 3 to 8 m/s. These wind speeds are frequently occuring in the area.

4.2 Annual average concentrations of SO_2

For estimating annual average concentration distribution of SO_2, the frequency matrix in Appendix A1 has been applied. Topographical features have been taken into account to a certain degree (see Appendix C, ch. 4.1.)

A typical concentration distribution pattern, presented in Figure 11, shows that the highest annual average concentrations will occur over the sea, on the Golf of San Jorge. The annual

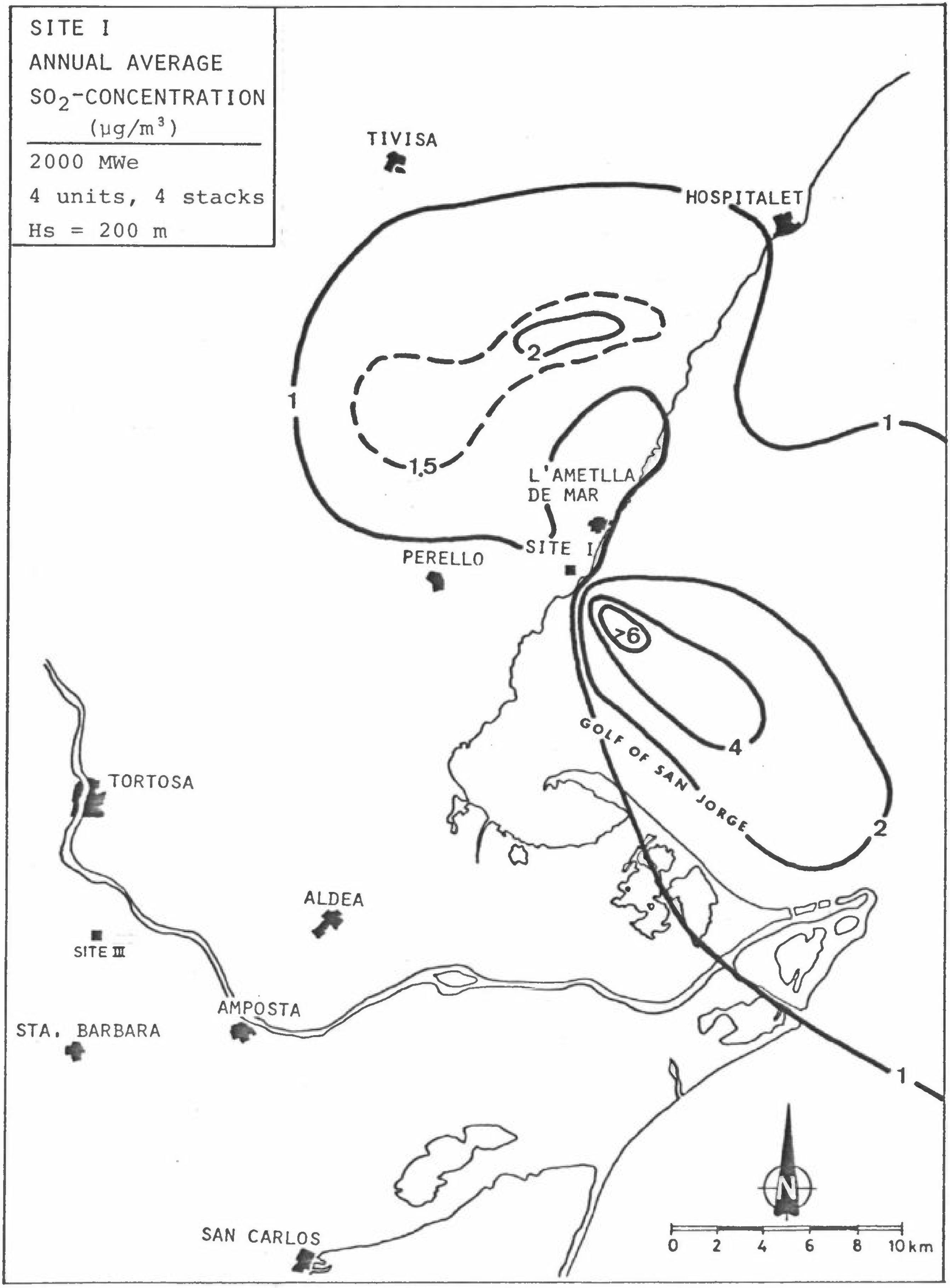


Figure 11: Annual average ground level concentrations of SO_2 ($\mu g/m^3$) for emissions from a 2000 MWe power plant with four 200 m high stacks.

average ground level concentrations on land are estimated to be less than 2 µg SO_2/m^3, except in the mountains ≃ 10 km north of a 2000 MWe power plant at Site I.

The annual average concentrations estimates are based upon the asumption of a homogeneous, stratified atmosphere all through the layer of dispersion. This might lead to an underestimate of concentrations as inversions above mixing heights and fumigation during inversion break up were not included. The underestimate should, however, be within a factor of 2.

4.3 Summer average concentrations of SO_2

A summer average frequency distribution of wind and stability is presented in Appendix A2, based upon three years of data from Vandellos (9). Estimates have been carried out to illustrate the higher impact on land during the summer season. An example for a 2000 MWe power plant at maximum load is presented in Figure 12.

The average concentrations during the summer might be higher than 3 µg SO_2/m^3 two to four km west of the plant at Site I and in the mountains ≃ 10 km north of Site I.

The above comments on the possible underestimate of annual average ground level concentrations in Section 4.2 also apply to the summer average concentrations.

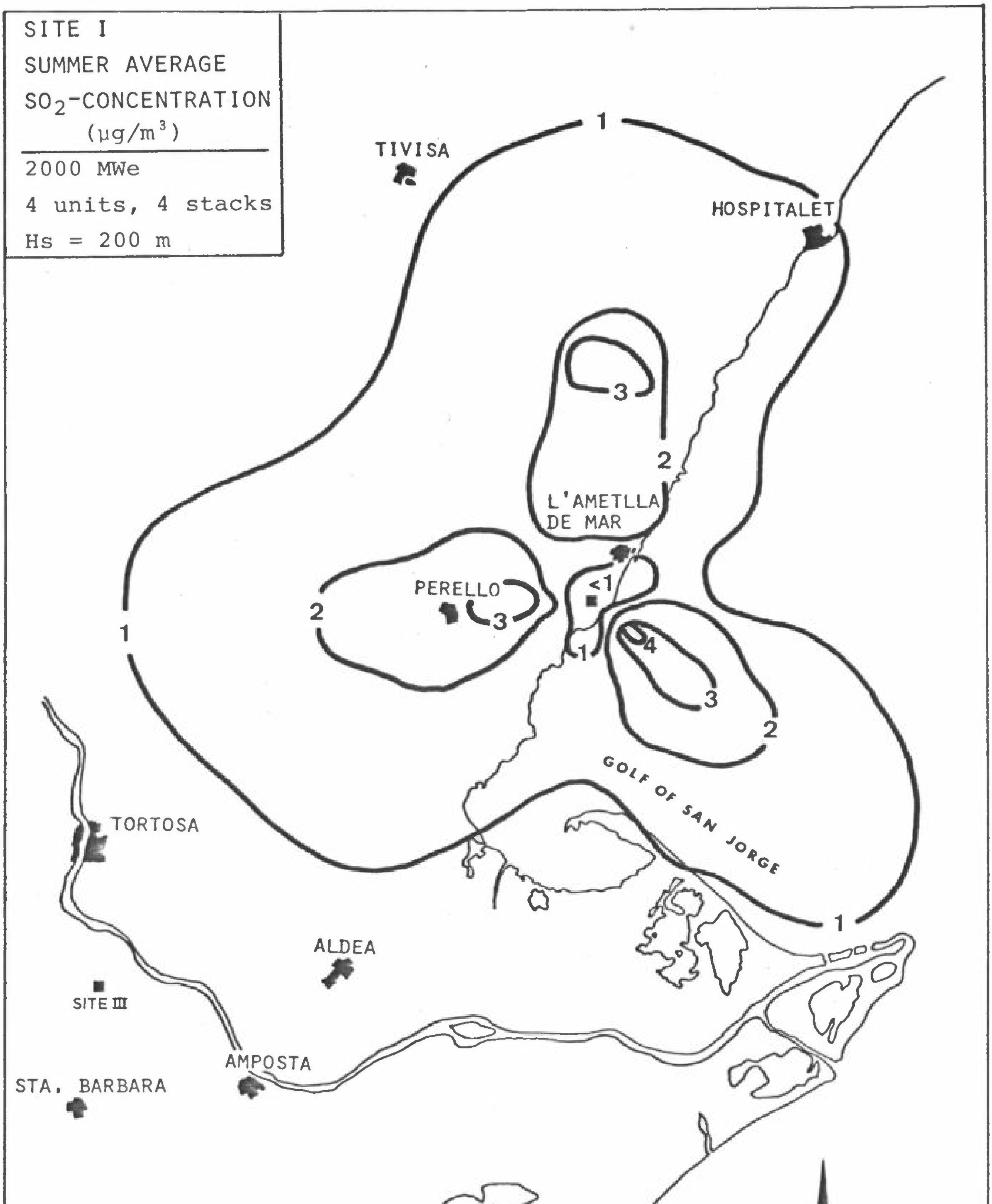


Figure 12: Summer season average ground level concentrations of SO_2 ($\mu g/m^3$) for emissions from a 2000 MWe power plant with four 200 m high stacks.

4.4 Maximum concentrations during sea breeze fumigation

A simple Gaussian type "sea breeze fumigation" model, used for estimating maximum ground level concentrations during these cases, is presented in Section 4.2 of Appendix C.

Results of estimates for a 250 m high stack are summarized in Table 4.

Table 4: Short term maximum ground level concentrations of SO_2 during sea breeze fumigation.

Power output (MWe)	Stack height (m)	Wind speed (m/s)	Maximum gr.level conc. ($\mu g\ SO_2/m^3$)	Distance to max. (km)
500	250	3	350	8
1000	250	3	700	8
2000	250	3	1400	10
		5	1000	10
		8	700	14

The estimates show that for a 1000 MWe power plant the maximum short term ground level concentrations might be as high as 700 $\mu g\ SO_2/m^3$ at maximum load. This maximum could occur at a distance of ≈ 8 km for a 3 m/s wind. As this situation is a transient one, the typical averaging time at a specific receptor point is about 5-20 minutes.

The ground level concentration at 5-10 km from a 2000 MWe power plant with 250 m tall stacks during sea breeze fumigation might exceed 1000 $\mu g\ SO_2/m^3$.

The total frequency of such high concentration situations was estimated to be between 2 and 5% of the time during the summer season. This was based upon the assumption that the stable cases with winds from around south and east (E+ESE+SE+SSE) at Vandellos, were occurred during sea breeze situations.

The estimated frequency is also in accordance with earlier investigations at an inland site in the northeastern part of Spain (10).

The frequency of occurence of the maximum ground level concentration during fumigation at one specific receptor point (as given in Table 4) will be much less than the total frequency of the sea breeze situations.

4.5 Concentrations of NO_2 and suspended particulates

Assuming that the EPA emission standards for nitrogen oxides (NO_x) are not violated, the following conclusions can be made for the maximum short term concentrations of NO_2. For a 2000 MWe power plant with 250 m high stacks, the maximum ground level concentrations of NO_2 will not exceed 170 $\mu g\ NO_2/m^3$. The background ozon level in the area was assumed to be more than 120 $\mu g\ O_3/m^3$, and the "Ozone Limiting Method" has been used for these estimates (11). At a 1000 MWe power plant, the maximum ground level concentrations were estimated to be less than 140 $\mu g\ NO_2/m^3$, even during sea breeze fumigation.

The short term concentrations of total suspended particulates assuming that filtering- or other cleaning equipment works perfect, will be less than 80 $\mu g/m^3$ for the worst meteorological case at a 2000 MWe plant with 250 m high stacks. It will be more interesting, in the future, to evaluate the impact of specified toxic elements.

4.6 Deposition of sulfates

The highest annual average dry deposition of sulfates on land has been estimated to occur about 8-10 km north and north east of Site I. This annual dry deposition rate will not be larger than 1 g SO_4/m^2.

5 DISCUSSION OF ALTERNATIVE SITES

The annual average concentration distribution, as presented in Figure 11, expresses the combined probability for the occurrence of high concentrations and high frequency of occurrence in the areas surrounding the power plant site.

If applying this concentration distribution (i.e. the same meteorological and topographical matrix as for Site I) as a first approximation of a siting index, the following comments can be made for Site II and Site III.

At Site II more people will be in areas where high concentrations occur frequently. The villages of Ulldecona and St. Barbara are also within the areas that might experience the sea breeze fumigation cases.

From an air pollution point of view, Site III is considered the least favorable. The highest ground level concentrations will occur at Tortosa during the summer season. On an annual average basis, villages such as Amposta, St. Barbara and San Carlos will be within the area of maximum ground level concentrations. The impact on the agricultural areas in the Ebro delta will also be considerable.

6 FUTURE ENVIRONMENTAL IMPACT STUDIES

This chapter very briefly outline some of the investigations which must be carried out to prepare a final environmental impact statement.

6.1 Emission data

A detailed inventory of future emissions has to be prepared. These data should contain information about:

- coal quality: heat of combusion
  particle size distribution
  the content of toxic trace elements
  sulfur, fluorides
- coal unloading and storage facilities
- plant layout, boilers, stack dimensions, gas flow rates, temperatures, etc.
- fractional efficiency of air pollutant control devices.

Information about other sources of air pollutants in the area should also be available.

6.2 Meteorological data

Meteorological data relevant for the dispersion of air pollutants from the surface and from high stacks at the sites should be collected. Available meteorological data from Vandellos and Tortosa could be used to establish annual and seasonal average frequency distributions of wind and stability. The representativity of these data should be investigated from data collected simultaneously at the site during short periods.

The frequency and the characteristics of the stable sea breeze regime (height, wind speed, wind direction, duration etc.) should be investigated.

6.3 Background air quality

Information about the background air quality in the area must be collected. This information should contain:

- average and maximum levels of SO_2, suspended particulates (size distribution, content of trace elements), nitrogen oxides and ozone;

- deposition of trace elements on vegetation and other surfaces;
- possible pre-existing vegetation damage.

6.4 Model calculations

Models applicable for the actual area should be prepared to perform estimates of:

- necessary stack heights;
- concentration distributions due to release of air pollutants during normal operation;
- accidental releases of pollutants;
- deposition patterns due to resuspension of dust from coal storage areas

6.5 Population distribution and area disposition

Present and projected population distributions for the area should be available. A mapping of land use and area disposition plans should be prepared. Background information about agricultural activities, crops, etc. is needed when estimating economical impact.

7 COMMENTS AND CONCLUSIONS

The estimates of ground level concentrations have been obtained with Gaussian type dispersion models. When discussing the results of these estimates, all the reservations and limitations presented in Appendix C6 have to be considered.

The estimates for emissions from more than one unit are considered to be conservative. The reason for this is that: 1) The initial spread of pollutants due to the physical distance between 2 or 4 stacks is not taken into account. All emissions have been assumed to be emitted from one stack. 2) The additional plume rise due to multiple stacks is not considered. The plume rise is estimated as if emitted from one unit only.

The effect of combining the exit gases from two units into one stack to increase the plume rise has been estimated. The impact on the ground level concentrations was not considerable, however, as long as the height of the two stacks were as high as about 200 m.

The estimated long term (annual and summer) average concentrations might have been somewhat underestimated, due to the fact that sea breeze fumigation cases and trapping of pollutants beneath a mixing height inversion have not been included.
With these comments in mind, the following conclusions can be made:

- From an air pollution point of view, Site I), at L'Ametlla de Mar, seems to be the best location for a coal fired power plant among the three sites considered.
- Maximum one-hour average SO_2 concentrations at ground level seem from this preliminary siting study to be the limiting stack height design criteria.
- To comply with internationally accepted air quality criteria for SO_2, the stack heights at the planned coal fired power plant must at least be:

  150 m for one unit of 500 MWe
  200 m for two units (total 1000 MWe)
  250 m for four units (total 2000 MWe)
- One can not, however, avoid high short-term ground level concentrations during adverse meteorological conditions (e.g. sea breeze fumigations). The probability of these cases should be investigated in more detail.
- The estimated annual and seasonal average concentrations of SO_2 were well below accepted air quality criteria, if the stack design was based upon the criteria for one hour average maximum ground level concentrations.

8 REFERENCES

(1) Jiminez, D. — Basic data for dispersion estimates letter to NILU, dated 18 January 1980.

(2) Meteorologia del Emplazamiento de la Central Nuclear de Ametlla de Mar. INYPSA Report. Madrid 1975.

(3) Rodés, L. — Contribucion al Estudio Climatologico de la Comarce de Tortosa, Resumen 1910-1934. Boletin *del Observatio del Ebro*, Vol. XXV-Fasciculo 2, Meteorologia, Tortosa 1936.

(4) INTECSA — Estudio de vientos en las estaciones de Tarragona y Reus. INTECSA Report. Madrid 1974.

(5) Boletin *del Observatio del Ebro*, 1960. Vol. XLVIII, Meteorologia 1967.

(6) Smith, M.J. — Recommended quide for the prediction of the dispersion of airborne effluents. New York, ASME 1968.

(7) Vogt, K.J. — Empirical investigation of the diffusion of waste air plumes in the atmosphere. *Nuclear Techn.* 34, 43 (1977).

(8) Briggs, G.A. — Plume rise. A recent critical review. *Nuclear Safety*, 12, 15-23 (1971).

(9) Meteorological data of Vandellos (168-1974). P.S.A.R. for Vandellos II Power station. Barcelona 1977.

(10) Sivertsen, B. Meteorological investigations at the Teruel power plant site. Lillestrøm, Norway, Norwegian Institute for Air Research 1979. (NILU OR 45/79.)

(11) Cole, H.S. Summerhago, J.E. A review of techniques available for estimating short-term NO_2-concentrations. *J.Air Poll. Contr. Ass.* 29, 812-817 (1979).

APPENDIX A

WIND STABILITY FREQUENCY MATRIX

A1: Annual averages at L'Ametlla de Mar

A2: Summer averages at Vandellos

Table A1: Annual average distributions at L'Ametlla de Mar.

Wind speed →	0-2 m/s				2-4 m/s				4-6 m/s				> 6 m/s			
Stability →	Unst.	Neutr.	Light stable	Stable	Unst.	Neutr.	Light stable	Stable	Unst.	Neutr.	Light stable	Stable	Unst.	Neutr.	Light stable	Stable
N	0.68	0.22	0.07	0.05	0.36	0.22	0.21	0	0.27	0.14	0.08	0	0.08	0.04	0	0
NNE	0.29	0.28	0.06	0.02	0.18	0.27	0.17	0	0.12	0.17	0.07	0	0.05	0.05	0.01	0
NE	0.16	0.32	0.08	0.01	0.08	0.31	0.23	0	0.06	0.19	0.09	0	0.03	0.05	0	0
ENE	0.06	0.25	0.06	0.01	0.03	0.25	0.17	0	0.02	0.16	0.06	0	0.02	0.04	0	0
E	0.15	0.40	0.07	0.03	0.09	0.39	0.21	0	0.05	0.25	0.08	0	0.04	0.07	0	0
ESE	0.63	0.76	0.16	0.09	0.35	0.74	0.50	0	0.25	0.47	0.21	0	0.13	0.13	0.01	0
SE	1.15	0.97	0.23	0.07	0.64	0.94	0.72	0	0.45	0.59	0.29	0	0.16	0.17	0.02	0
SSE	0.61	1.03	0.29	0.12	0.35	1.00	0.89	0	0.25	0.64	0.36	0	0.16	0.18	0.02	0
S	0.52	1.01	0.24	0.05	0.30	0.98	0.74	0	0.21	0.62	0.30	0	0.11	0.17	0.02	0
SSW	0.43	0.97	0.23	0.05	0.25	0.94	0.69	0	0.18	0.59	0.28	0	0.08	0.16	0.01	0
SW	1.08	0.65	0.24	0	0.58	0.63	0.74	0	0.40	0.40	0.30	0	0.14	0.11	0.02	0
WSW	1.54	0.95	0.30	0	0.86	0.92	0.93	0	0.63	0.57	0.38	0	0.27	0.16	0.02	0
W	1.93	0.93	0.36	0.09	1.06	0.91	1.12	0	0.74	0.57	0.46	0	0.26	0.16	0.02	0
WNW	2.96	1.21	0.47	0	1.73	1.17	1.45	0	1.19	0.75	0.60	0	0.45	0.21	0.03	0
NW	5.39	2.56	0.50	0	3.50	2.49	1.56	0	2.46	1.58	0.63	0	0.92	0.44	0.03	0
NNW	2.22	1.12	0.17	0	1.26	1.08	0.55	0	0.86	0.69	0.22	0	0.30	0.19	0.01	0
	19.80	13.63	3.53	0.59	11.62	13.24	10.88	0	8.14	8.38	4.45	0	3.20	2.33	0.22	0

Table A2: Summer average frequency distributions of wind and stability at Vandellos.

	1 m/s				2 m/s				4 m/s				7 m/s			
	I	N	L.S.	S	I	N	L.S	S	I	N	L.S	S	I	N	L.S	S
N	0.3	0.6	0.3	0.1	1.4	1.3	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.2	0.0	0.0
	0.3	0.9	0.2	0.0	1.6	1.0	0.0	0.0	0.3	0.6	0.0	0.0	0.0	0.2	0.0	0.0
NE	0.3	0.6	0.3	0.1	1.6	1.6	0.0.	0.0	0.6	0.8	0.0	0.0	0.0	0.3	0.0	0.0
	0.4	1.2	0.4	0.1	2.0	2.0	0.2	0.0	0.7	0.7	0.0	0.0	0.1	0.2	0.0	0.0
E	0.6	1.2	0.4	0.1	2.2	2.3	0.0	0.0	0.7	0.7	0.0	0.0	0.2	0.2	0.0	0.0
	0.8	0.5	0.3	0.2	1.8	1.7	0.1	0.0	0.5	0.5	0.0	0.0	0.1	0.1	0.0	0.0
SE	0.5	0.5	0.3	0.2	1.5	1.3	0.2	0.1	0.4	0.3	0.1	0.0	0.0	0.0	0.0	0.0
	0.6	2.0	0.3	0.2	2.0	2.0	0.2	0.1	0.7	0.4	0.2	0.0	0.0	0.1	0.0	0.0
S	0.6	1.5	0.4	0.2	2.5	2.7	0.1	0.0	0.8	1.2	0.1	0.0	0.0	0.2	0.0	0.0
	0.4	1.2	0.4	0.2	1.9	2.0	0.1	0.0	0.9	1.0	0.0	0.0	0.1	0.2	0.0	0.0
SW	0.4	0.6	0.2	0.1	1.0	1.0	0.0	0.0	0.7	0.6	0.0	0.0	0.1	0.2	0.0	0.0
	0.5	0.2	0.1	0.0	0.6	0.7	0.0	0.0	0.4	0.5	0.0	0.0	0.1	0.2	0.0	0.0
W	0.4	0.1	0.0	0.0	0.4	0.4	0.0	0.0	0.4	0.3	0.0	0.0	0.2	0.2	0.0	0.0
	0.6	0.2	0.0	0.0	0.3	0.4	0.0	0.0	0.6	0.3	0.0	0.0	1.0	1.1	0.0	0.0
NW	0.7	0.2	0.1	0.0	0.4	0.4	0.0	0.0	0.4	0.3	0.1	0.0	1.9	1.9	0.0	0.0
	0.8	0.2	0.2	0.0	1.0	0.8	0.0	0.0	0.4	0.3	0.0	0.0	1.0	1.1	0.0	0.0

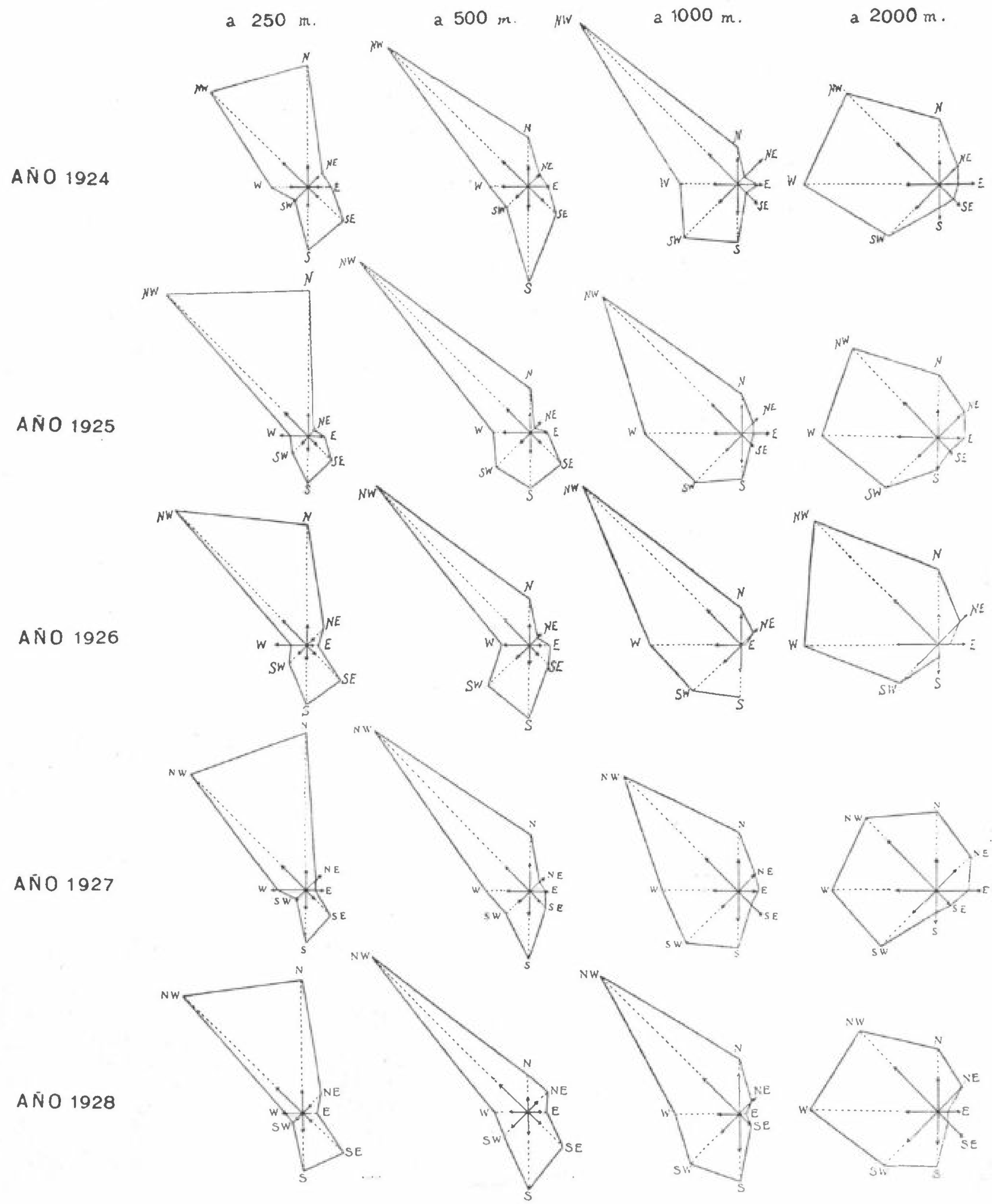
APPENDIX B

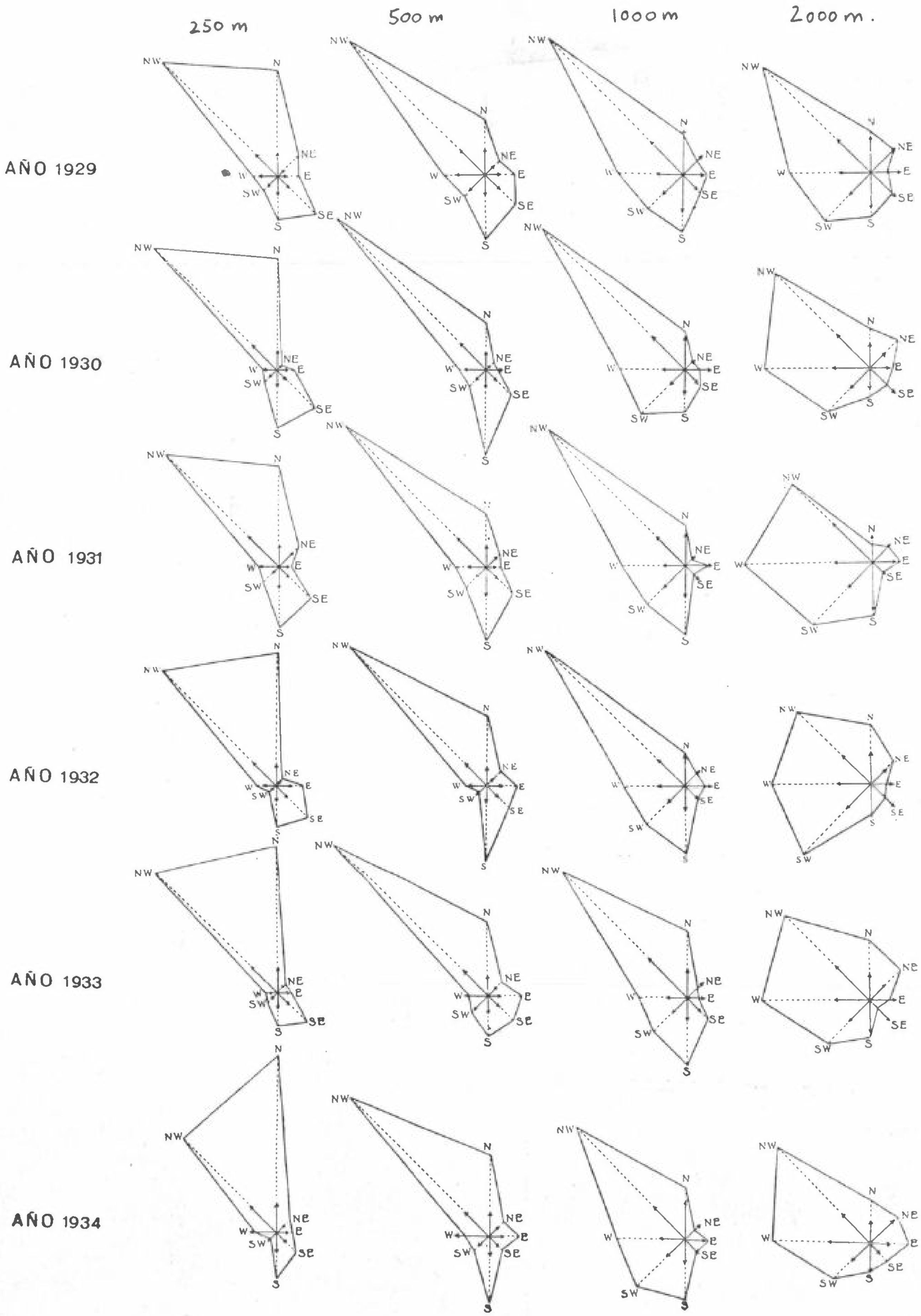
UPPER LEVEL WIND FREQUENCY DISTRIBUTIONS

TORTOSA 1924-34

SONDEO ATMOSFÉRICO

hasta 2,000 metros




250 m
500 m
1000 m
2000 m.
AÑO 1929
AÑO 1930
AÑO 1931
AÑO 1932
AÑO 1933
AÑO 1934
N
NE
E
SE
S
SW
W
NW

APPENDIX C

DISPERSION MODELS

THE NILU GAUSSIAN DISPERSION MODELS

1. INTRODUCTION

This Appendix presents the basics of Gaussian type dispersion models in use at the Norwegian Institute for Air Research (NILU). It is taken for granted that the theoretical background for these models, published in a large number of text book and papers (1,2,4,6), is well known.

2. THE GAUSSIAN PLUME EQUATION

The so-called Gaussian plume equation is a mathematical model for the calculation of the concentration "c" of a gas or a gas-equivalent air pollutant (e.g. dust with particle sizes of less than 10 μm) being emitted from a single source continuously:

$$c(x,y,z) = \frac{Q}{2\pi\bar{u}\cdot\sigma_y(x)\cdot\sigma_z(x)} \exp\left(-\frac{y^2}{2\sigma_y^2(x)}\right), \qquad (1)$$

where:

(x,y,z) = location of receptor point, given in rectangular coordinates with the origin at ground level at the source location and x-axis parallel to wind direction;

Q = continuous source emission rate of the air pollutant;

h = effective plume height (stack height (h_s)+plume rise (dh));

$\bar{u}$ = mean transport (wind) speed;

$\sigma_y(x)$, $\sigma_z(x)$ = diffusion parameters.

This equation is an analytical solution of the simplified diffusion equation

$$\bar{u} \frac{\partial c}{\partial x} = k_z \frac{\partial^2 c}{\partial z^2} + k_y \frac{\partial^2 c}{\partial y^2} , \qquad (2)$$

assuming Gaussian distributions of the pollutant concentration in the plume normal to the drift direction of the plume.

It is furthermore assumed that:

- the pollutant transfer by advection in the transport direction is greater than by turbulent diffusion;
- steady state conditions are prevailing, which implies that all variables and parameters are constant in time;
- k_y and k_z are constant in the x, y and z directions;
- no uptake or deposition at the ground occurs; this means, that the plume can be described mathematically as completely reflected at the ground level which is assumed to be flat.

The assumption which neglects the turbulent diffusion in the drift direction relative to advection implies that the Gaussian plume equation should usually be applied for average transport speeds of more than 1 m/s.

The use of a constant average transport speed and a fixed wind direction during the basic time period reflects the assumption of a stationary and homogeneous horizontal wind field. Directional wind shear in the boundary layer is not considered.

The Gaussian plume equation, therefore, can only calculate short term concentrations over basic time periods (of about ½ to 1 hour duration) for which there are no significant changes of wind direction and speed, and which can be represented by the diffusion parameters σ_y and σ_z.

The basic model does not consider the plume history, i.e. each basic time period is completely independent.

If calculations are to be performed at ground level (z = 0) only, equation *(1)* reduces to

$$c(x,y,z = 0) = \frac{Q}{\pi \cdot \bar{u} \cdot \sigma_y(x) \cdot \sigma_z(x)} \quad \exp\left(- \frac{y^2}{2\sigma_y^2(x)}\right) \cdot \exp\left(- \frac{h^2}{2\sigma_z^2(x)}\right) \qquad (3)$$

Vertical diffusion of a plume by turbulent mixing is limited both by the earth's surface and often by the existence of a stable layer of air aloft, i.e. an inversion layer (mixing height).

3. ELEMENTS OF THE GAUSSIAN PLUME EQUATION

3.1 Wind Speed

The mean transport velocity should be representative of the conditions throughout the vertical height interval in which the plume is dispersing. The wind speed in the lower atmosphere varies with height above ground, however. Since wind measurements are generally performed near ground level only (10 meters), an adjustment for the expected height range of dispersion has to be made. The variation of wind speed with height depends also on the atmospheric stability.

The height dependence of the wind speed is described by a power law:

$$\bar{u}\ (z) = \bar{u}\ (z_o)\ (\frac{z}{z_o})^m \qquad (4)$$

with

z = height above ground,
z_o = reference height above ground,
$\bar{u}$ = time average wind speed,
m = wind profile exponent:

$$\bar{u}(z < z_o) = u(z_o)$$

The mean transport speed representative of an appropriate height range, e.g. from the effective source height (h) to ground level (for dispersion calculations), or from physical (hs) to the effective source height (for plume rise calculations), may then be calculated via integration:

$$\bar{u} = \frac{1}{\Delta z} \int \bar{u}\ (z)\ dz = \frac{1}{(z_2-z_1)} \int_{z_1}^{z_2} \bar{u}\ (z_o) \cdot (\frac{z}{z_o})^m\ dz, \qquad (5)$$

where

z_1 = 0 or h_s,
z_2 = h

Several empirical values of wind profile exponents (m) for different turbulence conditions have been published (1,2,6). In the NILU models the following values have been applied:

	m
Unstable	0.20
Neutral	0.28
Slightly stable	0.36
Stable	0.42

3.2 Atmospheric stability

The diffusion of air pollutants in the lower atmosphere is strongly influenced by the local atmospheric stability. The unstable atmosphere disperses effluent more rapidly than the stable atmosphere.

The stability of the atmosphere can be derived from vertical and horizontal turbulence measurements, or from measurements of the vertical temperature profile and wind speed. Estimates of the net radiation or cloud cover, ceiling height, and solar elevation have also been used. For practical reasons the turbulence situations of the atmosphere is usually described by a discrete set of stability classes.

Different turbulent classification schemes have been developed and used (1,3,4,5,6). Pasquill (7) defined 6 turbulence classes:

A = extremely unstable
B = moderately unstable
C = slightly unstable
D = neutral
E = slightly stable
F = moderately stable

The meteorological data used to determine the turbulence type are usually the surface wind speed, daytime insolation, and nighttime cloudiness.

In the NILU data input for dispersion models, the 3 unstable classes have been combined into one. The stability classes are usually defined by vertical temperature gradients and by direct measurements of the standard deviation of the horizontal wind direction fluctuations, where such data are available. The stability classes are defined as follows:

Class	Temperature gradient dT (deg/100 m)	Corresponds to: Pasquill (5)	Klug (4)	Brookhaven (6)
Unstable	dT < 1	A + B + C	IV+V	$B_1 + B_2$
Neutral	$-1 \leq dT < 0$	D	III_1+III_2	C
Slightly stab.	$0 \leq dT < 1$	E	II	-
Stable	$dT \geq 1$	F	I	D

3.3 Diffusion Parameters

A main assumption for solving the diffusion equation is the existence of a Gaussian normal distribution of the plume concentrations perpendicular to the transport direction. The diffusion parameters σ_y and σ_z are defined as the standard deviations of these Gaussian distributions. They are functions of the downwind distance from the emission source and of the stability of the atmosphere. The standard deviations have been determined from tracer experiments (8,9,10,11) or measurements of the wind fluctuation (12,13,14).

The most appropriate set of diffusion parameters should be selected for a particular application. The choice will be dependent upon source height, surface roughness and, in some cases, averaging time or transport distance. A set of different parameters has been evaluated at NILU (15) and represents the basis for our selection of parameters.

When wind fluctuation measurements are not available, the following form of diffusion parameters is used:

$$\sigma_y(x) = ax^p, \qquad \sigma_z(x) = bx^q. \qquad (6)$$

The most commonly used coefficients are listed below, and apply to averaging times of up to one hour.

Source and surface specifications	Coefficients	Unst.	Neutr.	Sl. stable	Stable	Ref.
Surface	a	0.31	0.22	0.24	0.27	(1)
Emission	p	0.89	0.80	0.69	0.59	(5)
Low stacks	b	0.07	0.10	0.22	0.26	
Smooth surface	q	1.02	0.80	0.61	0.50	
Surface emissions	a	1.7	0.91	1.02	-	(10)
area sources	p	0.72	0.73	0.65	-	
Rough surface,	b	0.08	0.91	1.93	-	
urban	q	1.2	0.70	0.47	-	
High stacks	a	0.36	0.32	0.31	0.31	(6)
Smooth to	p	0.86	0.78	0.74	0.71	
medium rough	b	0.33	0.22	0.16	0.06	
surface	q	0.86	0.78	0.74	0.71	
High stacks	a	0.23	0.22	1.69	5.38	(11)
Rough surface	p	0.97	0.91	0.62	0.57	
	b	0.16	0.40	0.16	0.40	
	q	1.02	0.76	0.81	0.62	

For cases where the standard deviations of wind fluctuations are available, the following expression is used (12):

$$\sigma_y = \sigma_\theta \cdot x \cdot f\ (t/t_L), \qquad (7)$$

where:

$$f(1+0.055t^{\frac{1}{2}})^{-1} \quad ; \qquad (8)$$

for a roughness length of ~ 5-10 cm

$$f = 4.6 \cdot t^{-0.33}, \qquad (9)$$

σ_θ = the standard deviation of horizontal wind fluctuations (rad),
t = the transport time (x/u).

3.4 Effective Source Height

The concentration of air pollutants in the vicinity of a source depends strongly on the release height and the plume rise. The sum of both is often called the "effective source height". The plume rise is influenced by the difference in temperature between the exhaust gas and the ambient air, the wind speed, the exit gas velocity, and the stability of the atmosphere. Many attempts have been made to describe mathematically the plume behaviour immediately after it has left the source. However, there is not yet an ideal general formula available.

Based upon a consideration of several plume rise equations (16), a set of formulas for the plume rise (dh) has been selected for the NILU type Gaussian disperson models.

For small sources (heat output, $Q_h < 2 \cdot 10^5$ cal/s),

Holland (17): $dh = (1.5 \cdot d \cdot w + 4 \cdot 10^{-5} \cdot Q_h) \cdot u^{-1}$ (10)

For medium sized sources and industrial sources, ($2 \cdot 10^5 < Q_h < 7 \cdot 10^6$ cal/s).

Stümke (18): $dh = (1.5 \cdot d \cdot w + 65 \cdot d^{3/2}((T_s - T)/T_s)^{0.25}) \cdot u^{-1}$ (11)

Bringfelt (19):

$$\left. \begin{aligned} dh &= 167 \cdot Q_{MW}^{0.36} \cdot u_s^{-1} \quad (\text{for } x = 500 \text{ m}) \\ dh &= 224 \cdot Q_{MW}^{0.34} \cdot u_s^{-1} \quad (\text{for } x = 1000 \text{ m}) \end{aligned} \right\} \quad (12)$$

where Q_{MW} = heat output in MW ($\simeq 0.11 \cdot F$)

For large sources, tall stacks, power plants ($Q_h > 7 \cdot 10^6$ cal/s),

Biggs (20:

$$\left. \begin{aligned} dh &= F^{1/3} . x^{2/3} . u^{-1} \\ &\text{for } x \leq 10\ h_s \\ dh &= F^{1/3} . (10 \cdot h_s)^{2/3} . u^{-1}, \\ &\text{for } x > 10\ h_s \end{aligned} \right\} \text{for unstable and neutral cases.} \quad (13)$$

$$dh = 2.9 \cdot (F/(u \cdot 5))^{0.33}, \text{ for stable cases} \quad (14)$$

$$F = g \cdot w(d/2)^2 (T_s - T)/T_s, \quad s = (g/T)(\sigma\theta/\partial t) \quad (15)$$

3.5 Physical or Chemical Transformations

When solving the simplified diffusion equation it is assumed that the mass of air pollutants is conserved throughout the transport process. However, air pollutants may undergo physical or chemical transformations. Such chemical transformations may result in the loss of a pollutant due to decay to another substance. Physical transformations may also be, for example, dry or wet deposition, adsorption or absorption.

Dry deposition is taken care of by assuming a deposition velocity, V_d, which gives the amount of deposited material (D) proportional to the ground level concentration (C_o) (23):

$$D = V_d \cdot C_o \quad (16)$$

The deposition model is a so-called source depletion model, which reduces the source by an amount equal to that taken out by deposition. The source reduction factor for each distance increment, dx, is given by:

$$\frac{dQ_x^1}{dx} = - \int_{-\infty}^{\infty} D \, dy, \qquad (17)$$

which gives the reduced "source strength" at distance x from the source:

$$Q_x^1 = Q[\exp \int_0^x (\sigma_z \cdot \exp(h^2/2\sigma_z^2))^{-1} \cdot dx]^{-(V_d \cdot u^{-1} \cdot \sqrt{(2/\pi)})} \qquad (18)$$

<u>Wet deposition</u>

Wet deposition might be accounted for by a first order decay process:

$$\frac{dc}{dt} = - \Lambda \cdot c$$

$$c = c \cdot \exp(-\Lambda t) \qquad (19)$$

Λ is the washout coefficient

The washout rate is:

$$\omega = - \int_0^{\infty} (dc/dt) dz \simeq \frac{\Lambda \cdot Q_o \exp(-\Lambda t)}{\sqrt{2\pi} \cdot u \cdot \sigma_y} \exp(-y^2/2\sigma_y^2) \qquad (20)$$

Another subroutine assumes that the SO_2 in droplets is limited by the transformation of SO_2 to $H_2SO_3^-$ through

$$SO_2 + H_2O \rightleftarrows H_3O^+ + H_2SO_3^-$$

This means that the pH-value of the raindrops, before reaching the plume, is essential for the SO_2-uptake rate.

The wash-out is estimated from the plume centreline concentration and from an assumption of raindrop pH values. The model is based upon studies at Battelle Memorial Institute (24). This simple precipitation scavenging model includes approximations and uncertainties, and has subsequently been adjusted for large distances to match empirical wash-out data from Sweden (25).

4. SPECIAL PROBLEMS

The Gaussian plume formula is applicable only for flat, homogeneous terrain, steady state meteorological conditions, and homogeneous turbulence.

To take into account other effects, modifications and approximations are required. Nevertheless a few special cases might be simulated by the Gaussian type models.

4.1 Topography

The effect of elevated terrain on the ground level concentrations might to a certain degree be represented by reducing the effective plume hight (h) assuming:

$$h = h_s + dh - k \cdot h_t, \qquad (21)$$

where h_t is the height of terrain above stack base level, and k is a terrain factor ($0 < k < 1$) dependent upon steepness, distance from source, stability, etc.

4.2 Sea breeze fumigation

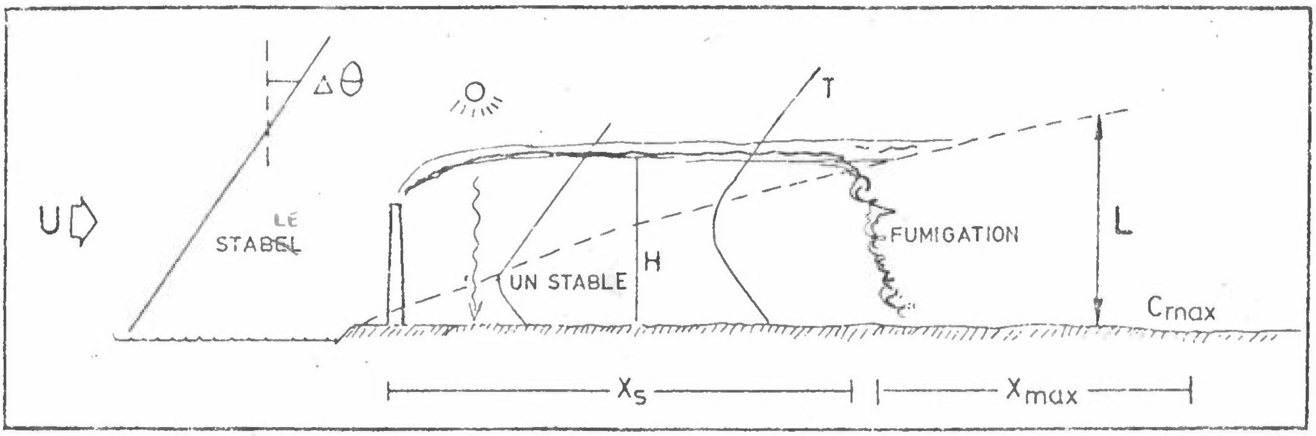


Figure 1: Sea breeze fumigation.

A rapid downwards mixing of pollutants to ghe ground fraom an elevated plume (fumigation) occurs when the stable sea breeze layer is advected inland and heated from below. The fumigation starts at the point where the unstable surface layer reaches the plume, (see Figure 1).

The following method for estimating maximum ground level concentrations during these cases has been applied at NILU.

The height to the unstable layer (L) is given by van der Hovens (26):

$$L = 8.8 \cdot \sqrt{\frac{x}{u \cdot \Delta\theta}} , \qquad (22)$$

where:

x = distance from sea (m),
u = wind speed (m/s),
Δθ = vertical temperature gradient (deg/100 m).

Fumigation of the plume take place when $x = X_S$:

$$X_S = \left(\frac{H}{8.8}\right)^2 \cdot u \cdot \Delta\theta \qquad (23)$$

Increase of σ_z during period of fumigation should be changed according to unstable dispersion (see Figure 1).

According to Turner (2), X_L, defined as the distance where the plume touches the ground, is:

$$2.15\ \sigma_z\ (X_L) = L. \text{ (As a first estimate: } L = H\text{)}$$

For unstable dispersion:

$$L = 8.8\sqrt{\frac{X_L + X_S}{u \cdot \Delta\theta}}\ , \qquad (24)$$

$$X_L = (0.47 \cdot L/0.33)^{1.49} \qquad (25)$$

L and X_L are determined by iteration.

Maximum concentration occurs at a distance $x_{max} = 2X_L$ (2), which gives:

$$L(X_S + 2X_L) = 8.8\sqrt{\frac{X_S + 2X_L}{u\Delta\theta}}\ , \qquad (26)$$

$$C_{max}\ (\text{sea breeze}) = \frac{Q}{\sqrt{2\Pi}\ \Sigma_y \cdot L(X_s + 2X_L) \cdot u}\ , \qquad (27)$$

$$\Sigma_y = \sigma_{y\ stab}(X_s) + \sigma_{y\ unstab.}(X_{max}) \qquad (28)$$

5 HANDLING MULTIPLE SOURCE (NILU model "Kilder")

In general, calculations of air pollutant concentrations (at ground level) have to be made for multiple sources in a given area. Under the restriction of no interdependence of the different sources, a superposition of a number of sources emitting the same air pollutant is described by Schjoldager (21) and Sivertsen (22).

6 LIMITATIONS

Due to the assumptions of atmospheric homogeneity and stationarity, the Gaussian plume equation should only be applied over those distances for which the aforementioned assumptions could be expected to reasonably hold.

The Gaussian plume formula should also be used only for downwind distances for which the dispersion parameters have been determined experimentally via tracer experiments or wind fluctuation measurements. The use of dispersion parameters extrapolated to distances of more than tens of kilometers or less than about 100 m are in accurate and can only show the general tendency of the concentrations.

Calm wind situations (wind speed of about 1 m/s or less) cannot be handled by the Gaussian plume equation because at such low wind speeds the turbulent diffusion is equivalent to or even supersedes the advection influence.

The estimates of deposition or depletion at the ground cannot be taken into account without violation of the Gaussian hypothesis. Chemical reactions are not allowed in such a model. However, the estimates with exponential correction factors for a half-life and the source depletion could be considered first-order "guesstimates".

Dispersion is influenced by the physical structure of obstenc-tions, such as the building complexes. For example, large objects can produce aerodynamic down-wash, causing higher pollutant concentrations in their wake. Additional assumptions then have to be made before using the Gaussian plume formula.

Uneven terrain (e.g. steps in the terrain), influences the air flow and the strictly horizontal transport of pollutants, as assumed in the Gaussian plume equation, is unrealistic under such conditions. Simple corrections by emans of equation *(21)* are uncertain, but take into account to a certain degree the effect of the topography.

7 REFERENCES

(1) Pasquill, F. — Atmospheric diffusion. 2nd ed. New York, John Wiley and Sons, 1974.

(2) Turner, O.B. — Workbook of atmospheric dispersion estimates. Washington D.C., US Dept. Health Ed. & Welfare, 1969. (Env. Health Service. Pub. no. 995-Ap - 26.)

(3) Gifford, F.A. — An outline of theories of diffusion in the lower layers of the atmo-sphere. In: *Meteorology and Atomic Energy*, edited by D.H. Slade, Spring-field, Va, 1968, pp. 66-116.

(4) Smith, M.E., Singer, J.A. — An improved method of estimating concentrations and related phenomena from a point source emission. *J. Appl. Meteorol.* 5, 631-639 (1966).

(5) Klug, W. — Ein Verfahren zur Bestimmung der Ausbreitungsbedingungen aus synop-tischen Beobachtungen. (A Method for the determination of diffusion conditions from synoptical obser-vations). *Staub* 29, 143-147 (1969).

(6) Smith, M. — Recommended guide for the prediction of the dispersion of airborne effluents. New York, The American Society of Mechanical Engineers, 1968.

(7) Pasquill, F. — The estimation of the dispersion of windborne material. *Meteorol. Mag.* 90, 33 (1961).

(8) Barad, M.L., Haugen, D.A. — Project Prairie Grass. Bedford Mass. Air Force Cambridge Research Center, (Geophys. Res. Paper Vols. I, II and III.) 1958-59.

(9) Singer, J.A., Smith, M.E. — Atmospheric dispersion at Brookhaven Laboratory. *Int. J. Air Water Poll.* 10, 125-135 (1966).

(10) Mc Elroy, J.L., Pooler, F. — St. Louis Dispersion Study, Vol II, Analysis. Arlington, U.S. Dep. of Health, Education and Welfare. National Air Pollution Control Administration, 1968.

(11) Vogt, K.J. — Empirical investigation of the diffusion of waste air plumes in the atmosphere. *Nuclear Techn.* 34, 43- (1977).

(12) Sivertsen, B. — Dispersion parameters determined from measurements of wind fluctuations (σ_θ), temperature and wind profiles. Proc. of NATO/CCMS 9th Int. Techn. Meet., Toronto Aug. 1978. (NILU TN 13/78).

(13) Meade, P.J. — The effect of meteorological factors on the dispersion of airborne material. *Atti del Congresso Scientifico, Sezione Nucleare* 2, 107- (1959).

(14) Jensen, K. — Meteorological measurements at Risö 1958-61, Risö Report. Roskilde, Atomenergikommissionen, Denmark, 1962.

(15) Sivertsen, B. Spredningsparametre for Gaussiske spredningsmodeller. Lillestrøm, Norway, Norwegian Institute for Air Research, NILU TN (in press).

(16) Sivertsen, B. Plume rise calculations. Kjeller, Norway, Norwegian Institute for Air Research 1974. (NILU TN 80/74.)

(17) Holland, J.Z. A meteorological survey of the Oak Ridge Area, ORO-99. U.S Atomic Energy Commission.

(18) Stümke, H. Vorschlag einer empirischen Formel für die Schornsteinüberhöhnung. (Suggestions for an empirical formula for chimney elevation.) *Staub* 23, 549- (1963).

(19) Bringfelt, B. Plume rise measurements at industrial chimneys. *Atmos.Environ.* 2, 575-598 (1968).

(20) Briggs, G.A. Plume Rise. AEC - Critical Review Series TID 25075, Division of Technical Information, US AEC. Springfield, UA, 1969.

(21) Schjoldager, J. Program "Kilder". Beregning av spredning fra punktkilder og volumkilder. Kjeller, Norway, Norwegian Institute for Air Research, 1975. (NILU TN 2/75.)

(22) Sivertsen, B. Application of the Norwegian multiple source model "KILDER" to the NATO/CCMS data base from the Frankfurt area. Lillestrøm, Norway, Norwegian Institute for Air Research 1977. NILU TN 1/77.)

(23) Gifford, F.A., Pack, D.H. Surface deposition of airborne material. *Nuclear Safety* 3, 76-80, (1962).

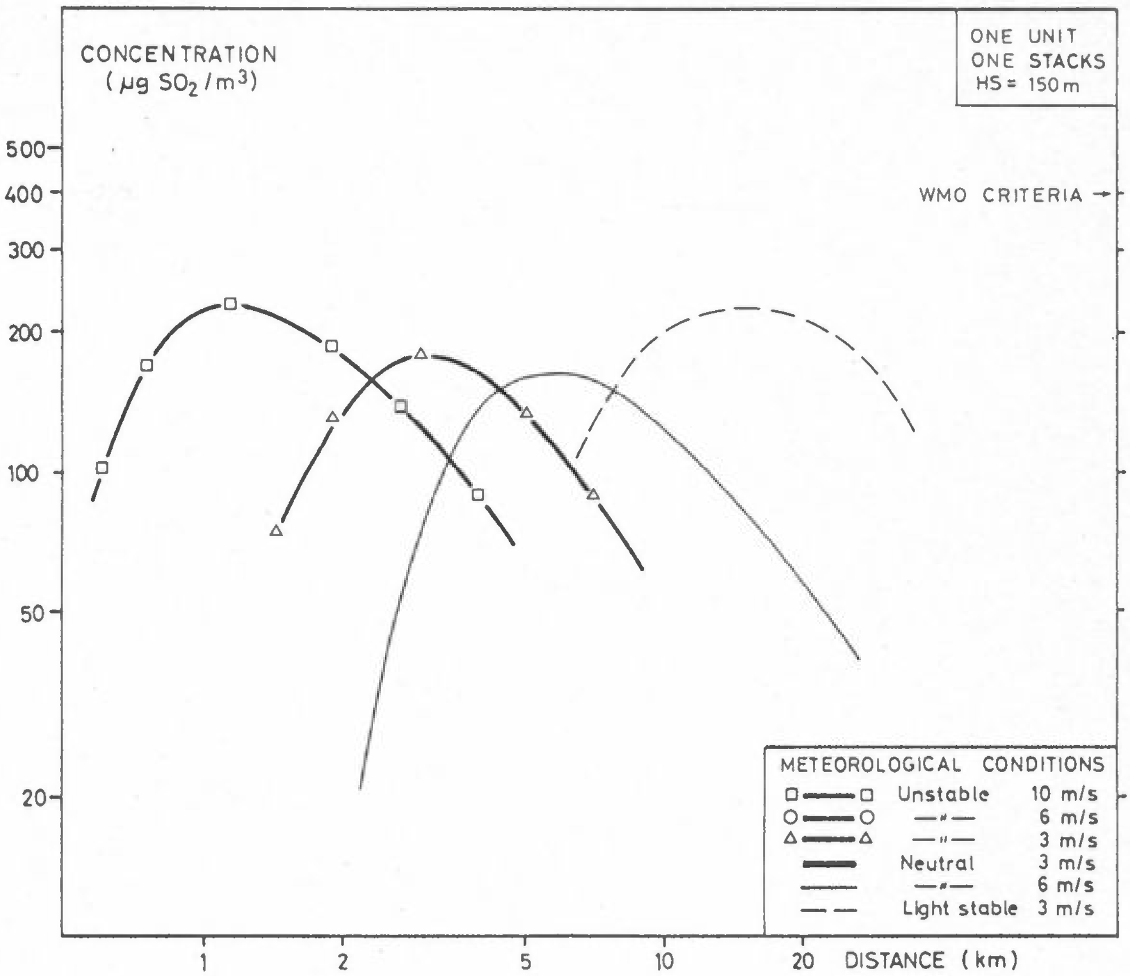
(24) Terry Dana, M.; Hales, J.M.; Slinn, W.G.N.; Wolf, M.A. — Natural precipitation wash-out of sulphur compounds from plumes. EPA-R3-73-047. Washington D.C., US-Env. Protection Agency, 1973.

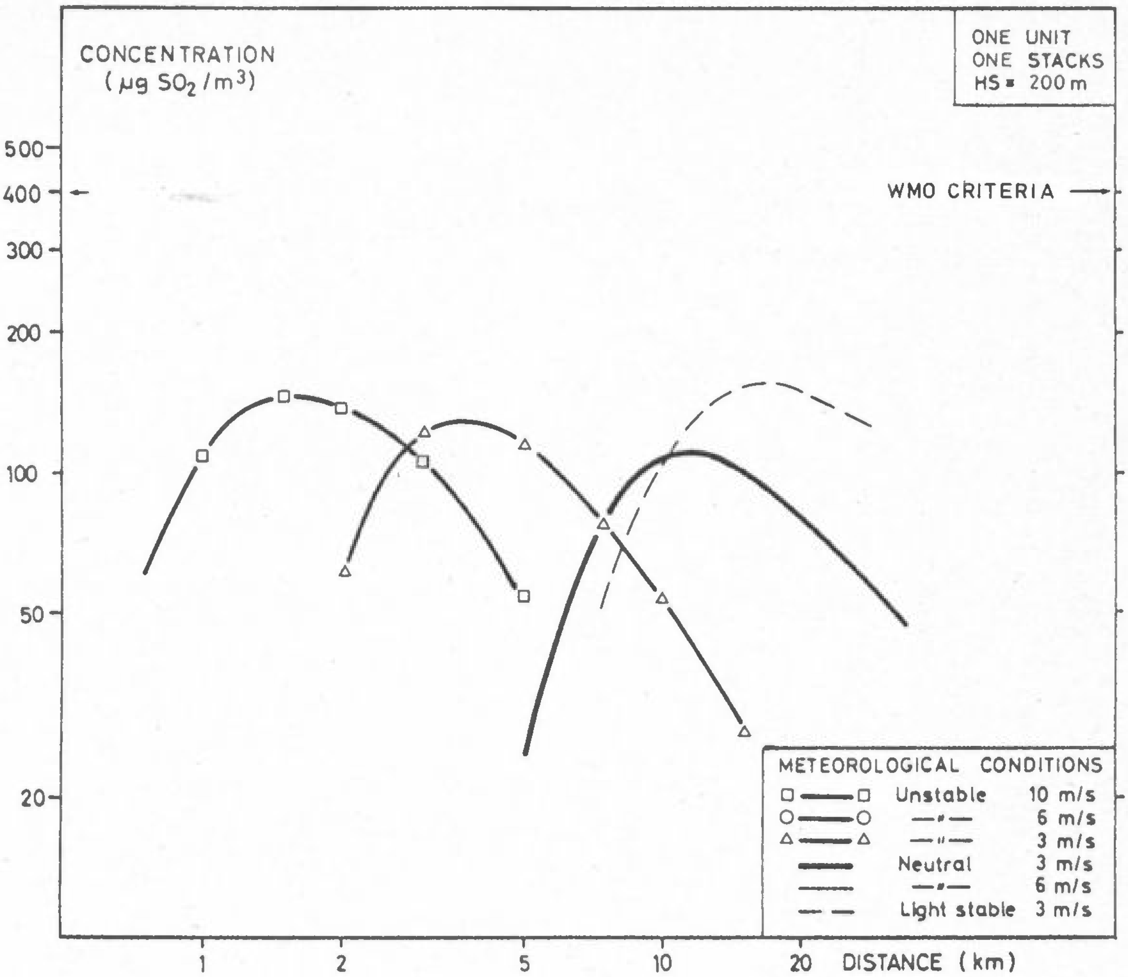
(25) Granat, L.; Rodhe, H. — A study of fallout by precipitation around an oilfired power plant. *Atmos.Environ.* 7, 781-92 (1973).

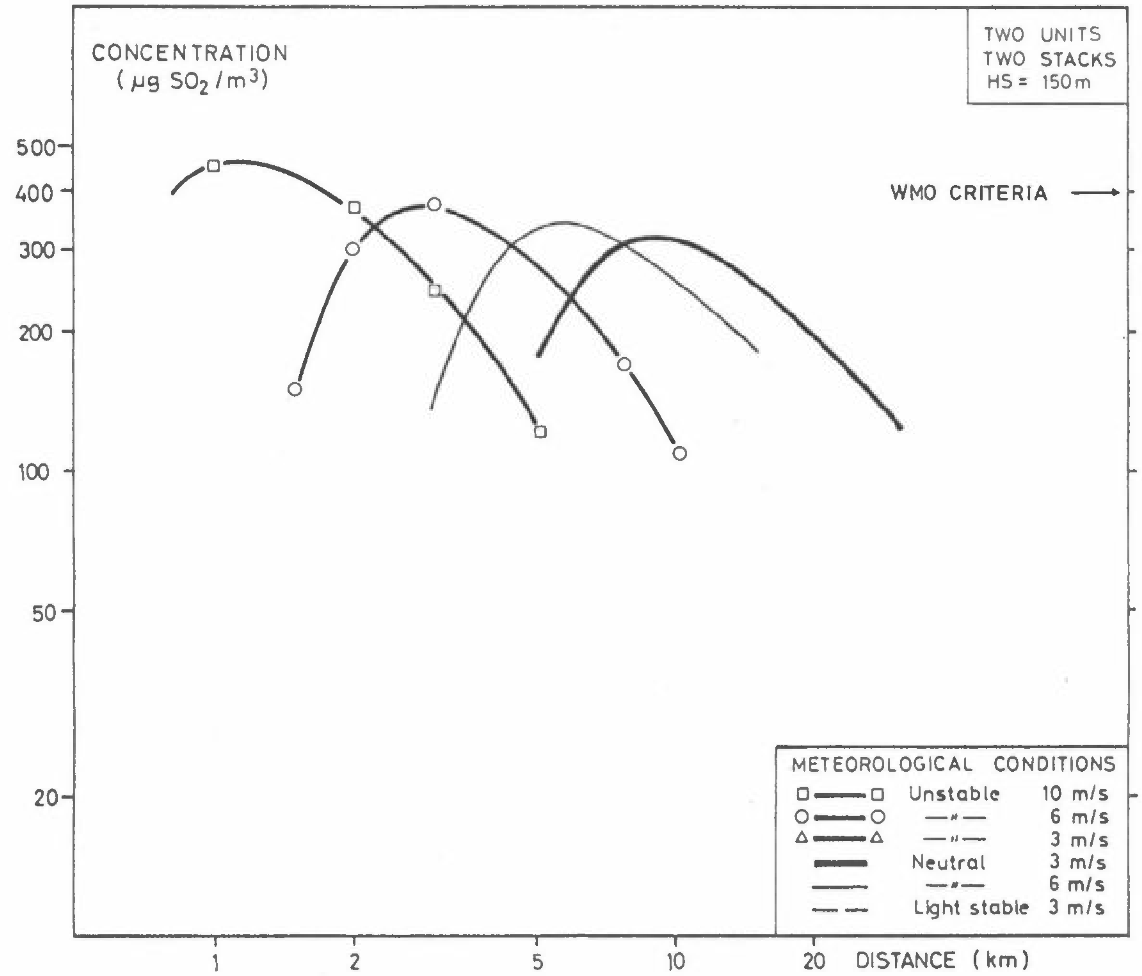
(26) Van der Hoven, I. — Atmospheric transport and diffusion at coastal sites. *Nuclear Safety* 8, 490-99 (1967).

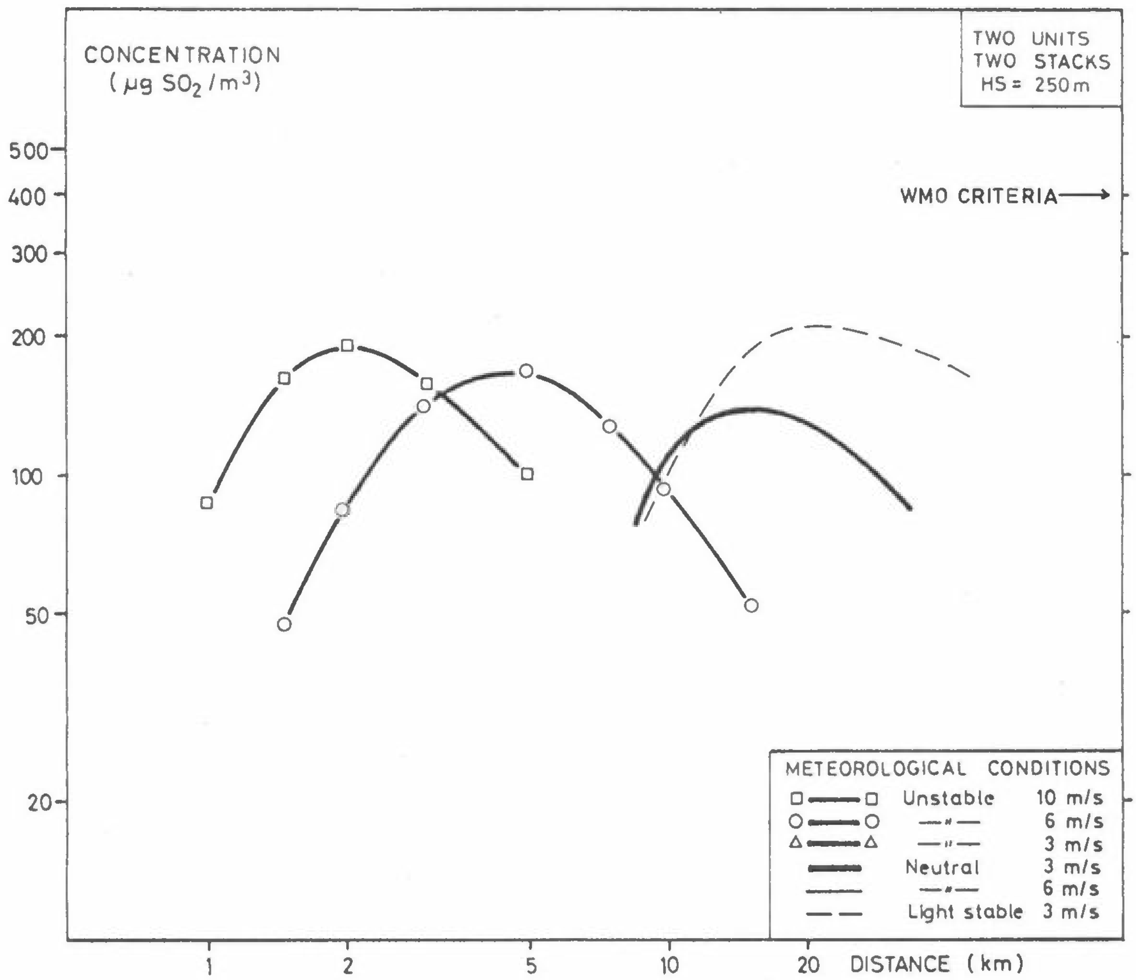
APPENDIX D

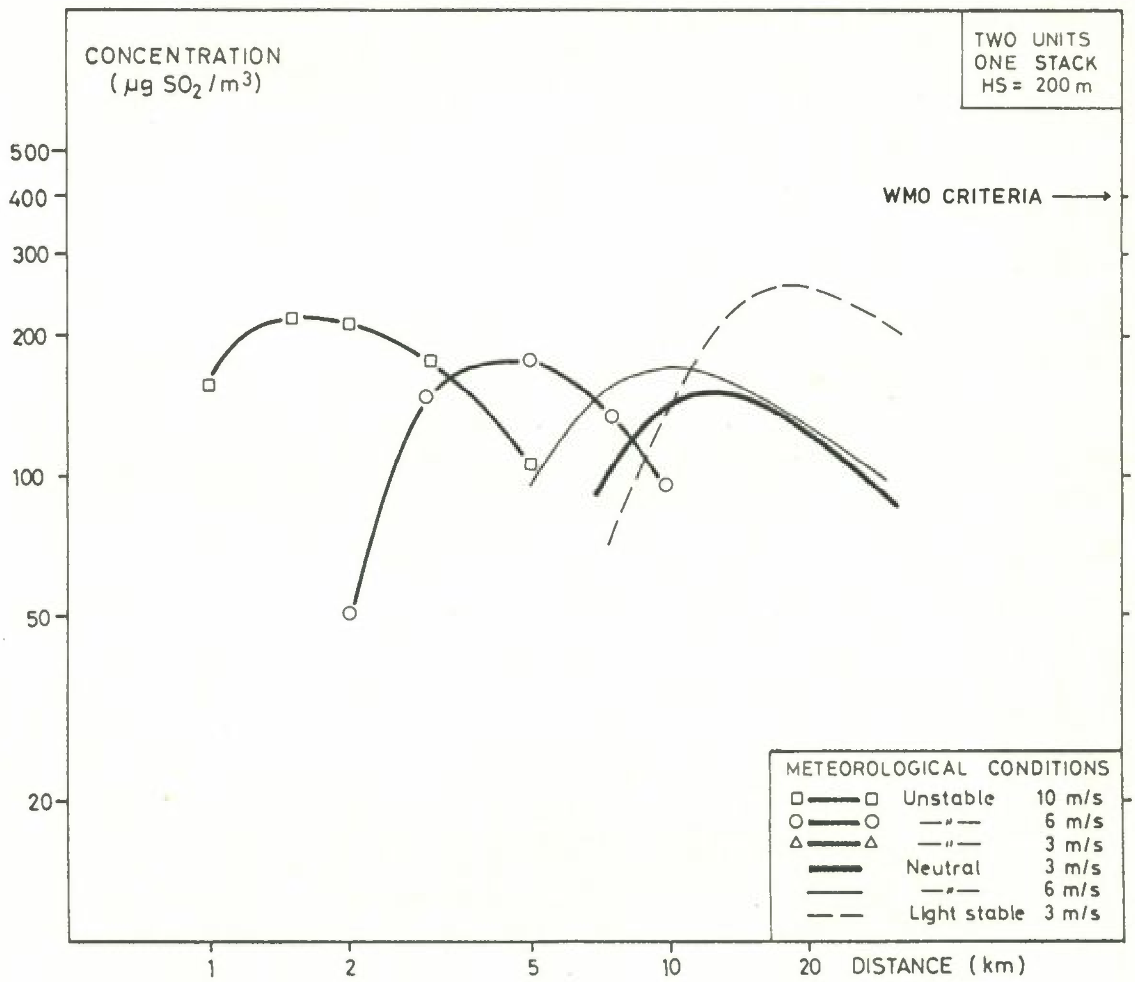
ESTIMATED ONE HOUR AVERAGE GROUND LEVEL CONCENTRATIONS OF SO_2

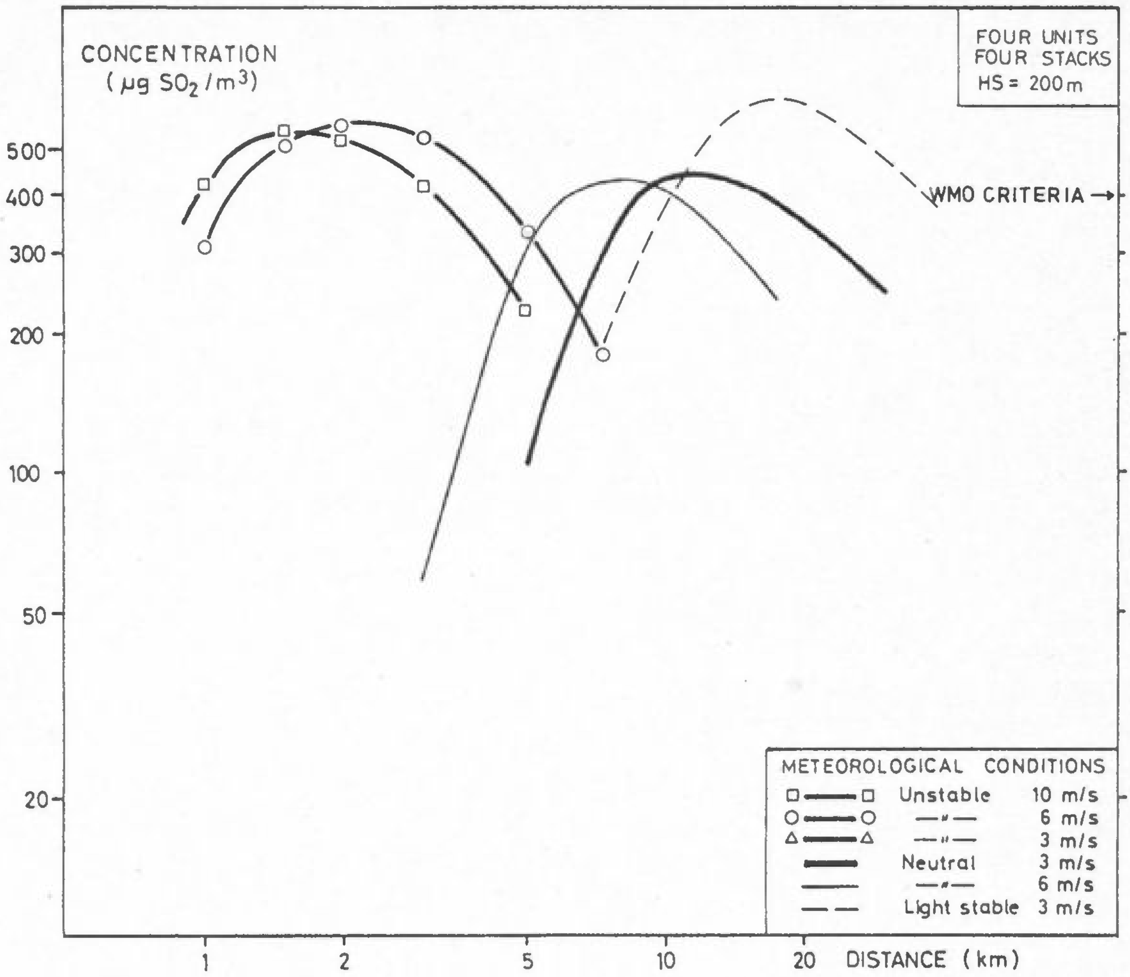

CONCENTRATION
(µg SO2 / m3)
ONE UNIT
ONE STACKS
HS = 150 m
WMO CRITERIA
500
400
300
200
100
50
20
1
2
5
10
20
DISTANCE (km)
METEOROLOGICAL CONDITIONS
Unstable 10 m/s
—"— 6 m/s
—"— 3 m/s
Neutral 3 m/s
—"— 6 m/s
Light stable 3 m/s


ONE UNIT
ONE STACKS
HS = 200 m
CONCENTRATION
(µg SO2 / m3)
500
400
300
200
100
50
20
WMO CRITERIA
1
2
5
10
20
DISTANCE (km)
METEOROLOGICAL CONDITIONS
Unstable 10 m/s
6 m/s
3 m/s
Neutral 3 m/s
6 m/s
Light stable 3 m/s

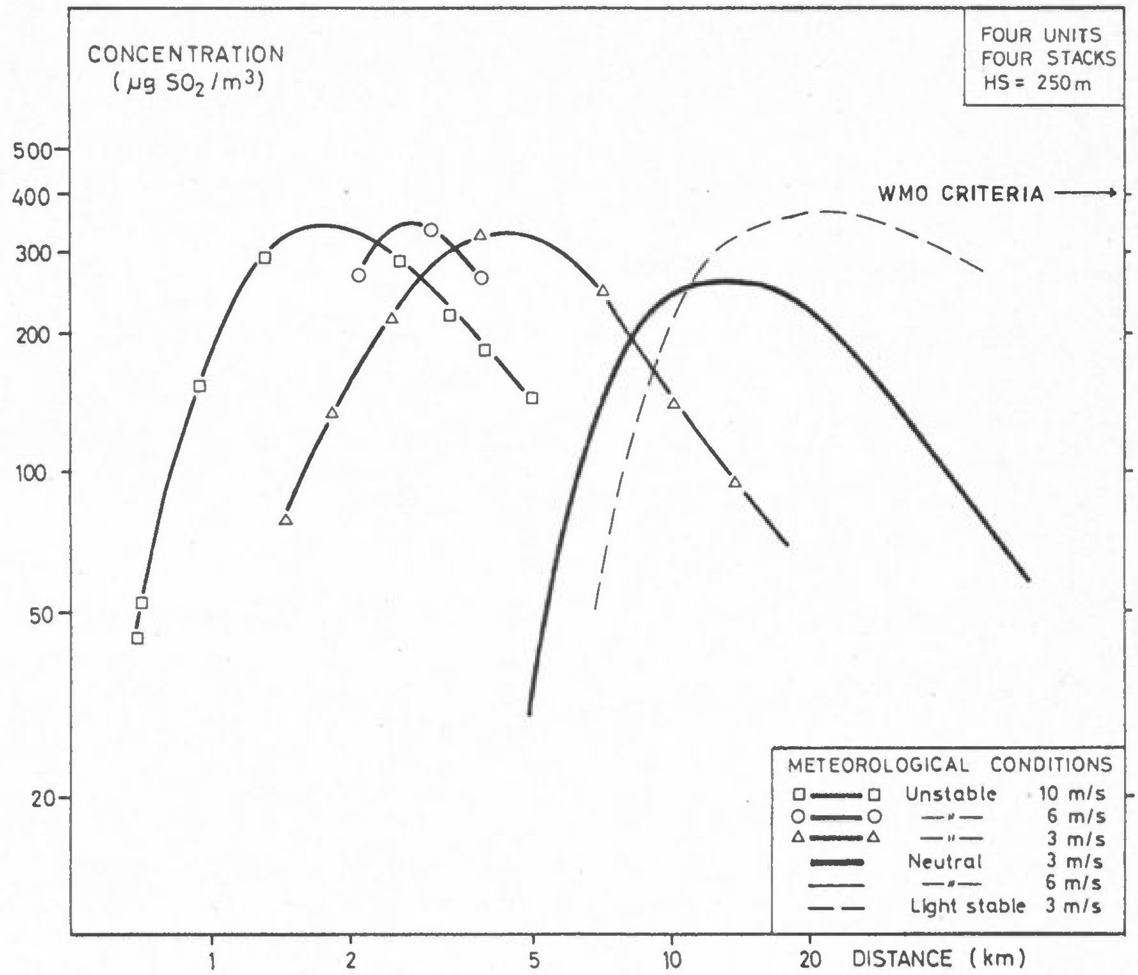

CONCENTRATION
(µg SO2 / m3)
TWO UNITS
TWO STACKS
HS = 150 m
500
400
300
200
100
50
20
WMO CRITERIA
METEOROLOGICAL CONDITIONS
Unstable 10 m/s
6 m/s
3 m/s
Neutral 3 m/s
6 m/s
Light stable 3 m/s
1
2
5
10
20
DISTANCE (km)

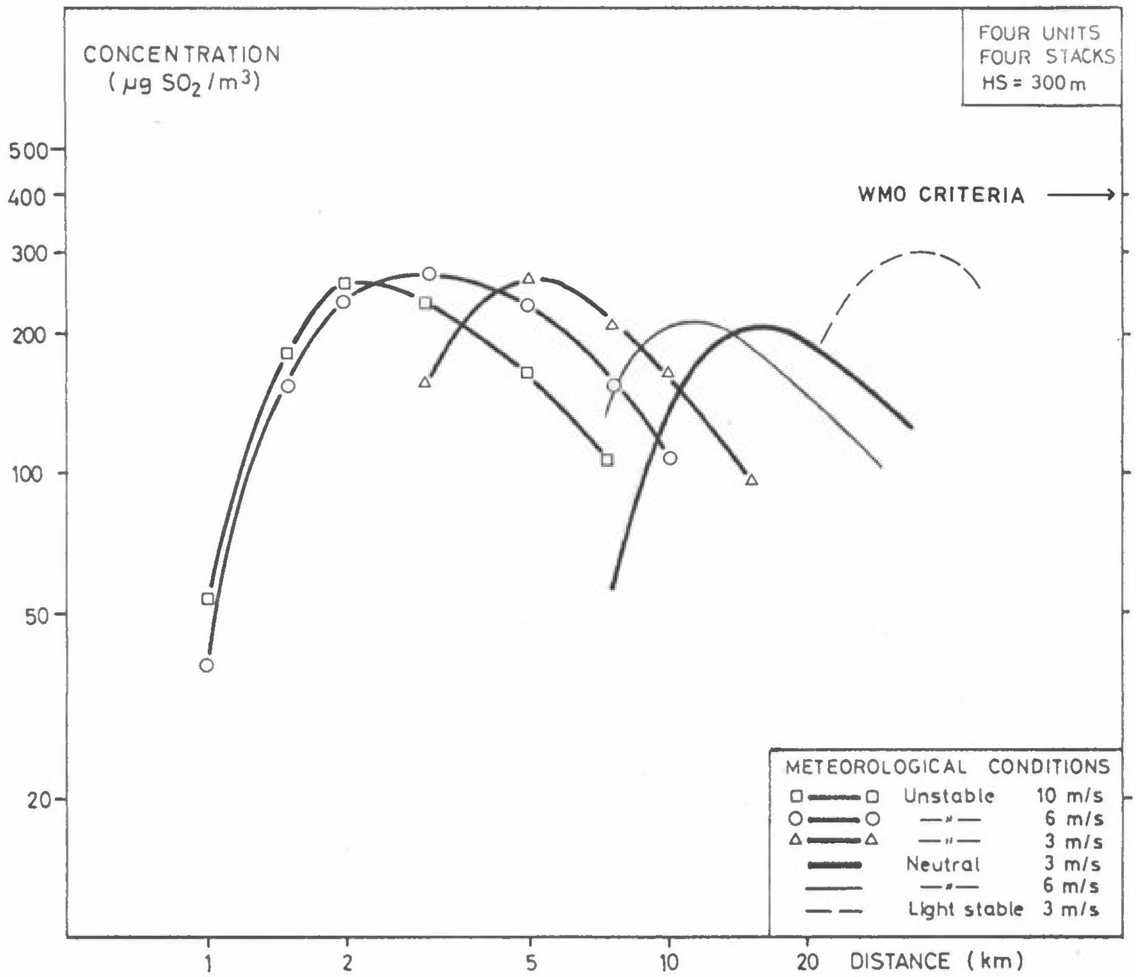

CONCENTRATION
(μg SO2 /m3)
TWO UNITS
TWO STACKS
HS = 250m
500
400
300
200
100
50
20
WMO CRITERIA
METEOROLOGICAL CONDITIONS
Unstable 10 m/s
6 m/s
3 m/s
Neutral 3 m/s
6 m/s
Light stable 3 m/s
1
2
5
10
20
DISTANCE (km)

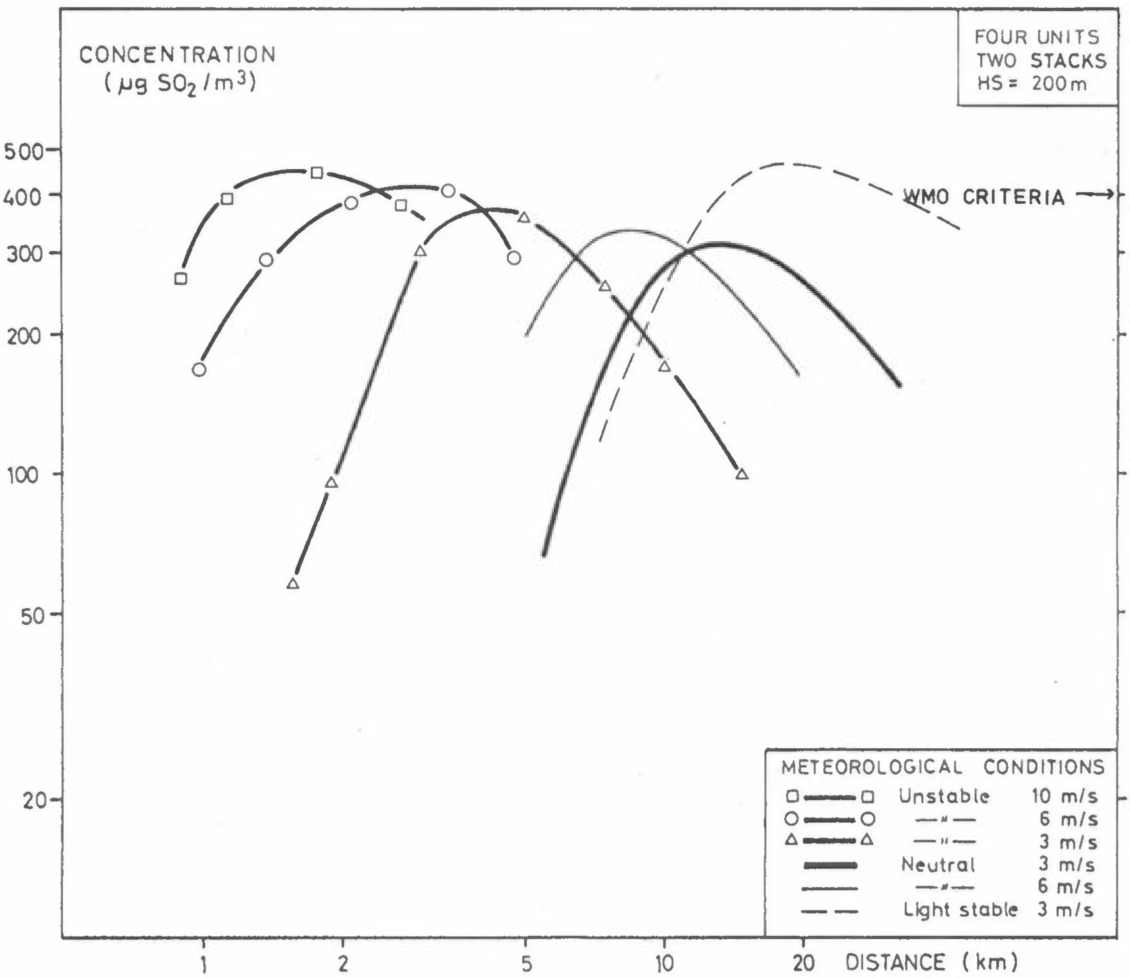

CONCENTRATION
(µg SO2 / m3)
TWO UNITS
ONE STACK
HS = 200 m
500
400
300
200
100
50
20
WMO CRITERIA
METEOROLOGICAL CONDITIONS
Unstable 10 m/s
— " — 6 m/s
— " — 3 m/s
Neutral 3 m/s
— " — 6 m/s
Light stable 3 m/s
1
2
5
10
20
DISTANCE (km)



CONCENTRATION
(μg SO2 / m3)
FOUR UNITS
FOUR STACKS
HS = 200 m
500
400
300
200
100
50
20
WMO CRITERIA
METEOROLOGICAL CONDITIONS
Unstable 10 m/s
6 m/s
3 m/s
Neutral 3 m/s
6 m/s
Light stable 3 m/s
1
2
5
10
20
DISTANCE (km)


CONCENTRATION
(µg SO2 / m3)
FOUR UNITS
FOUR STACKS
HS = 250 m
WMO CRITERIA
500
400
300
200
100
50
20
1
2
5
10
20
DISTANCE (km)
METEOROLOGICAL CONDITIONS
Unstable 10 m/s
6 m/s
3 m/s
Neutral 3 m/s
6 m/s
Light stable 3 m/s


CONCENTRATION
(µg SO2 / m3)
FOUR UNITS
FOUR STACKS
HS = 300 m
500
400
300
200
100
50
20
WMO CRITERIA
METEOROLOGICAL CONDITIONS
Unstable 10 m/s
—"— 6 m/s
—"— 3 m/s
Neutral 3 m/s
—"— 6 m/s
Light stable 3 m/s
1
2
5
10
20
DISTANCE (km)


CONCENTRATION
(µg SO2 / m3)
FOUR UNITS
TWO STACKS
HS = 200m
500
400
300
200
100
50
20
WMO CRITERIA
METEOROLOGICAL CONDITIONS
Unstable 10 m/s
—"— 6 m/s
—"— 3 m/s
Neutral 3 m/s
—"— 6 m/s
Light stable 3 m/s
1
2
5
10
20
DISTANCE (km)

NORSK INSTITUTT FOR LUFTFORSKNING

NILU

(NORGES TEKNISK-NATURVITENSKAPELIGE FORSKNINGSRÅD)
POSTBOKS 130, 2001 LILLESTRØM
ELVEGT. 52.
TLF. (02) 71 41 70

RAPPORTTYPE Oppdragsrapport	RAPPORTNR. OR 6/80	ISBN--82-7247-160-4
DATO MARS 1980	ANSV.SIGN. B.Ottar	ANT.SIDER 69
TITTEL Coal fired power plant FECSA/INYPSA. Preliminary site study.		PROSJEKTLEDER NILU PROSJEKT NR 21080
FORFATTER(E) Bjarne Sivertsen		TILGJENGELIGHET ** OPPDRAGSGIVERS REF.
OPPDRAGSGIVER FECSA/INYPSA v/Domingo Jiminez, Madrid		
3 STIKKORD (á maks.20 anslag) Site study	Dispersion estimates	Coal fired power plant.

REFERAT (maks. 300 anslag, 5-10 linjer)
Rapporten inneholder en bearbeidelse av meteorologiske data, spredningsberegninger og en diskusjon av alternative byggesteder for et kullfyrt varmekraftverk i området rundt Ebrodeltaet i nordøst Spania. Det er gjort beregninger for alternative utforminger av kraftverket. Framtidige undersøkelser for å skaffe data til en endelig konsekvensanalyse er også skissert.

TITLE Coal fired power plant FECSA/INYPSA. Preliminary site study.

ABSTRACT (max. 300 characters, 5-10 lines)
A preliminary study of the air pollution around alternative sites for a coal fired power plant in the Ebro delta area of north eastern Spain was requested. Estimates of ground level concentrations of SO_2, NO_2 and dust have been performed based upon meteorological data from the area.
Future environmental studies were briefly outlined.

**Kategorier: Åpen - kan bestilles fra NILU A
Må bestilles gjennom oppdragsgiver B
Kan ikke utleveres C