Air pollution in the planning and siting of industries

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SYNOPSIS

A method of evaluating the possible effect of an industry on the environment is presented, and the method is illustrated by its application to a hypothetical problem. An analysis is offered based on an actual survey of four industrial sites in the Lydenburg area of the eastern Transvaal. The survey showed that there is a high incidence of potentially unfavourable conditions, and there is a distinct possibility that a topographically induced eddying motion will extend over the town and the industrial sites. This moving air could entrap air pollutants, resulting in high concentrations of pollutants over the town. It is concluded that none of the sites is suitable for industries that pollute the atmosphere.

SAMEVATTING

'n Metode om die moontlike uitwerking van 'n nywerheid op die omgewing te bepaal word uiteengesit en die metode word geïllustreer deur die toepassing daarvan op 'n hipotetiese probleem. Daar word 'n ontleding gegee wat gebaseer is op 'n werklike opname van vier nywerheidspersele in die Lydenburggebied van Oos-Transvaal. Die opname het getoon dat daar 'n hoë voorkoms van potensieel ongunstige toestande is, en daar is duidelik 'n moontlikheid dat 'n topografies geïnduseerde werwelbeweging oor die dorp en die nywerheidspersele sal strek. Hierdie bewegende lug kan lugbesoedelstowwe vasvang wat hoë konsentrasies van besoedelstowwe oor die dorp tot gevolg kan hê. Die gevolgtrekking word gemaak dat geeneen van hierdie persele vir nywerhede wat die atmosfeer besoedel, geskik is nie.

Introduction

In the siting of an industrial plant, the many factors that have to be considered include transportation, water supply, and geological structure. To these must be added environmental factors, the most important being water and air pollution. This paper concentrates on the latter, and, although air pollution is not the only consideration in the planning and siting of industries, it is regarded as such in the discussion that follows.

Air pollution is caused by the emission into the air of substances that are mostly due to industrial activity. Although there are legal controls that aim at minimizing possible emissions, these controls cannot eliminate the emissions entirely. Because the remaining emissions can lead to localized undesirable situations, it is unwise to plan or site an industry on the basis that 'nothing will ever happen'.

A consideration of the problems that may arise from the emission of pollutants should include a wide variety of interconnected topics. However, although the methods used in analysing the possibility of air pollution range in complexity from rule-of-thumb procedures to elaborate calculations, none takes all these factors into account. The method that is discussed here evaluates the effect of industrial establishments on the environment, with the emphasis on the recognition of a possibly unfavourable situation before it arises so that steps can be taken in advance to avoid it.

Atmospheric processes have a considerable bearing on the suitability of any area for the siting of an industry that may pollute the air. Without a detailed knowledge of the polluting source (which is rarely available in the early planning stage of an industry), the suitability of a site depends largely on effective ventilation by the atmospheric processes and on the frequency of potentially unfavourable atmospheric conditions.

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Ventilation Potential

Wind speed and atmospheric stability are two important considerations. For a given constant rate of emission, a doubling of the wind speed will halve the amount of effluent in any given vertical slice of the atmosphere down-wind of the source. Broadly speaking, the role of thermal stability is either to enhance or to suppress atmospheric turbulence. Observation (and some imagination) will show that the pollutant plume from a point source stretches down-wind roughly in the form of a cone with its apex at the point of emission. This growth of the plume diameter with distance from source is the result of atmospheric turbulence and depends on atmospheric stability.

Atmospheric stability depends on the vertical gradient of the temperature. The atmosphere is *thermally unstable* if the ambient temperature gradient of the air is less than the rate at which a parcel of dry unsaturated air cools when it is displaced vertically, i.e. the *dry adiabatic lapse rate* (with a value of 1 °C per 100 m). If the observed temperature increases at a rate greater than the dry adiabatic lapse rate, the atmosphere is termed *thermally stable.* Inversions of temperature, in which the air temperature increases with height (stable atmosphere), offer the least favourable conditions for the efficient dispersal of pollutants. Stable atmospheric conditions are mainly due to radiational cooling of the surface, drainage of cold air down slopes (called *katabatic* air flow), and subsidence and compressional heating of the air.

For an area where a plant is to be sited but no details of the polluting source are known, it is clear that very little can be gained from a study of a single isolated situation. Much more can be obtained by attempting a statistical description of the characteristics of the atmosphere over the general area.

The main statistical parameters of interest are average stability, average wind field, and seasonal contrasts in the variables. To these must be added the influence of topography on the variables, i.e. the characteristics of the terrain. For a proper statistical evaluation, information on the various parameters are needed over a sufficiently long time, but much can be deduced from a well-planned study of limited extent. This can most easily be illustrated by an example, the example chosen being based on an actual study in the Lydenburg area in the eastern Transvaal. For obvious reasons, the exact problem is not stated, but the data that were gathered are applied to a hypothetical problem.

Hypothetical Problem

The problem was an assessment of the relative merits of four sites in the Lydenburg area (A, B, C, D in Fig. 1) for the establishment of industries with a potential for polluting the air.

The relevant information can be obtained from Weather Bureau data, from data gathered in other studies (if available), and from an intensive meso-meteorological survey. In the ideal case, a survey of the wind and temperature fields would be made over a period of a year or more, or at least over the winter period, so that the average meteorological properties of the area could be satisfactorily characterized.

This was not possible for the Lydenburg study, and instead an intensive programme of measurements was followed during the months of September and October, 1975. Although it was already too late for the winter situation to be investigated in detail, it was possible to infer most of the winter characteristics of the atmosphere with the assistance of the daily synoptic situation over the measurement period as given by the Weather Bureau. This shows that high pressure prevailed for a large proportion of the time during September 1975, which is a typical winter situation over the interior of South Africa. The winter in this area is normally characterized by clear skies and light winds, with associated poor conditions for the dispersal of pollutants — in contrast to the generally favourable situation during summer.

The wind speed and direction were recorded continuously at the four sites at a height of 10 m above the surface, and at pre-selected times vertical soundings of wind direction and temperature were taken. Owing to instrumental difficulties, vertical soundings of wind speed were made for only a very limited period.

Results and Discussion

When the skies are clear and the large-scale winds are light (generally when the pressure is high), intense temperature inversions regularly develop, with accompanying well-developed katabatic air flow. Because of the strong stabilities, these flows are of great importance to air pollution. The opposite process (*anabatic* flow, i.e. flow up slopes) occurs by day as a result of warming of the surface and consequent heating of the air.

Although much can be deduced from a study of the flow patterns of the low-level winds, the important processes are obscured if the wind analysis is done on a diurnal basis. Therefore, the wind statistics for Lydenburg were divided into day and night components. Figs. 2 and 3 show the results for September 1975 in the form of wind roses for the four measurement sites.

A study of these figures shows strong katabatic development at night and anabatic flow by day. As remarked earlier, this is a typical winter situation. The role played by topography in channelling and deflecting the wind is also evident from Fig. 2, being especially marked at site 4. It should be noted that the day-time situation, with the wind blowing from the opposite direction, does not reflect such a marked influence (Fig. 3). A comparison of the wind roses for the four measurement sites indicates a chaotic air-flow pattern at night at site 4 owing to deflective forces. To a lesser extent this also applies to sites 1 and 2. This point is

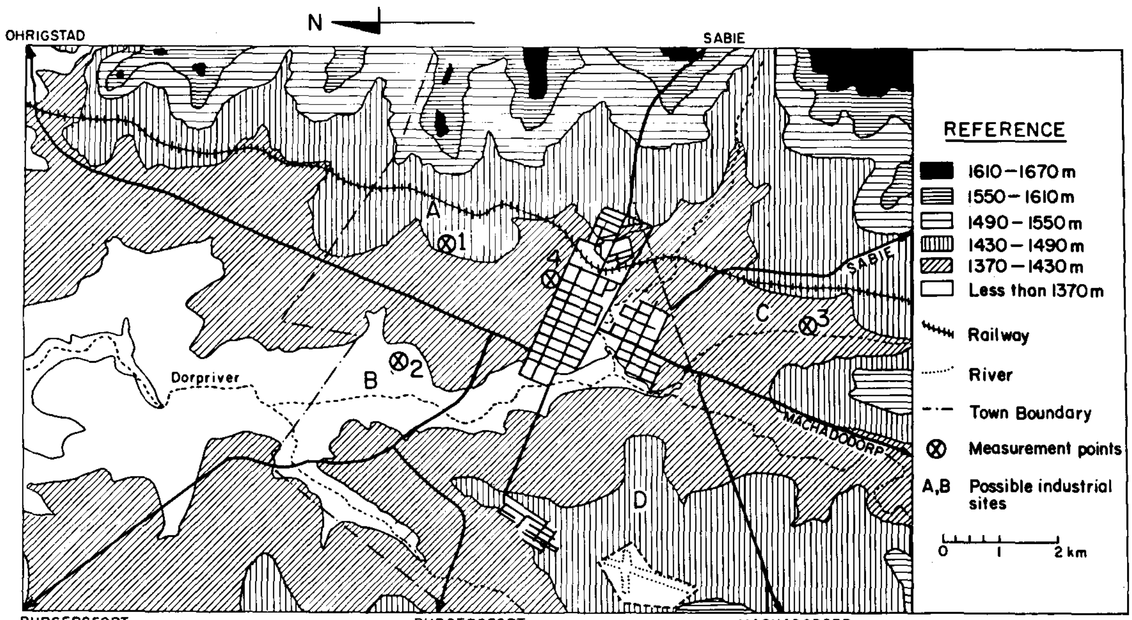

Fig. 1—The general area around Lydenburg

elaborated on later in connection with the vertical soundings.

The night-time statistics for sites 1 and 2 in October 1975 are shown graphically in Fig. 4. Comparison of Fig. 4 with Fig. 2 shows that the conditions during October approximated the expected summer situation, i.e. katabatic flow not so well-defined and mean wind speeds greater than during the winter. This can also be inferred from Table I, which summarizes the average situation shown graphically in Figs. 2 to 4. Table I also shows that the mean wind speed for September was about 1,8 m/s, which is almost half the day-time value for the same period.

Based on this information alone, some conclusions can be drawn about the suitability of the four sites for industrial development. However, the results of the vertical soundings, which clarify the situation, are discussed first.

A study of Table II, which summarizes the vertical soundings, reveals two important night-time features.

(a) During the sounding period, there was a high percentage of northerly winds at high level, whereas at low level the katabatic flow was well developed. Owing to the diagonally opposing winds at these levels, there is a strong possibility that a percentage of the pollutants that may be released at intermediate heights will be recirculated. This is obviously not a

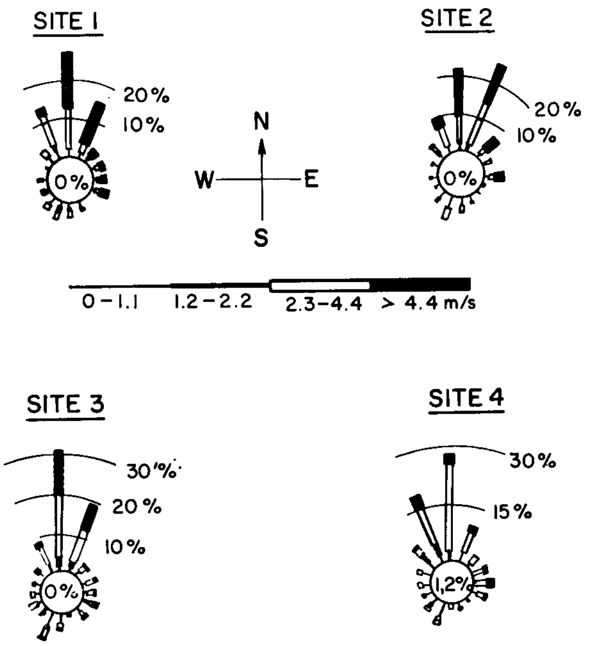

Fig. 3—Wind roses for the twelve day-hours for September 1975

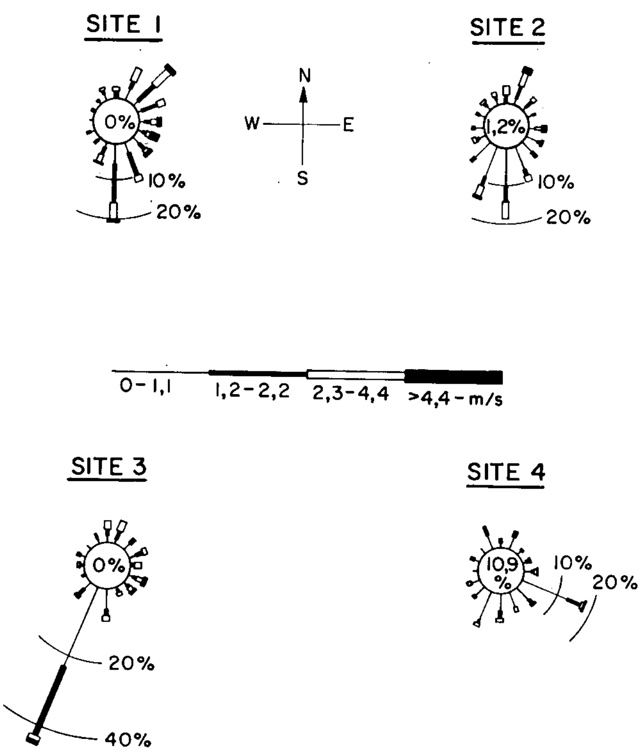

Fig. 2—Wind roses for the twelve night-hours for September 1975

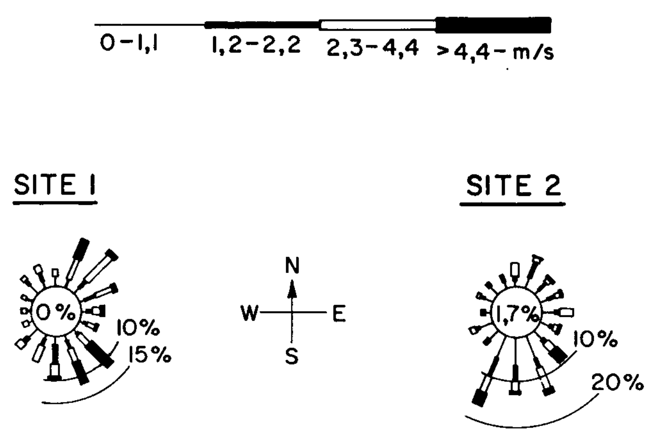

Fig. 4—Wind roses for the twelve night-hours for October 1975

TABLE I

FREQUENCY (%) OF THE LOW-LEVEL WINDS OVER THE LYDENBURG AREA FOR SEPTEMBER AND OCTOBER 1975

Wind-speed interval, m/s	September								October	
	18h00–06h00				06h00–18h00				18h00–06h00	
	1	2	3	4	1	2	3	4	1	2
0–1,1	28,6	54,1	42,3	77,5	10,5	12,0	12,7	16,9	16,9	44.3
1,2–2,2	37,8	23,3	40,0	16,8	14,2	11,5	15,0	17,9	20,4	23,7
2,3–4,4	26,3	18,1	14,5	3,9	37,2	44,3	44,4	53,5	41,4	22,1
4,4	7,3	4,5	3,2	1,8	38,1	32,2	27,9	11,7	21,3	9,9
Mean wind speed, m/s	2,4	1,7	1,9	1,0	3,9	3,4	3,4	2,6	3,6	2,3

good situation. The thermal stability is fairly severe and, as Table I suggests, the wind speeds are low.

(b) With southerly upper winds, the stability is still strong but not as severe as for (a), the recirculation of pollutants being unlikely under these conditions. The wind speeds should also be higher for (a) because the katabatic and large-scale influences should be additive.

The possibility of a chaotic air-flow pattern at sites 1, 2, and 4 can now be investigated more fully. From the definition of katabatic flow and from the general topography of the area (Fig. 1), it could be expected that the low-level night-time flow would be in a general northerly direction. Because a wind rose is a graphical representation of the average situation, it does not show the finer detail, and the actual wind records had to be studied. The records revealed a tendency for an eddying motion to develop over the general area of sites 1, 2, and 4. This is demonstrated graphically in Fig. 5, in which the wind directions at the four sites are plotted in a time sequence. The records also show that the eddying motion is not an isolated occurrence but develops on all nights when the katabatic flow is well developed and the upper winds are northerly.

TABLE II

VERTICAL TEMPERATURE SOUNDINGS OVER LYDENBURG

Direction sector	Wind direction frequency (%) at 225 m
NE — NW	80%
SE — SW	20%

Sounding time	Average wind direction at 225 m	Mean inversion strength °C/100 m	*Mean estimated height of katabatic flow m
02h30	N	2,25	38
	S	1,65	†
04h00	N	2,57	74
	S	1,64	†
05h30	N	2,86	79
	S	1,73	†
‡05h30	N	4,4	—
	S	3,0	—

*Height of gravitationally induced flow estimated from changes in wind direction

†Because of the direction of the upper winds, these values cannot be estimated from the directional changes

‡Maximum value

NOTE: 1. Total number of soundings in the period 12.9.75 to 1.10.75: 77

2. Total number of double soundings (i.e. at two sites at the same time): 15

3. Normal sounding period: 02h00 to 07h00

4. Mean maximum sounding height: 225 m

It is of great importance to establish to what height this eddying motion extends. This can be done by use of the simultaneous vertical measurements taken on a few occasions at two of the four sites. A time sequence of these measurements (Fig. 6), together with the low-level values, reveals that the eddying motion extends to the top of the katabatic flow regime, which is about 100 m. However, this does not imply that the top of the katabatic layer and the top of the inversion layer coincide.

Before the relative merits of the industrial sites were assessed, one further important point was noted, i.e. the physical distance of the sites from the town. The importance of this consideration lies in the fact that, under unstable (mostly day-time) thermal conditions, the concentration of effluent decreases inversely to the square of the distance from the source, and, under stable conditions (usually at night — strongest in winter), the concentration decreases by much less than the inverse of the square of the distance (usually a factor between 1,2 and 1,5).

Assessment

Based on the results, the suitability of the four sites was assessed as follows.

Sites A and B

Because of the eddying motion, which may result in a

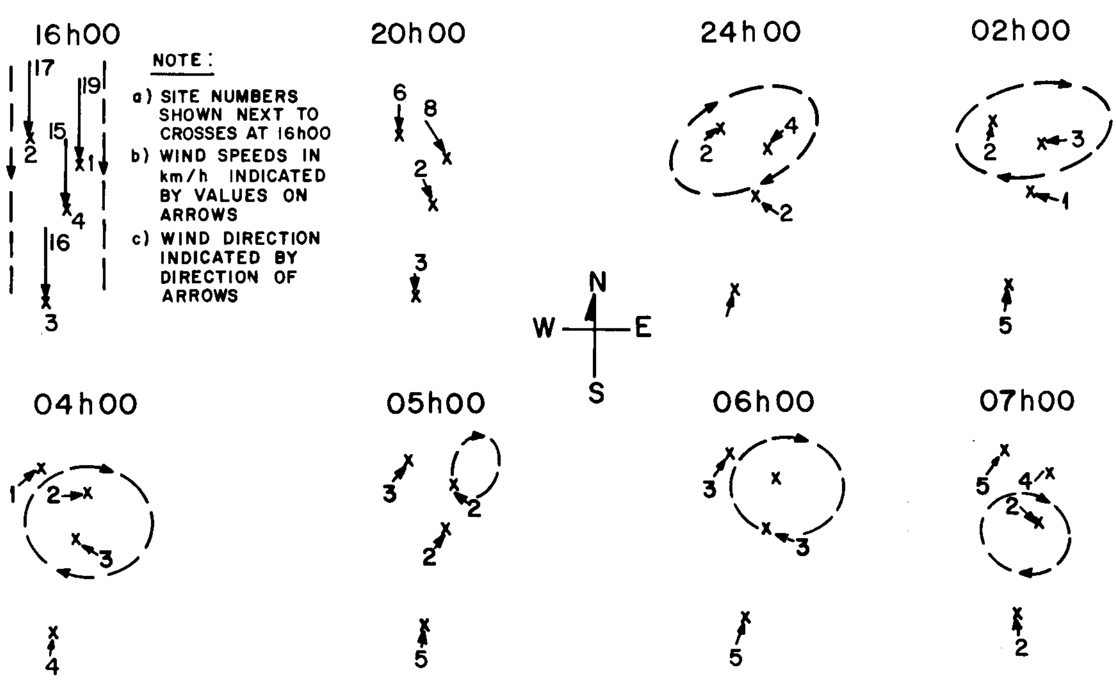

Fig. 5—Illustration of eddying motion (11th to 12th September, 1975)

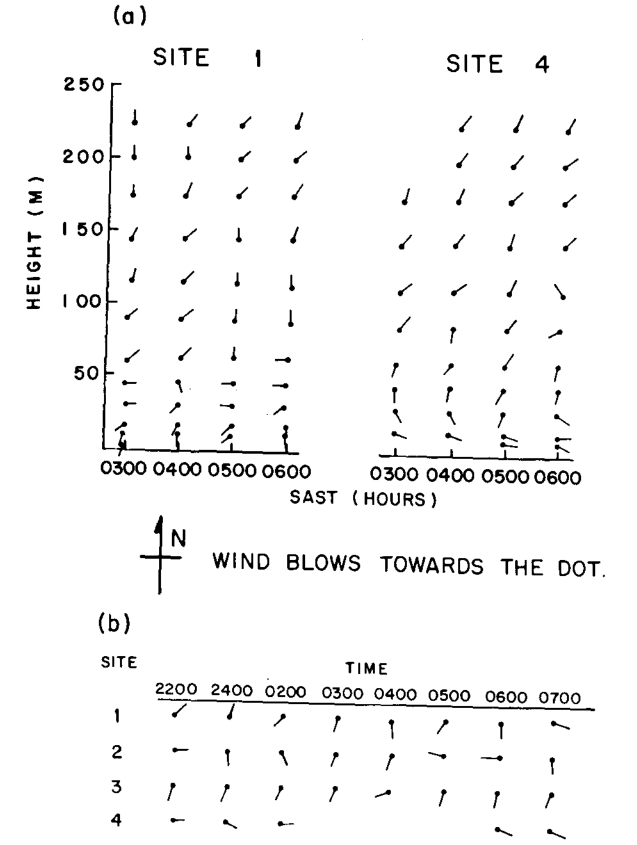

Fig. 6—Wind field over Lydenburg (22nd to 23rd September, 1975)
(a) Vertical development (b) Horizontal development

continuous input of effluent into the eddy with little or no output, pollutants are likely to build up over the town. This is a winter situation and should not create any problem in summer. The low wind speeds in the eddy and the high stabilities will also result in high concentrations of pollutants.

Site C

There is a possibility that pollutants may be entrained in the eddy. Furthermore, with the direction of the katabatic flow from measurement site 3 to the town, this is probably the worst of the four industrial sites.

Site D

Although the possibility of entrainment of pollutants into the eddy cannot be ruled out, all the other factors are favourable in terms of the town of Lydenburg: general direction of katabatic flow past the town, daytime winds away from the town, etc. However, the township directly to the north of this site rules it out for industrial use.

Because of the above, and also because of the large percentage of relatively light winds by day (Table I), it is evident that sites A and B are too close to the town for industrial use. In addition, by day in the winter, especially with subsidence inversion situations, effluent will not be able to spread vertically, implying, once again, that there will be high concentrations of pollutants over the town.

A much better area for a site of this nature (i.e. for development of a heavy industry) would be the general area further to the north of sites A and B (Fig. 1). In fact, this area has almost all the characteristics of the ideal site: direction of katabatic flow, large percentage of the prevailing winds, and general slope of the ground—all away from the town. Coupled with its relatively long distance from the town, these characteristics make it a very good site indeed.

Conclusion

A general observation that can be made from this paper is that many potential air-pollution problems can be averted if a proper evaluation is made before the siting of industries likely to pollute the air.

Acknowledgement

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Symposium on tin

The International Tin Symposium is to be held in La Paz, Bolivia, from 14th to 21st November, 1977. It is being held under the auspices of the Ministry of Mining and Metallurgy and of the private mining and metallurgical sector of Bolivia. The languages of the symposium are Spanish and English.

The symposium will cover the following subjects:

Geology: Prospecting and Exploration.

Mining: Underground, open-pit, and alluvial mining methods.

Processing: Preconcentration, concentration, flotation, and pyrometallurgical methods of beneficiation.

Metallurgy: Technical aspects of smelting.

Uses of Tin.

Marketing: Concentrates, ingots, alloys, and other tin products.

Additional information may be requested from the following address:

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