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Particulate Stack Emissions from Coal Fired Power Stations

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Introduction

Coal fired power stations are generally accounted to be amongst the major potential contributors to atmospheric pollution. Eskom, as one of South Africa's prime producers of power, has been — and remains – committed to maintaining a responsible approach towards all environmental issues, especially air quality. Since the primary generation of power is derived from coal fired Stations serving a heavily populated area, considerable attention has been focussed over the years on the issues of particulate and gaseous stack emission levels.

The levels of particulate and SO_2 emissions are influenced primarily by the characteristics of the coal burnt, but may also be controlled by how (and when) the coal is mined and by the design and operation of the various items of power plant. Many studies have been carried out — particularly in the western world — to investigate the emission levels of plants in operation. That is, monitoring in and around power stations is carried out to quantify the levels of emissions and their impact on the local environment (cf. Cressie et al., 1990, Dixon 1989, Pitelka and Raynal 1989).

The studies described in this paper differ in both nature and environmental impact, in that they are carried out *before* the coal reaches the power station. That is:

- the coal *in situ* is analysed for its potential emission characteristics;
- the mine plan is superimposed on these characteristics to assess the quality of the coal *before burning*;
- potential stack emissions are predicted on a year-to-year basis using different mining scenarios.

This type of study has proved invaluable in the assessment of: the planned mining of coal seams; in the amount of blending and/or quality control sampling which

is required during production; in the decision to use or extend the use of washing plants; and — perhaps most important in this context — in the design of the power plant and the control of stack emissions. At the time of writing, three detailed studies have been carried out on particulate stack emissions. In each case, significant changes have been made to either the mine design, the processing of the coal or to the planned gas cleaning equipment.

This paper describes a typical investigation into the potential particulate stack emission characteristics of a coal mine over its planned life and demonstrates how geostatistical methods may be used to control air pollution *before* its inception. Some comments are made on the planned extension of this work to the quantification of potential SO_2 emissions.

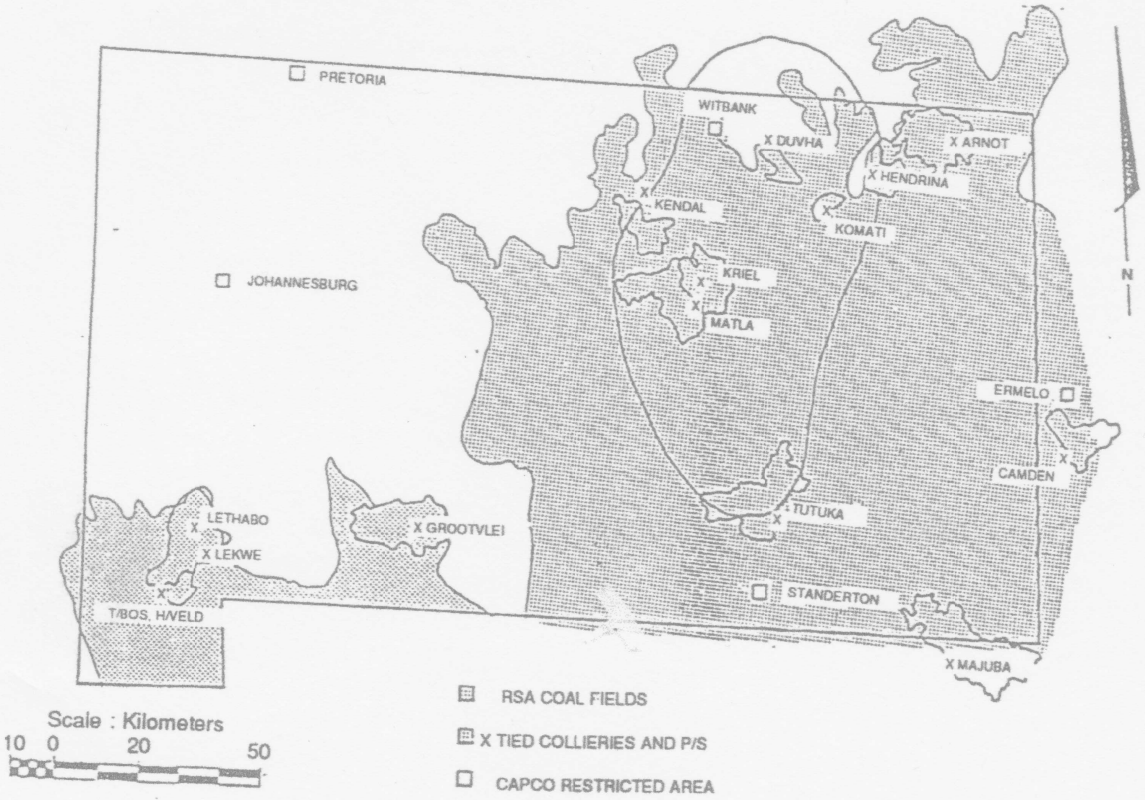
Coal Fired Power Stations in the Eastern Transvaal

Eskom is one of South Africa's key producers of power, which it generates primarily from coal fired Power Stations. The majority of these Stations are located in the Eastern Transvaal, relatively close to the heavily populated Pretoria/Witwatersrand/Vereeniging area (See Figure 1). Because of this juxtaposition, a considerable amount of attention has been directed to the potential problems of air pollution — both particulate and gaseous. The concentration of Stations and their potential impact on air quality is an ongoing subject of intense debate with the licensing authorities, principally the Chief Air Pollution Control Officer (CAPCO).

In the late 1970's, CAPCO designated an area in the Eastern Transvaal — referred to as the air pollution "egg" – within which the level of air pollution could not be increased further. The 1981 limits of this "egg" are shown in Figure 1. The current limits of the controlled area (now referred to as a "blanket") cover the whole of the area in Figure 1. This essentially means that any new Power Station constructed within this area has to adhere to, or improve upon, specific environmental standards for particulate and show predicted gaseous emissions, not yet subject tp legal standards.

The standards or licence limits which are set for particulate emissions have over the years become increasingly strict. Vierfontein Power Station, for example, which was commissioned in the mid–1950's, had a limit of 1020 mg/Sm^3. Highveld Power Station, completed in the early 1960's, had a limit of 396 mg/Sm^3. Matla (1979–1983) has an average limit of 245 mg/Sm^3, whilst the currently developing Power Stations are subjected to limits of 90–100 mg/Sm^3. There has been a consequent need to improve upon plant design and operation to reduce potential levels of particulate emissions. It seems likely that CAPCO will expect improvement of plant performance and installation of control technology to impact positively on the air quality parameters under the "blanket".

Figure 1: RSA Coal Field



The levels of emission from a power station are influenced principally by the characteristics of the coal burned. However, the method of mining, the mine design and processing (if carried out) affect the quality of the coal delivered to the Station. The design and operation of the power and gas cleaning plant itself has a major impact on the particulates released from the stack. Historically, the power plant design — including precipitators — within Eskom was based upon the descriptive analysis of the geological data as provided in the tender document for that coal field. Often the only data utilised were global averages for coal quality parameters over the field and over the life of the mine. The likely variability of the coal quality over the life of the mine plan was not generally considered in power plant design, until the late 1970's. In addition, geological data and quality predictions supplied by the mining companies often proved unreliable or overly optimistic.

It should, perhaps, be noted that the regulatory levels specified in the CAPCO licences are *continuous* limits. That is, *any* violation of these limits over whatever

period is subject to severe penalty. It should also be noted that most mine plans and schedules supplied to Eskom are made on the basis of the mining company's financial year. It is necessary, therefore, to assess whether there is any chance of exceeding the limits during a particular year of operation of the power station — and if so, over what period the limits are likely to be exceeded.

The studies described in this paper were aimed at remedying the short-comings of a 'global' approach to evaluating the potential emission levels, especially as regards the spatial variability of coal quality parameters and the temporal variability introduced by the mining procedures.

Emission Levels

The potential particulate emission level from coal burned depends on various coal quality parameters and on the method of mining and associated factors. These factors can be modified by processing ('washing'). This discussion will be confined to *in situ* characteristics of the coal. The relevant factors are:

- the sulphur content of the coal;
- the ash content of the coal;
- the calorific value of the coal;
- the total moisture in the coal;
- the level of stone contamination introduced by the mining process.

This last factor is generally assumed to be constant for a particular mining method and will have a significant impact on the dust generated when the product is burned. The projected emission level can be calculated from these parameters, using formulae developed by Eskom's Boiler Plant Engineering department for each specific gas cleaning plant. These formulae must contain plant-specific characteristics, such as gas volumes and velocities, dust burdens, input temperatures and precipitator collecting efficiency. The resulting emission level is expressed in mg/Sm^3 — that is, milligrams per standard cubic metre.

In the earliest study (1988) within Eskom, particulate emission levels were calculated for each borehole intersection available in the projected mine area. These values were then used to (arbitrarily) contour the emission levels over the study area, at levels of 20 mg/Sm^3. The mine plan prepared by the colliery was overlaid on this contour plan and typical emission levels read along the centre line of each planned mining panel. It was thus possible to quantify the likely emission level for a specific year of production, or for any specific period after mining had commenced.

Three such studies were undertaken and potential levels of non-compliance were indicated. The results of these (fairly simplistic) studies suggested that a more flexible, computer based approach would be invaluable.

Why Geostatistics?

The relative success of the above simple methodology suggested that spatial and temporal analysis of the mine plan yielded valuable decision making information. Statistical and geostatistical methods were considered for these studies to provide:

- more reliable forecasts of particulate emission levels, in particular for Power plant design purposes;
- results which could be presented and assessed with a greater degree of confidence by the licencing authorities;
- greater flexibility in studying various mining and plant design scenarios;
- information on the interaction between coal quality parameters and trends across the mine area.
- objective confidence levels for the final estimates for each and every scenario.

Geostatistical methods allow us to predict the average values over each mining panel *and* the likely variability of the coal within each panel. Standard errors associated with these estimates may be used to provide confidence levels to assess the reliability of the final projections. Panels can be combined over any planned time period to assess the likely non-compliance with CAPCO limitations.

It is felt that the information which geostatistics can generate will be invaluable in predicting emission levels, identifying time periods of non-compliance and, thus, in modifying production and in negotiating with CAPCO. This information will also aid in planning and in setting of policy.

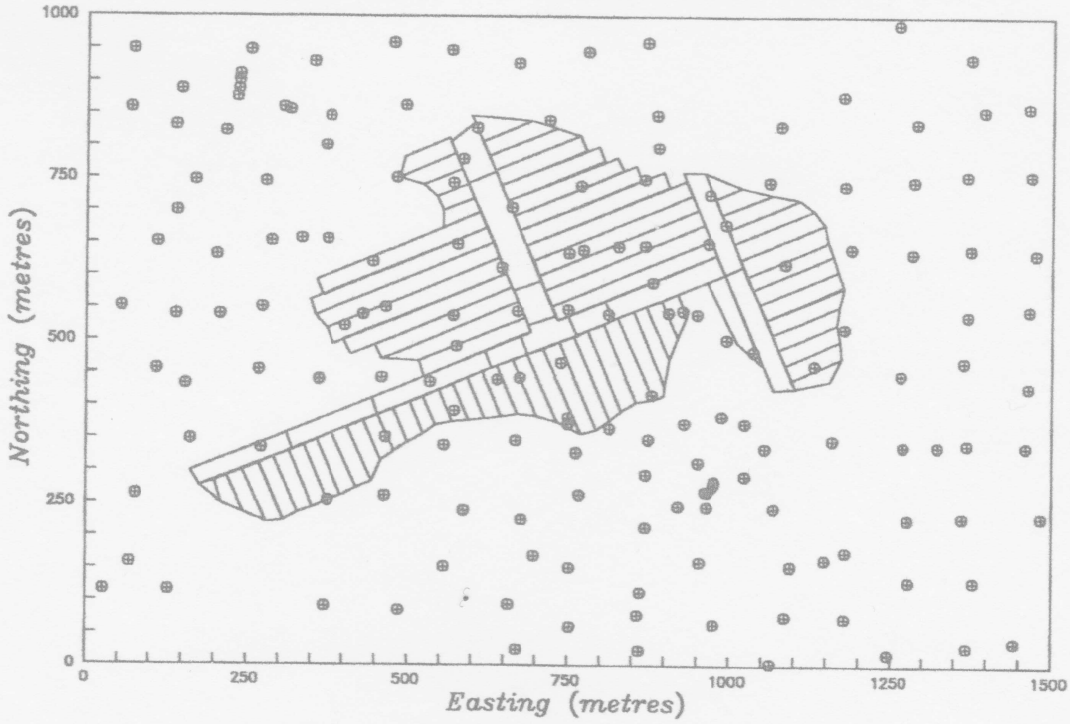
A Typical Study

The procedure which has been developed over the studies carried out to date will be described *in general* in the following section. Due to confidentiality concerns, it is not possible to publish a detailed case study to illustrate this process. However, the following should give a reasonable idea of the procedure.

The necessary information for such a study consists of:

- Plans and sections of the coalfield, showing borehole collar locations and major geological features;
- Plans showing the location, shape and size of the proposed mining panels and details as to the year in which each is to be mined;
- Data on the elevation and/or dip, width of seam, calorific and ash values, sulphur content, the resulting predicted emission levels and any other relevant variables for the individual boreholes.

Figure 2: Planned mining panels and boreholes



A typical area is shown in Figure 2, with borehole locations and a typical mining panel layout. Panels are generally irregular in shape, conforming to mining considerations and to local geological characteristics. The study is undertaken in various stages:

a. Statistical analysis of the various measurements, with special emphasis on the behaviour of the emission levels. Histograms were constructed for each variable and studied for outliers and inconsistencies.

b. Scatterplots were used to establish relationships amongst the variables and also to identify aberrant behaviour.

c. Trend surface analysis was used to determine large scale 'regional' movements in value for various variables — where appropriate. Residuals from these trend surfaces were inspected for evidence of outliers and/or data inconsistencies.

d. Semi-variogram graphs were constructed to display the spatial continuity or 'predictability' of values from one location to another within the coal seam. The particular variables of interest are the thickness of the seam and the projected emission level. Simple models were fitted to these graphs for estimation purposes.

e. The method of 'cross validation' was used to test the fit of the semi-variogram model and to highlight extreme values or outliers within the sample data set. This analysis also provided an opportunity to study the potential distribution of estimation errors.

f. Data value corrections were made on the basis of these analyses and the whole process repeated once more.

g. Using the distribution and semi-variogram models, values were estimated for each mining panel within the mine plan. These values — weighted by volume of panel — were summarised for each year of mining.

h. Using the panel estimates, two scenarios were constructed:

   a 'best case', where it is assumed that controlled blending will take place at all times — i.e. the yearly average can be maintained throughout the year;

   a 'worst case' scenario, in which it is assumed that no quality control or blending will take place and mining panels will be mined one at a time in sequence.

i. Results from the 'best case' and 'worst case' scenarios are summarised in the form of simple graphs for clarity, showing the likelihood of emission levels exceeding the established permissible CAPCO level.

As a very limited example of the type of intermediate results produced by such a study, Figures 3 and 4 are provided. Figure 3 shows a 'spotted dog' illustrating the particulate emission levels for each borehole. It can be seen that the levels vary considerably over a relatively small area — but still retain a certain spatial continuity, which may be described by a semi-variogram model. Figure 4 shows a typical kriged map of emission levels over the study area. Such a map is produced by Ordinary Kriging of values at points on a grid placed over the study area. This map is, of course, too *smooth* to be used in the 'worst case' scenario described below. However, it gives a good idea of the likely fluctuation in level for (say) mining panels.

Best Case Scenario

Two 'scenarios' are considered in each study. In this first scenario, we assume that the quality of the coal mined in any specific year can be kept constant over that year by carefully controlled blending and, possibly, a quality control sampling campaign carried out during production. Around 40 mining panels are shown in Figure 2. For the 'best' case, we need to estimate the average value of each year's production. Contiguous panels planned to be mined in a specified year are combined into 'polygons' for estimation purposes. For each specified year of production we must estimate the average value over each polygonal area. These individual averages

Figure 3: Emission Level --- mg/Sm^3 (OK)

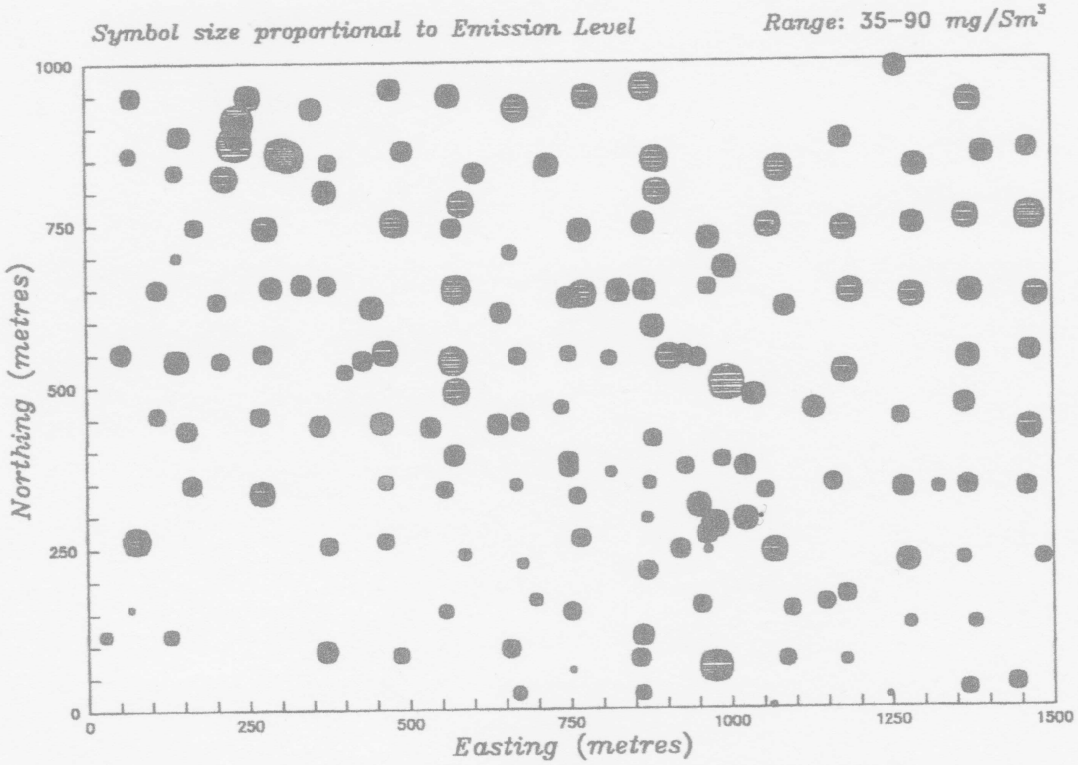
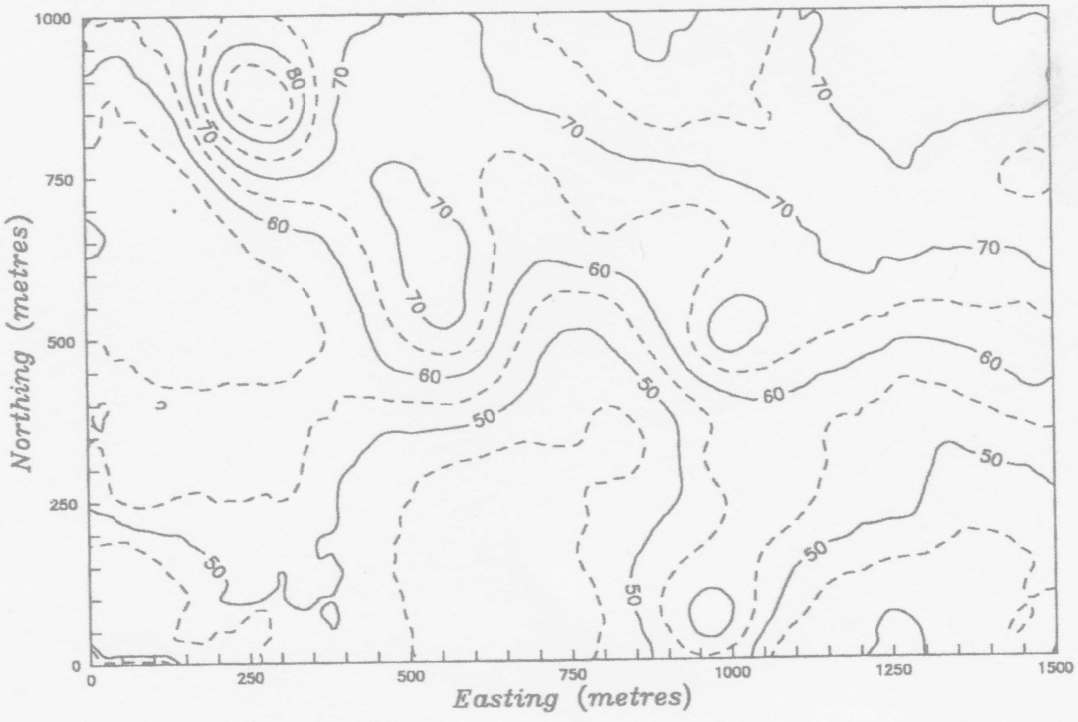


Figure 4: Estimated Emission Level --- mg/Sm^3 (OK)



may then be combined to form the yearly average *and* its associated standard error may be calculated.

The average emission level for each year of production, then, is calculated by combining the estimated emission level per panel, the seam thickness per panel and the year of mining as follows:

> The volume mined from each panel is average width × area, corrected for dip if necessary;
>
> The emission level from each panel is weighted by the volume to be mined from that panel;
>
> All panels to be mined in one year are combined by volume and the yearly average calculated;
>
> The standard error of this estimate is found by a similar combination of the individual panel standard errors.

This last stage can only be carried out on the assumption that the areas mined in a particular year are fairly widely scattered over the study area. In most RSA coal mines this assumption seems to be fairly realistic — except, perhaps, in the initial years of mining.

Having produced an average emission level for each year of mining and an associated standard error for this average we may also produce statistics such as *confidence levels* on the results. If we can assume a particular distribution for the estimated values — and for the error of estimation — we can reverse the calculation and find out exactly how probable it is that the yearly mined average will exceed the limit. A cross validation exercise was carried out during each study to verify the likely distribution of estimation errors. In most cases, a Normal distribution could be assumed. In the remainder, lognormal estimation theory was used.

Prior to applying geostatistics, the effective approach was to assume a 'best case' scenario using the overall average for the whole mine. Assuming 'best case' or average coals over the lifetime of a mine — or, at least, a power station — has resulted in non-compliance emissions and, thus, in confrontation with CAPCO. An estimation method which produces better/more data on the likelihood of mining poor quailty coal will allow coal blending or washing to achieve compliance with the CAPCO emission limits.

Worst Case Scenario

In the previous section we assumed that the coal could be mined to the estimated average value — at all times. That is, we assume that the coal can be blended in such a way as to maintain an even feed to the power station over each year of mining. This was viewed as a "best case scenario". Under these assumptions, we might find that the emission levels are unlikely to exceed the CAPCO limits in a particular year.

The 1988 Eskom study considered a "worst case scenario" — that is, supposing that no blending or quality control took place and that the coal was simply mined from one 'end' of the first mining panel to the other 'end' of the last. The variation of values within each mining panel was estimated by taking several points within the panel and estimating the value at each. The proportion of points with values above the CAPCO level was assessed and this figure quoted as the "worst possible case".

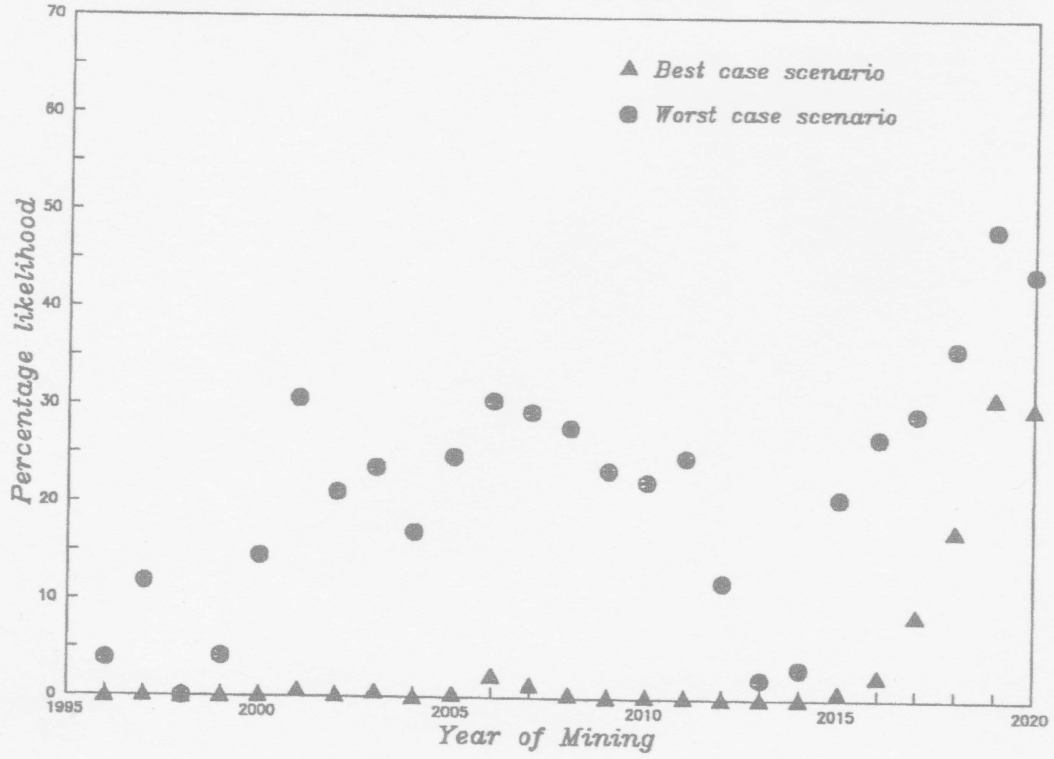
In a geostatistical study, we need to estimate (or simulate) the emission value at each individual *point* within each mining panel. In cases where the density of sampling permits estimation without the inherent *smoothing* problems of kriging, a dense grid of points was estimated within each panel. Where drilling is more sparse, simulation methods or 'support' corrections are used to insure the correct variability for the expected emission levels.

We can then assess how many of these *points* are above the acceptable limit and express them as a percentage of the whole mining panel. For each mining panel, then, we will have a 'percentage exceeding CAPCO limit (mg/Sm^3)'. As noted before, each mining panel represents a different mined tonnage which we have approximated by a 'mined volume' — area of mining panel $\times$ width. For each year of mining, then, we take all panels to be mined in that year and form a weighted average of the 'percentage' according to the *volume* of coal to be mined.

Figure 5 shows a typical graph illustrating the probability of exceedance for both 'best' and 'worst' cases. We can see the considerable impact that controlled blending would have on the coal produced. Although a high percentage of the coal may exceed the permitted limit, blending with 'better' coal can reduce this well below the required level. This implies that the production quality control sampling should be an important factor in the detailed mine plan.

Using these two 'best' and 'worst' scenarios effectively *brackets* the likely power station performance for coal supplied under a specified mine plan. The difference between these two outcomes in the case illustrated in Figure 5, demonstrates that control of particulate emissions can (in some cases) be controlled by modifying the planning and scheduling of the actual mining — so that better quality coal can be provided for cleaner burning.

Figure 5: Likelihood of exceeding permitted emission level



Summary

On the basis of the results of the initial studies it is apparent that being able to predict particulate emission levels from geological data provides an important decision-making tool in terms of power plant design and operation.

This approach enables alternative mine and Power Station development options to be modelled and evaluated from a technical and economic point of view. For example, in one case studied several development options were considered, including:

1. Modification of the mine plan, a reduction in stone contamination and blending between panels which would lead to good quality coal within the CAPCO limits for most of the life of the mine. After this period, SO_3 injection could be retrofitted to improve collecting efficiency so as to maintain acceptable levels of particulate emission.
2. The precipitators could be enlarged or SO_3 injection fitted earlier — putting the onus on the Power Station rather than the mine.
3. A complete change in gas cleaning plant design could be made to reduce stack emission — for example, the fitting of fabric filters.

In a different study, the mine was found to be in danger of non-compliance during almost every year of its life (even in the 'best case'). In this case, the need to fit SO_3 injection is being critically reviewed together with the possible introduction of partial beneficiation of the coal to reduce the dust burden. However, this last option has to be considered very carefully as beneficiation also reduces the inherent sulphur in the coal. Since sulphur acts to reduce the level of particulate emission, a delicate balance must be maintained in any planned beneficiation.

In view of the success achieved in the studies of particulate emission using geostatistics, a similar approach is being adopted for the study of SO_2 emission levels. The study of particulate and SO_2 emission levels in coal fired Power Stations is considered to be of fundamental importance in Eskom's continued efforts to minimise air pollution.

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