# COST-EFFECTIVE STRATEGIES FOR DUST CONTROL IN AN OPENCAST COAL MINE

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## DECLARATION

I declare that this project report is my own, unaided work, except where otherwise acknowledged. It is being submitted for the degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other university.

Signed this 15th day of September 1997

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## ABSTRACT

Opencast coal mining operations release significant quantities of dust into the atmosphere and this can be a cause of nuisance and annoyance to local residents. Dust dramatically limits visibility, raises the cost of operating vehicles, increases their downtime and escalates repair cost. The best strategy for avoiding or mitigating potential liabilities of opencast coal mining is to employ proper management of dust. To achieve this goal, an emission inventory which provides the most fundamental basis for planning dust control strategies and evaluating their results, is required.

A comprehensive airborne dust emission inventory has been compiled for an opencast coal mine. This inventory involved identification of dust emission sources, collection of site specific data and use of emission factor equations to quantify each sources contribution to dust output of the mine. Results indicate that haul road dust emissions represent nearly 77 % of all particulate emissions from the mine. Because haul roads are such a major source, this source category has been the primary focus of a dust control cost-effectiveness investigation.

In this study an economic model has been developed to evaluate alternative haul road dust control strategies. Various control strategies can be used to mitigate dust emissions from haul roads. The economic evaluation was limited to watering and three selected chemical dust suppressants which are currently available in South Africa, namely calcium chloride, ligno-sulphonate and polymerised bitumen. Economic analysis indicates that the most cost-effective dust control is provided by calcium chloride. Caution is given that factors other than cost-effectiveness, such as slipperiness of treated surfaces, may influence final product selection. The sensitivity of results to certain cost components is explored. It was determined that the model was effective in evaluating the cost-effectiveness of dust control strategies.

Identifying strategies that are cost-effective will help to increase their use and reduce dust emission levels at opencast coal mines. Cost curves, used to depict the results of the economic analysis, show the most efficient strategy or combination of strategies at various dust control levels. This information can be used to select appropriate mitigation approaches, formulate guidance policies, and determine the cost of dust reduction from opencast coal mines.

In loving memory of my father
who never doubted it was possible....

To our Lord who met me at every
corner and inspired each innovation.
May the glory be His eternally

To Cynthia, Maxwell, Edina and David.
Their patience was stretched
beyond all reasonable limits yet their
understanding held out miraculously

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# GLOSSARY OF TERMS

**Application Frequency** - Number of applications of a control measure to a specific source per unit time; equivalently, the inverse of time between applications.

**Application intensity** - Volume of water or chemical solution applied per unit area of the treated surface

**Bucket-Wheel-Excavator (BWE)** - A continuous digging machine with a boom on which is mounted a rotating vertical wheel having buckets on its periphery. As the rotating wheel is pressed into the material to be dug, the buckets cut, gather, and discharge the material onto a conveyor belt where it is moved to the mined-materials transport system.

**Burden** - The distance between the explosive charge and the free face of the material to be blasted.

**Chemical Stabilisation** - The use of chemical dust suppressants for the control of fugitive particulate emissions from open dust sources or material storage piles.

**Control Efficiency** - Percent decrease in controlled emissions from the uncontrolled state.

**Cost-Effectiveness** - The cost of control per unit mass of reduced particulate emissions.

**Dilution Ratio** - Ratio of the number of parts of chemical concentrate to the number of parts of water (e.g. one part chemical to four parts of water).

**Dozer** - A highly versatile piece of earth excavating and moving equipment especially useful in land clearing and levelling work, in stripping topsoil, in road and ramp building and in floor or bench cleanup and gathering operations.

**Dragline** - A type of excavating equipment which casts a rope-hung bucket a considerable distance, collects the dug material by pulling the bucket toward itself on the ground with a second rope, elevates the bucket, and dumps the material on a spoil bank or on a pile.

**Dust Suppressants** - Water or chemical solution which, when applied to an aggregate material, binds suspendable particulate to larger particles.

**Emission Factor** - An estimate of the mass of uncontrolled emissions released to the atmosphere per unit of source extent.

**Emission Rate** - Mass of emissions generated per unit time.

**Emissions Inventory** - A listing and classification of all sources of emissions, and the quantity of emissions generated for a specific geographic area or facility.

**Erosion Potential** - Total quantity of erodible particles, in any size range, present on surface (per unit area) prior to the onset of erosion.

**Eskom** - Electricity Supply Commission.

**Exposed Area** - Outdoor ground area subject to the action of wind and protected by little or no vegetation.

**Front End Loader** - A tractor loader with a digging bucket mounted and operated at the front end of the tractor.

**Fugitive Dust** - Solid particles generated by the action of wind or machinery which are not emitted from a stack, duct or flue.

**Haul Road** - A road built to carry heavily loaded trucks that transport coal to the preparation plant. It is also used by loading facilities and provide personnel and equipment access to the pits and mine area.

**Materials Handling** - The receiving and transport of raw, intermediate and waste materials, including stacking and reclaiming of aggregates, conveyor transport and associated conveyor transfer and screening stations.

**Moisture content** - The mass proportion of an aggregate sample consisting of unbound moisture as determined from weight loss in oven drying.

**Opencast Mine** - A mine working or excavation open to the surface.

**Open Dust Sources** - Sources of fugitive emissions that entail generation of particulate matter by the forces of wind or machinery acting on exposed (i.e. open) materials where no physical or chemical change occurs to the particle-generating material.

**Overburden** - Barren or non-coal material that overlies and must be removed to gain access to the coal.

**Particle Diameter, Aerodynamic** - The diameter of a hypothetical sphere of unit density (1 $\mu g/cm^3$) having the same terminal settling velocity as the particle in question, regardless of its geometric size, shape and true density.

**Physical Stabilisation** - Any measure which physically reduces the emissions potential of a source resulting from either mechanical disturbance or wind erosion.

**PM-10** - Particulate matter less than or equal to 10 μm in aerodynamic diameter.

**Process Sources** - Sources of fugitive emissions associated with industrial operations that alter the chemical and physical characteristics of a feed material.

**Road, Paved** - A roadway constructed of rigid surface materials such as asphalt, cement, concrete and brick.

**Road, Unpaved** - A roadway constructed of nonrigid surface materials such as gravel (crushed stone) and chip surfaces.

**Road Surface Dust Loading** - The mass of loose surface dust on a paved roadway, per area of roadway as determined by dry vacuuming.

**Road Surface Material** - Loose material present on the surface of unpaved road.

**Silt Content** - The mass proportion of an aggregate sample smaller than 75 μm in diameter as determined by dry sieving.

**Silt Loading (sL)** - The mass of silt-size material per unit area of the travel surface, it is the product of the silt fraction and the total dust loading

**Source, Area** - A collection of many small, unidentified points of air pollution emissions within a specified area, all emitting less than the minimum level prescribed for point sources.

**Source, Point** - A source that emit more than specified levels of certain pollutants.

**Source Extent** - The measure of the level of source activity. For roads, the source extent is in vehicle kilometre travelled (VKT) per year.

**Total Suspended Particulate (TSP)** - Particulate matter measured by a high volume sampler with an inlet 50% cut-off 30 - 50 µm in aerodynamic diameter.

**Vehicle, Heavy-Duty** - A motor vehicle with a gross vehicle travelling weight exceeding 30 tons.

**Vehicle, Light-Duty** - A motor vehicle with a gross vehicle travelling weight not exceeding 3 tons.

**Vehicle, Medium-Duty** - A motor vehicle with a gross vehicle travelling weight greater than 3 tons.

**Waste, Spoil** - The overburden or non-coal material removed in gaining access to the coal in surface mining.

**Wet suppression** - The application of water to the surface of the material producing emissions to inhibit the generation of particulate matter emissions.

**Wind Erosion** - The release of fines from either aggregate storage piles or open areas by high winds.

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# CHAPTER 1

# INTRODUCTION

## 1.1 Statement of the Problem

The nature of opencast coal mining is a large material handling operation. It involves stripping of topsoil, drilling and blasting to fragment the overburden and coal, removal of overburden by dragline, loading of coal by shovel, hauling of coal by dump trucks to the crushing plant, coal preparation and its transfer either to a power station or to stockpiles. All these operations are on the surface and are inherently dust-producing. Airborne dust emissions at opencast mines are classified as fugitive dust because they result mainly from machinery movement, wind action, and material transfer at or near ground level (Olson and Veith, 1987).

Excessive levels of fugitive dust from opencast coal mining may result in operational and environmental problems. The effect on the local community of persistent dust as a result of opencast mining is its potential to cause annoyance and nuisance. Fugitive dust can cause serious visibility problems which may result in decrease in production owing to reduced haulage speed. It can cause expensive damage to equipment when abrasive materials enter engines, bearings and other moving parts. Excessive dust escalates maintenance cost resulting in more frequent oil changes and filter replacement. Furthermore, heavy haul trucks tend to fracture road surface aggregates, causing significant fines to be generated and increasing loss of material and road maintenance.

The best strategy for avoiding or minimising potential liabilities on opencast coal mines is to employ proper management of dust. A rational dust control plan requires sound decision-making based on high quality information and decision-making tools. One of such decision-making tools is an emission inventory which provides the most fundamental basis for planning dust reduction strategies and evaluating their results. With such an inventory as a starting point, rational control plans may then be devised for individual facilities in the context of their fractional contribution to the overall atmospheric burden.

The identification and implementation of a sound dust control plan in opencast coal mines would provide the means for cost-effective use of resources whilst significantly reducing fugitive dust levels. However, one of the major difficulties has been the inability to quantify rapidly the total financial benefit of available and new dust control strategies. A cost model that acknowledges the interrelationship of key components and their effect on the total cost that can be used to effectively evaluate alternative dust controls will help alleviate this problem.

Any rational dust control plan, based on a costing analysis, should allow cost-effective allocation of resources within the atmospheric pollution budget of the operation in relation to other sections of the environmental control plan. It will provide actual data in motivations to the board for capital expenditure as well as a rational basis for interactions with the control authorities and the community. A well conceived dust control plan will also provide a credible base for environmental auditing. Furthermore, identification of cost-effective dust control strategies will encourage their acceptance and use in the coal mining industry.

## 1.2 Purpose of the Research

The primary aim of this research is to develop an economic model that will enable more cost-effective use of resources for control of dust emissions from an opencast coal mine. The specific objectives of the study are to:

- reassess the existing (1992) airborne dust emission inventory of an opencast coal mine,

- review and evaluate dust control technologies based on effectiveness, technical feasibility, economics and long-term environmental impact,

- develop a systematic approach in seeking the optimal dust control strategy,

- develop a spreadsheet cost model of dust control on the mine in order to determine possible savings and/or reallocation of resources.

## 1.3 The Scope of the Study

The scope of this study is to develop cost-effective strategies for dust control in an opencast coal mine. This involves

- carrying out an emission inventory to identify dust emission sources and quantify each source's contribution to total airborne dust emissions,
- identifying control strategies to deal with the dust problem,
- developing a cost model and
- applying this model to evaluate existing and alternative dust control measures.

This study takes place on an operating mine, New Vaal Colliery, which is situated in the northern part of the Vereeniging/Sasolburg coalfield some 70 km south of Johannesburg. The colliery is a large opencast mine contracted to supply 15 million tons of coal per annum to Eskom's Lethabo Power Station. It operates in close proximity to Vereeniging and the Three Rivers residential area. The mining area is bounded on three sides by the Vaal River and to the south lies the power station. A locality plan of the area is shown in Figure 1.1. A site of 720 ha within the mining area has been earmarked as an ash dump for the nearby power station (Ford and Stenzel, 1996). This colliery is different from other mines supplying feedstock to a power station in South Africa because it produces the lowest quality coal and it is the first major colliery developed to mine coal by opencast methods from reserves mined previously by underground means (New Vaal Colliery, 1997a).

New Vaal Colliery was, therefore, selected for dust emission assessment and cost-effective dust control strategy investigation because of its operations and location which poses considerable concern in terms of environmental pollution, particularly dust and noise. Excluded from the study are dust emissions resulting from the power station, including ash handling and wind erosion from ash dumps.

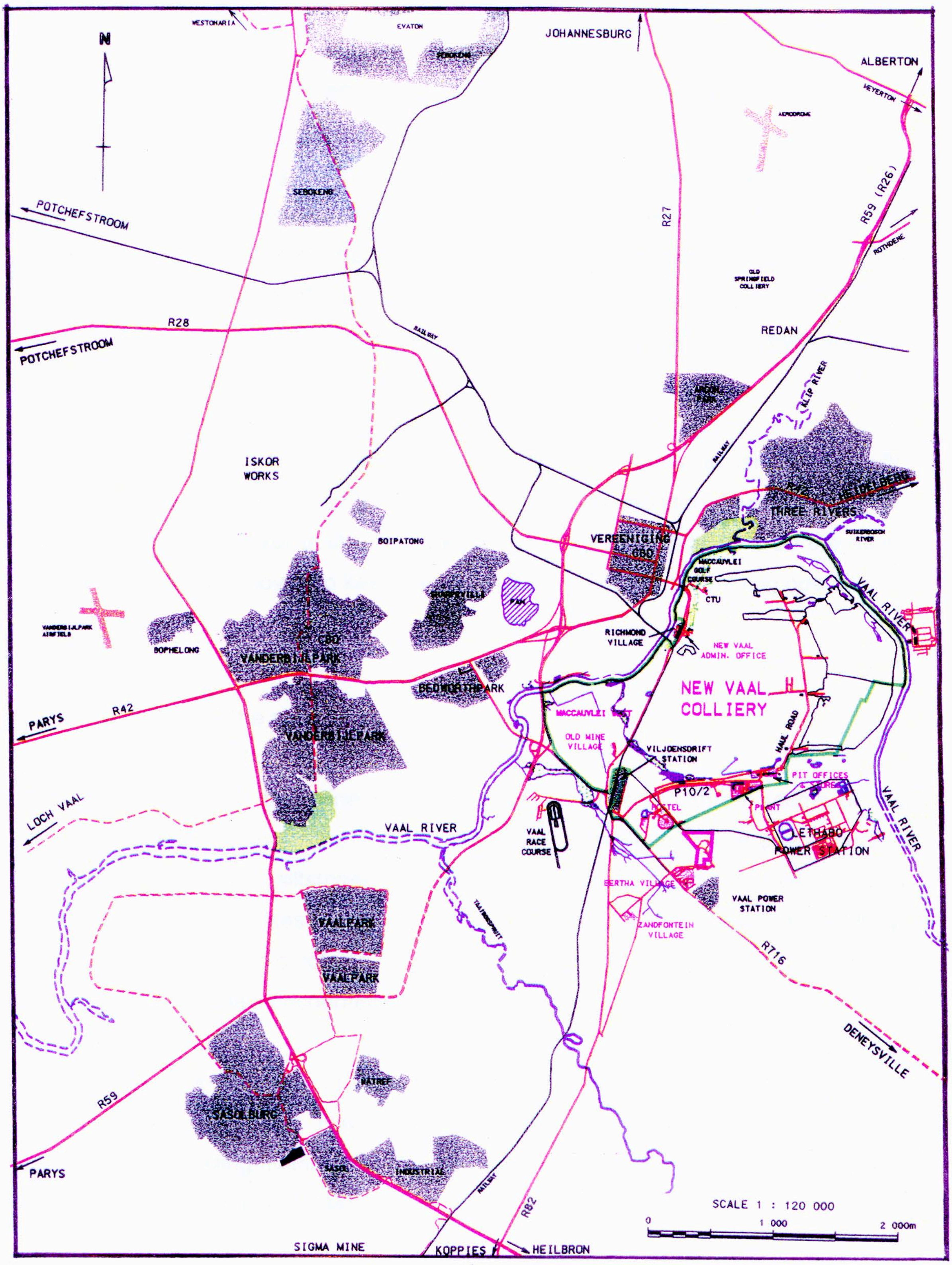


**Fig. 1.1: Locality plan of the study area (New Vaal Colliery, 1994)**

## 1.4 The Study Area

### 1.4.1 Air quality management

The systematic watering down of haul roads using large water tankers and the necessary dust suppression in the plant form the current levels of dust control at the colliery. Dust is controlled on the haul roads by watering with water pumped from the mine workings to a dam. Sprays or dust extractors are used to control dust at the Run-Of-Mine (ROM) tip, primary and secondary screens, and conveyor transfer points.

Measurement of dust levels around the colliery's operations is carried out, with particular regard to Vereeniging. Dust on the mine is monitored using 26 single bucket and 9 twin bucket dust collectors placed at strategic positions on the mine. The bucket sites are moved to keep pace with the progress of the mining operation.

### 1.4.2 Geology of the area

The coal reserves in the mine lease area are contained in three seams of the Vryheid Formation; namely the Top, Middle and Bottom Seams. The coal occurs in the Karoo sandstones, siltstones and shales. The Karoo sediments overlie a thin sequence of Dwyka tillites which rest on Transvaal dolomites (New Vaal Colliery, 1997a). The stratigraphic column, as illustrated in Figure 1.2, shows a typical cross section of the materials encountered during the mining operations.

The Overburden consists of two main parts. Firstly, a 16 m thick layer of unconsolidated sand and clay is encountered. Below this is a layer of hard overburden consisting mainly of shales and sandstone, with an average thickness of 7.4 m (New Vaal Colliery, 1994).

The Top Seam is almost totally unmined by underground bord-and-pillar method . It has an average thickness of 7.0 m and a maximum development of 13.0 m. The Interburden has a coarsening upward sequence grading from carbonaceous mudstone forming the Middle Seam roof, through shale and siltstone to fine-grained sandstone forming the Top Seam floor (New Vaal Colliery, 1997b). This unit averages 11.6 m in thickness.

| LITH. | AVERAGE THICKNESS (m) | ROCK TYPE | HORIZON | CLASSIFICATION |
|---|---|---|---|---|
| | 1.0 | SOIL | SOFT OVERBURDEN | |
| | 15.0 | SAND & MINOR CLAY | SOFT OVERBURDEN | |
| | 7.4 | SHALE SILTSTONE & SANDSTONE | HARD OVERBURDEN | VRYHEID FORMATION / ECCA GROUP / KAROO SYSTEM |
| | 7.0 | **COAL - TOP SEAM** | TOP SEAM | VRYHEID FORMATION / ECCA GROUP / KAROO SYSTEM |
| | 11.6 | SANDSTONE SILTSTONE SHALES | INTERBURDEN | VRYHEID FORMATION / ECCA GROUP / KAROO SYSTEM |
| | 6.9 | **COAL - MIDDLE SEAM** | MIDDLE SEAM | VRYHEID FORMATION / ECCA GROUP / KAROO SYSTEM |
| | 1.5 | SILTSTONE/GRIT | PARTING | VRYHEID FORMATION / ECCA GROUP / KAROO SYSTEM |
| | 4.2 | **COAL - BOTTOM SEAM** | BOTTOM SEAM | VRYHEID FORMATION / ECCA GROUP / KAROO SYSTEM |
| | | DWYKA | FLOOR | DWYKA / KAROO SYSTEM |
| | | DOLOMITE | | TRANSVAAL SYSTEM |

**Fig. 1.2 : Stratigraphy of the study area (New Vaal Colliery, 1997b)**

The Middle Seam averages 6.9 m in thickness and it has been previously mined over about 25 % of the mine lease area (New Vaal Colliery, 1997b). The Parting is a carbonaceous, silty to gritty mudstone overlying a thin grit bed. This unit averages 1.5 m in thickness but ranges from 0.1 to 7.5 m.

The Bottom Seam with an average thickness of 4.2 m has previously been mined over about 36 % of the mine area. It consists of hard bright bonded coal and it is of better quality than the Top or Middle Seams (New Vaal Colliery, 1997b). The Dwyka Formation is a sequence of interbedded shale, coal, sandstone, grit, conglomerate and tillites.

### 1.4.3 Opencast coal mining

The mining method used at New Vaal Colliery involves the sequential removal of the various layers of overburden so that each of the coal seams is exposed in turn. The initial operation is the removal of topsoil and sand which constitute soft overburden by using a bucket-wheel-excavator (BWE), spreader and three conveyor belts. The BWE has a rotating wheel which continuously scoops up sand and delivers it on to a conveyor system which, at present, has a length of 4.2 km (New Vaal Colliery, 1997a). Spreaders then deposit the sand according to rehabilitation requirements.

After the topsoil and unconsolidated sand and clay have been removed the hard overburden and interburden which comprise shales, sandstones and siltstones are drilled and blasted. Removal of blasted hard material is done by draglines and sidecasted onto the spoils side of the pit. This waste material is dumped above ground in the most advantageous position, having regard to the position of the final void or the possibility of putting the dump in an area where the levels are to be raised in the course of restoration, thus minimising subsequent rehandling of material.

The coal seam then becomes accessible for mining. The exposed coal is drilled and blasted. Electrically-driven rope shovels are used to load the broken coal into 170 ton rear dump trucks, and it is taken out of the pit along graded haul roads to the primary tip. The coal mining sequence is controlled by the mine's Planning Department, which schedules daily coal quality and the amount of rock contamination that is permissible to dilute coal quality (New Vaal Colliery, 1997a).

Rehabilitation, which forms an integral part of the mining operation, is aimed at restoring the surface to a land form to create the best practical conditions for future use. The process involves returning soft and hard overburden together with waste material to the mined-out-areas. These are then levelled and profiled by track dozers. Topsoil, containing organic matter and indigenous grass seeds is replaced onto the levelled and profiled surface and spread by a grader to give an even coverage. The area is then prepared by tilling and fertilisation and is planted with grass species.

### 1.4.4 Coal treatment process

Coal from the opencast mine is unsized and contaminated with rock. The level of contamination increases in mining areas that were previously mined by underground methods (New Vaal Colliery, 1997a). The coal processing plant has therefore been designed to reduce the size of the mined coal by crushing and screening the coal to sort it into various groups for selective processing. It is also washed to reduce contamination levels.

An isometric view of the Coal Preparation Plant is shown in Appendix A. Raw coal from the pit is dumped into primary tip bunkers by rear dump haul trucks, from which it is withdrawn by two apron feeders and delivered onto vibrating grizzlies separating the feed into - 300 mm and + 300 mm material. The - 300 mm feed is conveyed straight out of the tip whilst the + 300 mm is fed to the primary crushers which reduce the feed to - 200 mm for transportation by overland conveyor to either the ROM stockpiles or to the primary screening building. The two ROM stockpiles, each with a capacity of 30 000 tons, are used to provide storage capacity between the mine and the plant to buffer interruptions between the mining operation and screening plant (New Vaal Colliery, 1997a).

The feed is screened in the primary and secondary plants into three fractions; namely - 25 mm, + 25 to - 90 mm and + 90 to - 300 mm. The first fraction is directly fed to the Eskom stockyard whilst the two remaining fractions can be directed either to the Dense Medium Separator (DMS) plant for de-stoning or to the secondary crusher.

At the DMS plant the coal is wet-screened to remove fine material adhering to the + 25 mm lumps. The fines are dewatered on vibrating screens and horizontal vacuum belt filters and join the feed to the power station stockyard (New Vaal Colliery, 1997a).

The screened stone/shale and coal directed to the DMS plant is fed into a Drewboy washing vessel containing a mixture of magnetite and water at a relative density of approximately 2.0 (New Vaal Colliery, 1994). The heavier stone/shale (discards) sinks while the coal floats. The washing plant function is to de-shale the coal rather than the more conventional beneficiation operation (Wessel, 1996). The discards are sent via conveyors to the 2 000 ton discard silo for transportation back into the pit whilst the coal is sent to the secondary crushers to be reduced to - 25 mm size before it is fed to the Eskom stockyard.

### 1.4.5 Lethabo coal stockyard

Lethabo stockyard, which is an Eskom facility, is operated by New Vaal Colliery on contract. It provides for surge between the mine and power station and is intended to blend coal prior to delivery to the power station, in order to reduce variations in the quality of the coal delivered (New Vaal Colliery, 1994). The stockyard is operated so as to ensure that coal is delivered to the power station at a constant calorific value as close to 16 MJ/kg as possible.

900 000 t or up to three weeks of the power station's coal requirements are stored in live stockpiles while up to three months' stock can be held in compacted stockpiles (New Vaal Colliery, 1997a). There are three stacker/reclaimers that stack out coal onto six live stockpiles each 950 m long in the windrow pattern and then reclaim the coal in rotation for delivery to the power station.

Coal is also removed as required from the live stockpiles to strategic piles which can hold 3.2 Mt. Coal in the strategic stockpiles is compacted to prevent combustion. These strategic piles provide a reserve for higher power station burning rates during winter, or as a contingency against a major delay in the coal-supply route to the stockyard (New Vaal Colliery, 1997a).

# CHAPTER 2

# EMISSIONS INVENTORY OF THE MINE

An emission inventory is a comprehensive, accurate and current determination of air pollutant emissions and associated data from sources within a specific area over a specific time interval (U.S. EPA, 1981a). It serves as a baseline for a control programme in that as the inventory is updated from year to year it is possible to chart the progress of the programme. Additionally, an emission inventory is required as an input for dispersion modelling to enable prediction of ambient pollutant levels to be made and serves as a guide in the selection of parameters for monitoring programmes.

The purpose of this chapter is to present qualitative and quantitative procedures that are used to compile a comprehensive and reliable source inventory. Firstly, the status of the existing inventory is presented and its limitations are discussed. This is followed by the methodology for compilation of the current emission inventory. Finally, an outline of the procedures used to calculate emission rates for each of the sources is presented.

## 2.1 Status of the Existing Inventory

An emission inventory of particulate pollutants was compiled for the Vaal Triangle for the 1992 calendar year. Total suspended particulate (TSP) and particulate matter with aerodynamic diameter equal to or less than 10 $\mu$m (PM-10) from point and area sources were quantified. Results of the existing inventory indicate that New Vaal Colliery contributed 14 240 and 4 968 tons of TSP and PM-10 respectively (van Nierop, 1995). This was found to be about 10 % of the particulate pollutants in the Vaal Region. These high figures may be attributed to large values that were assigned to certain parameters, such as silt and total moisture content of unpaved road surface material and aggregate stockpiles, based on default values from United States Environmental Protection Agency (U.S. EPA) literature. This was inappropriate since these parameters depend on site-specific meteorological factors as well as material properties.

The existing emission inventory was compiled by mine personnel without background information other than the questionnaire which was provided. This study is aimed at re-assessing the inventory, validating it and bringing it up to auditable standards. All the input data and dust control efficiencies are examined, updated and properly documented.

One of the limitations of the existing emission inventory, however, is that some important sources, such as paved roads, wind erosion from material stockpiles, dozing and grading were not quantified. There is, therefore, the need to extend the inventory to include dust from all source categories.

The existing inventory is for the 1992 calendar year. This is already five years out of date and, for planning purposes, it needs to be updated on a more regular basis to take into account the change in geometry of the mine and current dust control strategies.

### 2.2 Methodology for Compilation of Source Inventory

The general approach was to apply U.S. EPA procedures for emission inventory compilation. This involved collection of data, making use of single-value and predictive emission factor equations and other physical parameters from the mine to calculate emissions.

First, a list of all fugitive dust source categories that exist within the study area, as well as emission factors and their associated parameters necessary for calculation of emissions, was compiled. Data and other information, such as actual traffic count on paved areas and unpaved haul roads, necessary for calculation of emission rates and grab samples from paved/unpaved roads and coal stockpiles were then collected from the mine. Laboratory analysis of grab samples was conducted to determine more important site specific parameters such as silt content.

### 2.2.1 Identification and classification of dust emission sources

Sources of fugitive dust emissions can be divided into two categories; namely open dust sources and process sources (Cowherd, 1993). Open dust sources include mining activities that generate fugitive emissions of solid particles by blasting, forces of wind or machinery acting on exposed materials. Process sources are those associated with operations, such as material handling and coal processing activities, that change the physical and chemical characteristics of the feed material.

Open dust emissions are generated by mining activities that disturb topsoil, overburden, and coal; causing dust to be emitted into the air. Sources of fugitive dust at the mine can be conveniently discussed in the same sequence that mining occurs. This involves stripping of topsoil using bucket-wheel-excavators, drilling and blasting of overburden and coal, overburden and coal removal, and hauling of coal by dump trucks along unpaved haul roads to the primary tip. Other open dust sources include emissions from paved roads due to vehicular movement and wind erosion from material stockpiles and exposed areas.

Most of the process sources that generate dust emissions take place within an enclosure of some sort to prevent wind blown emissions and to allow dust to be routed to air cleaning devices. Process sources include coal dumping, crushing and screening. Other sources are emissions from coal conveyors and transfer points.

### 2.2.2 Selection of emission factors

Dust emission rates from opencast mining activity are most frequently determined from an emission factor that relates dust emission rates to soil characteristics, meteorological conditions and surface activities (Chow and Watson, 1994). An emission factor as defined by U.S. EPA (1985) is an average value that relates the quantity per unit time of a pollutant released into the atmosphere with the activity associated with the release of that pollutant.

An emission factor may be presented as a single-value arithmetic mean or in the form of a predictive equation derived by linear regression analysis of test data. The predictive emission factor equation mathematically relates emissions to parameters which characterise source conditions. It enables more reliable estimates of source emissions on a site-specific basis by allowing for correction of the emission factor to specific source conditions (U.S. EPA, 1987).

Due to the absence of locally generated emission factors, use was made of the comprehensive set of emission factors published by U.S. EPA in its AP-42 document known as "Compilation of Air Pollutant Emission Factors" (U.S. EPA, 1995). This AP-42 represents official agency guidelines on the emission factors to be used for a wide variety of fugitive dust emission sources (U.S. EPA, 1991a).

Selection of specific emission factors is a very important part of preparing an emission inventory and the key to selecting the best factor to predict emissions from a particular mining activity is to choose one that best represents prevailing operational conditions (U.S. EPA, 1991b). Appendix B presents a number of emission factors from the AP-42 compilation which were used to prepare this emission inventory.

The reliability and accuracy of AP-42 emission factors are indicated by rating which ranges from A through E, with A being the best. The emission factor rating reflects both the amount, and the representative characteristic, of those data on which the factor is based. Emission factor ratings are only applicable if all the actual parameter values fall within specified allowable ranges and site specific data (such as silt and moisture content) are available (U.S. EPA, 1987). Ratings are lowered by one if assumptions are made for site specific data or if the actual parameter values do not fall within the allowable limits.

### 2.2.3 Data collection

In order to collect the necessary data required for compilation of the source inventory, several methods were employed including the use of a questionnaire, site-visits, correspondence and telephonic interviews. In certain instances, data were collected by personal involvement in work done by certain departments of the colliery and personal communication with personnel who head such departments. The major advantage of physically being at the mine for data collection was that it provided more thorough and accurate information about the study area than would a questionnaire alone. Copies of all forms used have been presented in Appendix C and data sources are well documented in Appendix D.

### 2.2.4 Sample collection

The method used for sample collection was based on AP-42 Appendix C1 (U.S. EPA, 1995) which presents procedures recommended for the collection of material samples from paved and unpaved roads and from bulk storage piles. Dust from paved and unpaved roads was sampled by sweeping 0.5 to 1.0 kg of the material into airtight ziplock bags for laboratory analysis. Sampling areas were identified from emission site surveys. For each general area that was identified, multiple samples were taken and mixed to obtain a representative composition.

For a network consisting of many relatively short roads contained in this well defined study area, samples were collected for each 0.8 km length, or portion thereof, for each major road segment as recommended by U.S. EPA (1991a). String was used to mark an ~ 0.3 m wide portion across the road. With a whisk broom and dustpan, the loose surface material from the hard road base was removed. Sweeping was performed slowly so that fine surface material was not injected into the air. In all, 14 samples were collected from the main haul road and the ramps. Haul road sampling points and labelled road segments are presented in Appendix E.

Samples for paved areas were collected from roads and parking areas surrounding the plant (16 samples) and the pit offices (7 samples). As a vacuum cleaner, which is the recommended sampling device for collecting paved road dust samples was not available, a whisk broom and a dustpan were used. Again care was taken to ensure that fine loose material was not disposed into the air.

Samples were also taken from each of the coal stockpiles at the stockyard. To reduce the total number of individual samples for such large storage piles, a transect sampling plan was developed and a minimum of ten samples were collected and mixed to form an integrated representative of the material as a whole. Coal samples were collected to a depth of 10 to 15 cm with a straight-point shovel and the samples were stored in clean labelled plastic buckets with cover.

### 2.2.5 Laboratory analysis

The method used for the laboratory analysis of surface/bulk dust loading samples was based on recommended procedures outlined in Appendix C2 of U.S. EPA (1995). The total moisture content of coal of 8.3 % was obtained from New Vaal Colliery (1995). Samples of road dust and grab samples from coal stockpiles were stored in airtight containers until they were sieved. The nest of tared sieves was placed on a conventional shaker for 10 minutes. Each sieve was then weighed to determine the distribution of material and the silt content. The portion of the material passing through a 75 μm screen is defined as the silt content (U.S. EPA, 1991a). Results of silt analysis are shown in Table 2.1.

**Table 2.1 : Results of silt analysis**

| TYPE OF SOURCE | NUMBER OF SAMPLES ANALYSED | SILT CONTENT (%) | | |
|---|---|---|---|---|
| | | RANGE | MEAN | STANDARD DEVIATION |
| Haul Roads (unpaved) | 16 | 4.5 - 7.0 | 5.8 | 0.48 |
| Paved Roads (Plant) | 8 | 13.0 - 18.4 | 15.7 | 1.64 |
| Paved Roads (Pit Offices) | 4 | 7.8 - 9.1 | 8.2 | 0.54 |
| Coal Stockpiles | 6 | 0.7 - 1.9 | 1.4 | 0.54 |

## 2.3 Estimation of Dust Emission Rates

The rates of dust emissions for the assessment are determined for individual operations using the expected extent of the operations such as coal production figures, volumes of overburden handled, the length of haul roads, stockpile size or the area of disturbed surfaces together with emission factors for unit operations (Zib, 1991).

In using emission factors to calculate dust emissions, inputs to the estimation algorithm, such as activity information from the source inventory, emission factors to translate the activity information into "uncontrolled" emission estimates, and control efficiency information to provide the basis for estimation of emissions, are required (U.S. EPA, 1981b). The source extent is the appropriate measure of source size or level of activity which is used to scale the uncontrolled emission factor to the particular source in question (Cowherd, 1993). The general mathematical equation used to calculate the dust emission rate from any given source as provided by Cowherd *et al.* (1988) is as follows:

$$R = M * E * [1 - c] \quad (2.1)$$

where:

R = estimated mass emission rate
M = source extent (i.e., surface area for most open dust sources)
E = uncontrolled emission factor (i.e., mass of uncontrolled emissions per unit of source extent)
c = fractional efficiency of control

The accuracy of the emission estimate is dependent upon the relative accuracy of each of these individual components and therefore care was taken in selection or estimation of these three data variables.

### 2.3.1 Estimation of dust emissions from paved roads

Dust emission from paved roads has been found to vary with the "silt loading" present on the road surface as well as the average weight of vehicles travelling the road (U.S. EPA, 1995). The term silt loading (sL) refers to the mass of silt-size material per unit area of the travel surface (Chow and Watson, 1994). The current AP-42 emission factor predictive equation, which is rated A, for estimating quantity of dust emissions from vehicle traffic on paved roads is given by the following empirical expression (U.S. EPA, 1995):

$$E = K * (sL/2)^{0.65} * (W/3)^{1.5} \quad (2.2)$$

where:

E = particulate emission factor, g/VKT

K = particle size multiplier

sL = surface silt loading, $g/m^2$

s = surface silt content, %

L = total road surface dust loading, $g/m^2$

W = average weight of vehicles travelling the road, tons

The particle size multiplier K varies with aerodynamic diameter. AP-42 particle size multiplier values used for dust emission estimation were 24 and 4.6 for TSP and PM -10 respectively. The total road surface dust loading is that of loose material that can be collected by sweeping (by broom) and vacuuming of the travelled portion of the paved road. Silt loading is determined by finding the product of the silt fraction and the total dust loading (U.S. EPA, 1995).

Mean values of surface dust and silt loadings for paved roads were determined from results of silt analyses and physical measurement of the area of sampling strips. Table F1 gives an idea of the extent of surface dust loading on paved roads at the coal treatment plant and those surrounding the pit offices. Arithmetic mean values of dust and silt loadings for the paved areas are shown in Table F2.

Another parameter of interest in estimation of dust emissions from paved roads is vehicle kilometres travelled (VKT). VKT along the paved roads were obtained by conducting a traffic count and multiplying this value by the length of the road. Results of the traffic count is shown in Table G1. The assumptions used are outlined in Appendix G.

Emission rates were calculated by multiplying the emission factor by paved road VKT per year. The VKT per year was obtained by multiplying VKT per day by 6 days per week and 52 weeks per year according to the mine's work schedule. The average weight of vehicles travelling on all paved roads was taken to be 3 tons with due consideration being given to the high percentage of light duty vehicles that uses the roads. Estimated annual emission rates for paved roads are shown in Table H1.

### 2.3.2 Estimation of dust emissions from haul roads

The data base required for estimation of dust emissions from unpaved haul roads include vehicle kilometres travelled, vehicle speed, average daily traffic, silt content of road surface material, number of days with rainfall greater than 0.25 mm, and the average number of wheels per vehicle (U.S. EPA, 1977). The predictive emission factor equation for unpaved road is provided by Chow and Watson (1994) as follows:

$$E = K * 1.7 * (s/12) * (\mathbf{S}/48) * (\mathbf{W}/2.7)^{0.7} * (w/4)^{0.5} * (365-p)/365 \qquad (2.3)$$

where:

E = PM-10 emission factor, (kg/VKT)

K = particle size multiplier, (dimensionless)

s = silt content of road surface material ( %)

**S** = mean vehicle speed, (km/h)

**W** = mean vehicle weight, Mg (ton)

w = mean number of wheels (dimensionless)

p = number of days with at least 0.25 mm of precipitation per year

In estimating dust emissions from haul roads, AP-42 particle size multiplier values of 1 and 0.36 were used for TSP and PM-10 respectively. Information on vehicle weight was obtained from New Vaal Colliery (1985). Data sources relating to vehicle speed and number of wheels have been documented in Appendix D. The vehicle kilometres travelled on the haul road was obtained by conducting traffic count and multiplying this value by the length of the haul road. The results of the traffic count on the haul road are shown in Table G2 and the assumptions used are presented in Appendix G. Rainfall data was obtained from Nefale (1996).

Dust emission estimates were obtained by multiplying the emission factors obtained from predictive equation 2.3 by the haul road VKT and an efficiency term. An empirical model for calculating the performance of watering as a control technique has been developed by Cowherd *et al.* (1988). The model is as shown below:

$$C = 100 - [(0.8 * p * d * t) / i] \qquad (2.4)$$

where: $C$ = average control efficiency, %

$p$ = potential average hourly daytime evaporation rate, mm/h

$d$ = average hourly daytime traffic rate, vehicles/hr

$i$ = application intensity of water, $\ell/m^2$

$t$ = time between watering applications, hr

The control efficiency of water spraying at New Vaal Colliery was calculated to be 70% based on the above performance model. Parameter values used for the calculation include application intensity of water of 0.5 $\ell/m^2$, average daytime hourly evaporation rate of 0.21 mm/hr and average daytime hourly traffic rate of 88 veh/hr. The sources of data used are presented in Appendix D. It must be pointed out that the frequency of watering depends on the dustiness of haul roads but, in this calculation, one hour was used as the time interval between applications after discussion with the mine personnel involved with the watering programme and personal observation during the study. TSP and PM-10 control efficiencies were assumed to be equal for all fugitive dust sources.

Total annual dust emissions from haul road were calculated using the formula:

$$T = \sum_{i=1}^{8} [E_i * G_i * (1 - c)] \qquad (2.5)$$

where:

$T$ = total emissions, (kg)

$E_i$ = emission factor for vehicle class i

$i$ = class of vehicle ranging from 1 to 8

$G_i$ = VKT for vehicle class i

$c$ = fractional efficiency of dust control

Table H2 shows the contribution from each class of vehicle to the total annual dust emission from the haul road.

### 2.3.3 Estimation of coal handling emissions

Coal stockpiles are left uncovered because of the need for frequent coal transfer into or out of the stockpile. The quantity of dust emissions from coal storage operations varies with the volume of coal passing through the storage cycle and correction parameters such as total moisture content, proportion of coal fines and wind speed. The following AP-42 predictive equation was used to estimate emissions due to coal handling of stockpiles (Cowherd *et al.*, 1988):

$$E = K * (0.0016) * [U/2.2]^{1.3} / [M/2]^{1.4} \qquad (2.6)$$

where:

E = emission factor, kg per metric ton transferred (kg/Mg)
K = particle size multiplier, (dimensionless)
U = mean wind speed, (m/s)
M = material moisture content, (%)

The particle size multiplier, K, varies with aerodynamic particle diameter. The AP-42 particle size multiplier values used for this calculation were 1 and 0.35 for TSP and PM-10 respectively. The mean wind speed of 3.0 m/s was obtained from climatic records of the study area. Production planning or actual production figures provided the total number of tons of coal handled. Information regarding coal production, moisture content and other important parameters was obtained from New Vaal Colliery (1995).

Emissions were estimated by multiplying the emission factor calculated using equation 2.6 by the amount of coal deposited on and removed from the pile per annum. The results of the emissions from coal handling of each of the stockpiles are as shown in Table H3.

### 2.3.4 Wind erosion of storage piles and exposed areas

Dust emissions may be generated by wind erosion of open aggregate storage piles and exposed areas. For emissions from wind erosion of active storage piles, the following TSP emission factor equation is recommended (Cowherd, 1993):

$$E = 1.9\,(s/1.5)\,[(365 - p)/235]\,(f/15) \qquad (2.7)$$

where:

E = total suspended particulate emission factor, (kg/day/ha)
s = silt content of aggregate (%)
p = number of days with $\geq$ 0.25 mm of precipitate per year
f = percentage of time that the unobstructed wind speed exceeds 5.4 m/s at the mean pile height

The fraction of TSP which is PM-10 is estimated at 0.5 and is consistent with the PM -10/TSP ratios for material handling and wind erosion. From the available wind data obtained from Annegarn Environmental Research (AER), the percentage of time that the wind speed exceeds 5.4 m/s at the mean pile height was 20 %. The particulate emissions owing to wind erosion from coal stockpiles and exposed areas are presented in Table H4.

### 2.3.5 Other fugitive dust emission calculations

**Open dust sources**

Dust emissions due to mining activities, such as topsoil removal and dumping, drilling and blasting, overburden removal and replacement, and coal removal are calculated by using uncontrolled emission factors presented in Appendix B and applicable source extents shown in Table H5.

Blast hole drilling and subsequent blasting are effective means of loosening and fragmenting overburden or coal prior to excavation. The number of holes required is dependent on the size of the block in bank cubic metres (BCM), hole spacing (burden and spacing) and depth of hole. The drilling pattern of overburden and coal depends on the thickness of the material and, if the area has been previously mined by underground method, the interval between pillar centres is taken into consideration. Overburden of thickness 3 - 7 m requires 6 m x 7 m pattern whilst that of 20 - 26 m needs a 7.5 m x 9.0 m pattern. For previously mined-out areas with 18.3 m pillar centres, a 9.14 m x 9.14 m grid is used whilst a grid pattern of 7.62 m x 7.62 m is used for 15.2 m pillar centres for coal. For areas which have not been mined previously, a drilling pattern of 7.5 m x 8.5 m is used. Bottom Seam and parting of thickness 3 - 6 m uses either a 6 m x 6 m or a 5 m x 5 m pattern.

Data obtained from the mine indicate that 100 blast holes of 171 mm diameter and 50 blast holes of 250 mm diameter are drilled each day for 6 days per week and 52 weeks per year in readiness for blasting the overburden. In addition, 100 vertical blast holes of 171 mm diameter are drilled in the coal seams per day by means of diesel powered hydraulic operated rotary drills. Blasting of overburden and coal takes place 6 days per week.

In calculating dust emissions emanating from the removal of overburden by dragline, the average drop height of the dragline and moisture content were taken as 7.5 m and 7.9 % respectively, based on discussion in AP-42. In cases where an emission factor for PM-10 emissions was not available, estimates were obtained by multiplying the TSP value by 0.5 which is the PM-10/TSP ratio.

Dozers and graders are ideal for grading and levelling of spoils. In reclamation work, these machines are the basic tools for levelling and recontouring mined out land. They are also used for clean up operations such as grading and levelling of mining benches since draglines, electric shovels and wheel excavators require a flat work surface free of boulders (Martin *et al.*, 1982). All these earthmoving activities generate dust and this was quantified using the emission factors presented in Appendix B.

Information obtained from New Vaal Colliery (1994) indicates that 70 ha of area disturbed by mining operation was levelled in 1995 and that the number of dozer hours per hectare was 170, which is about 11 900 dozing hours per year. In estimating dust emissions from grading, mean vehicle speed was taken to be

10 km/hr, with a fleet of 4 graders working 12 hours per day for 5 days per week. A summary of open dust emission rates is shown in Table H6.

**Process emission calculations**

The AP-42 provided emission factor for only coal dumping in the process sources category. Emissions from coal crushing, screening, and transfer points were calculated using uncontrolled emission factors which are available in Cole and Kerch (1990). Input data for emission calculations, such as source extents, control device for each of the process sources and their corresponding control efficiencies, are as indicated in Table H7. All the data sources have been documented in Appendix D. A summary of TSP and PM-10 emission rates for process sources have been presented in Table H8.

# CHAPTER 3

# RESULTS OF THE EMISSION INVENTORY

## 3.1 Current Emission Inventory Results

Results of the airborne dust emission inventory are presented in Table 3.1. Fugitive dust emissions were categorised into open dust sources and process sources. Emission rates were calculated for controlled and uncontrolled scenarios especially where industry supplied control devices with their corresponding control efficiencies were available.

Controlled emission estimates were obtained by using uncontrolled emission factors with industry supplied control efficiencies that best reflect the effectiveness of the dust control devices. This was assumed to be more accurate than the efficiency implied by the use of AP-42 controlled emission factors or the use of control efficiencies from literature. Uncontrolled emission estimates were based on the product of emission factor and source activity level or source extent without any control term.

Table H6 shows emission estimates for open dust sources. Haul road dust emissions emerged as the largest contributor. Sources such as drilling, blasting, dozing and grading, paved roads, and coal handling at stockpiles were found to be insignificant emitters. The contribution of each of the sources to open dust output is presented in graphical form using pie-charts as shown in Figures 3.1 - 3.4.

Table H7 presents controlled and uncontrolled emission rates for process sources. Coal crushing was the major contributor, followed by combined operation of primary and secondary screens. Coal dumping at the primary tip was the third major contributor and the least contributor was conveyor transfer points at the primary tip, ROM, DMS and screens. Figures 3.5 - 3.6 depicts the contributions of each of the process sources.

**Table 3.1 : 1995 New Vaal Colliery emission inventory results**

| SOURCE ACTIVITIES | CONTROL DEVICE/ METHOD | CONTROL EFFICIENCY % | EMISSION RATES (tons/yr) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTROLLED | | | | UNCONTROLLED | | | |
| | | | TSP | % | PM-10 | % | TSP | % | PM-10 | % |
| **OPEN DUST SOURCES** | | | | | | | | | | |
| DRILLING (overburden & coal) | | | 31 | 0.3 | 15 | 0.4 | 31 | 0.1 | 15 | 0.1 |
| BLASTING (overburden & coal) | | | 58 | 0.5 | 30 | 0.8 | 58 | 0.2 | 30 | 0.3 |
| TOPSOIL (removal & dumping) | | | 597 | 5.3 | 299 | 7.5 | 597 | 1.9 | 299 | 2.6 |
| OVERBURDEN (removal/replacement) | | | 795 | 7.0 | 181 | 4.6 | 795 | 2.5 | 181 | 1.6 |
| COAL REMOVAL | | | 644 | 5.7 | 93 | 2.3 | 644 | 2.0 | 93 | 0.8 |
| PAVED ROADS | | | 71 | 0.6 | 14 | 0.3 | 71 | 0.2 | 14 | 0.1 |
| HAUL ROADS | Watering | 70 | 8 662 | 76.4 | 3 118 | 78.4 | 28 873 | 90.8 | 10 394 | 91.3 |
| COAL HANDLING (stockpiles) | | | 12 | 0.1 | 4 | 0.1 | 12 | 0.0 | 4 | 0.0 |
| WIND EROSION (stockpiles) | | | 20 | 0.2 | 10 | 0.2 | 20 | 0.1 | 10 | 0.1 |
| WIND EROSION (exposed areas) | | | 170 | 1.5 | 85 | 2.1 | 170 | 0.5 | 85 | 0.7 |
| DOZING & GRADING | | | 35 | 0.3 | 11 | 0.3 | 35 | 0.1 | 11 | 0.1 |
| **PROCESS SOURCES** | | | | | | | | | | |
| COAL DUMPING | Dust scrubber | 50 | 27 | 0.2 | 13 | 0.3 | 54 | 0.2 | 27 | 0.2 |
| PRIMARY CRUSHING | Dust scrubber | 50 | 54 | 0.5 | 27 | 0.7 | 108 | 0.3 | 54 | 0.5 |
| SECONDARY CRUSHING | Dust scrubber | 60 | 61 | 0.5 | 31 | 0.8 | 154 | 0.5 | 77 | 0.7 |
| PRIMARY SCREENING | Sonicore spray | 40 | 65 | 0.6 | 32 | 0.8 | 108 | 0.3 | 54 | 0.5 |
| SECONDARY SCREENING | Sonicore spray | 60 | 24 | 0.2 | 12 | 0.3 | 60 | 0.2 | 30 | 0.3 |
| TIP TRANSFER POINT | Sprays & scrubbers | 50 | 2 | 0.0 | 1 | 0.0 | 5 | 0.0 | 2 | 0.0 |
| ROM TRANSFER POINT | Dust scrubber | 60 | 2 | 0.0 | 1 | 0.0 | 5 | 0.0 | 2 | 0.0 |
| DMS TRANSFER POINT | Dust scrubber | 60 | 3.29 E-01 | 0.0 | 1.64 E-01 | 0.0 | 8.22 E-01 | 0.0 | 4.11 E-01 | 0.0 |
| SCREENS TRANSFER POINT | Sonicore sprays | 40 | 2 | 0.0 | 1 | 0.0 | 4 | 0.0 | 4 | 0.0 |
| **TOTAL INVENTORY** | | | **11 333** | **100.0** | **3 979** | **100.0** | **31 803** | **100.0** | **11 384** | **100.0** |

The emission inventory was further presented in the form of activity-related sources. Topsoil related activities included removal and dumping. Overburden related activities were made up of drilling, blasting, removal and replacement. Coal seam related activities included drilling, blasting, truck and shovel loading, all the process sources, coal handling and wind erosion of stockpiles. Vehicle travel on paved and unpaved roads was the major source. Sources such as grading/leveling related activities and wind erosion from open areas made an insignificant contribution. Graphical representation of the results are shown in Figures 3.7 - 3.10.

The total inventory results as summarised in Table 3.1 indicate that haul road emissions are the predominant source. Other sources that made a significant contribution were topsoil, overburden and coal removal and dumping activities. Contributions made by all the process sources put together were less than 5 %. Graphical representation of the total inventory is as presented in Figures 3.11 -3.14.

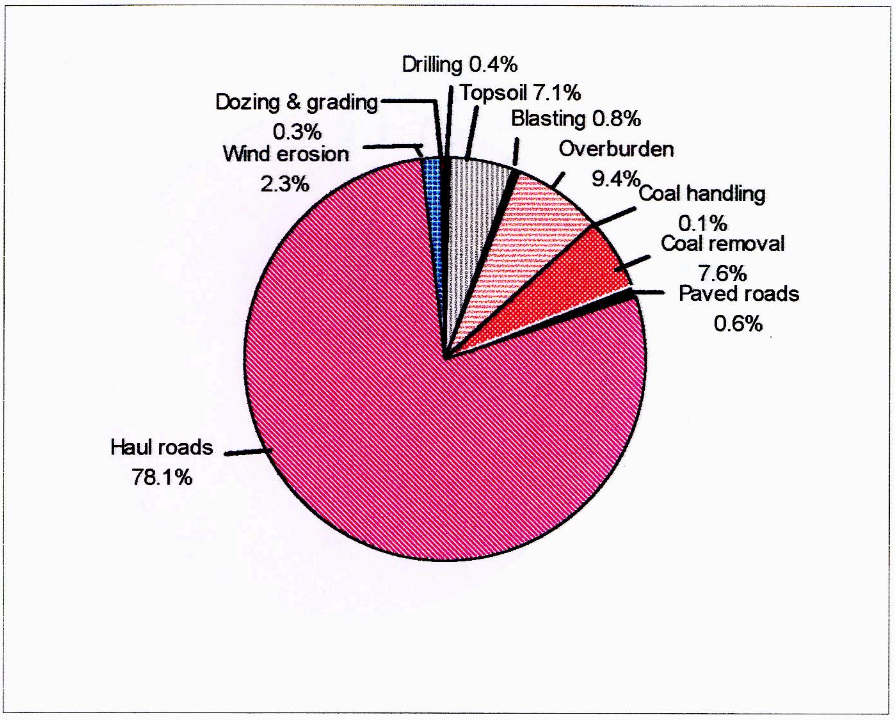


**Figure 3.1 : TSP open dust controlled emissions**

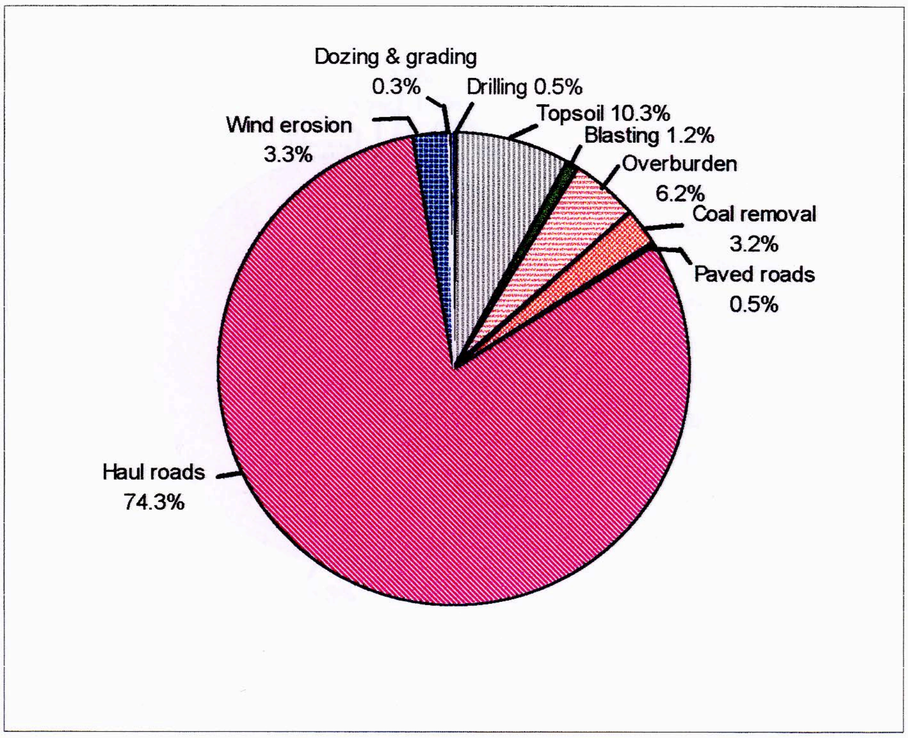


**Fig. 3.2 : PM-10 open dust controlled emissions**

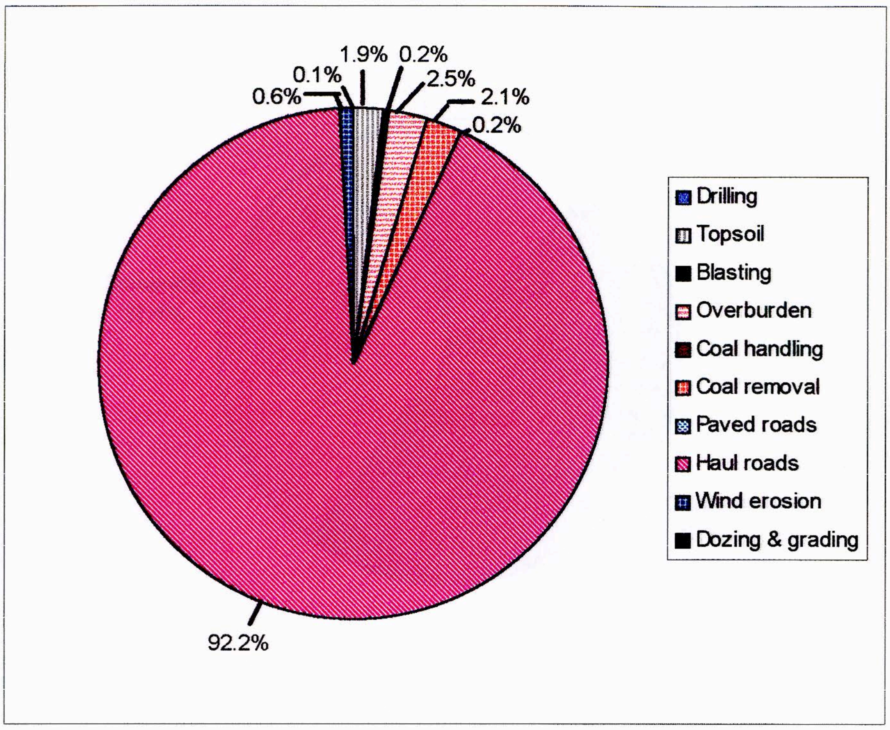


**Fig. 3.3 : TSP open dust uncontrolled emissions**

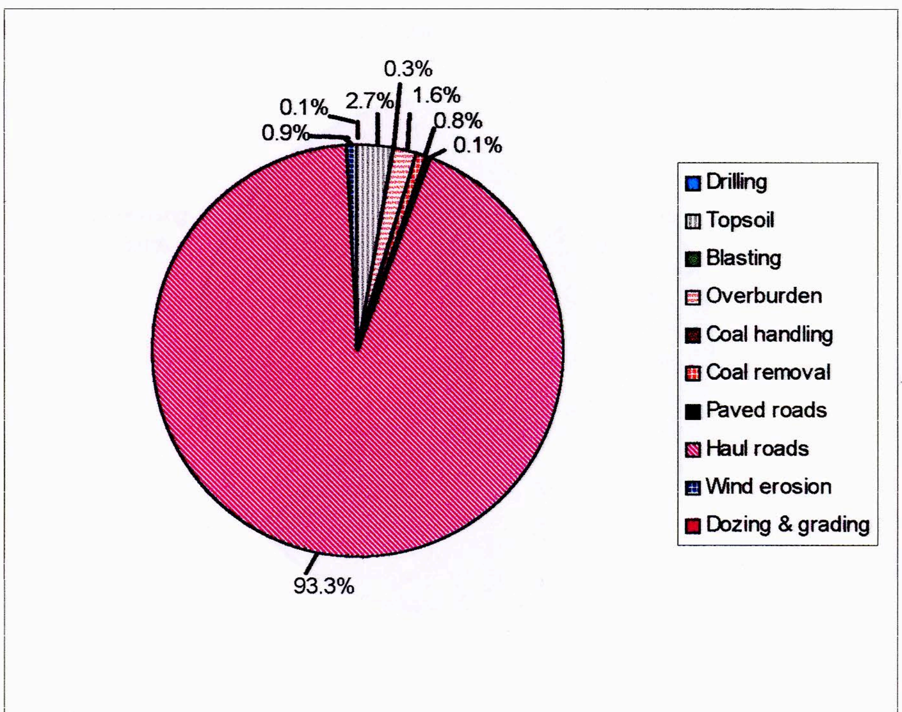


**Fig. 3.4 : PM-10 open dust uncontrolled emissions**

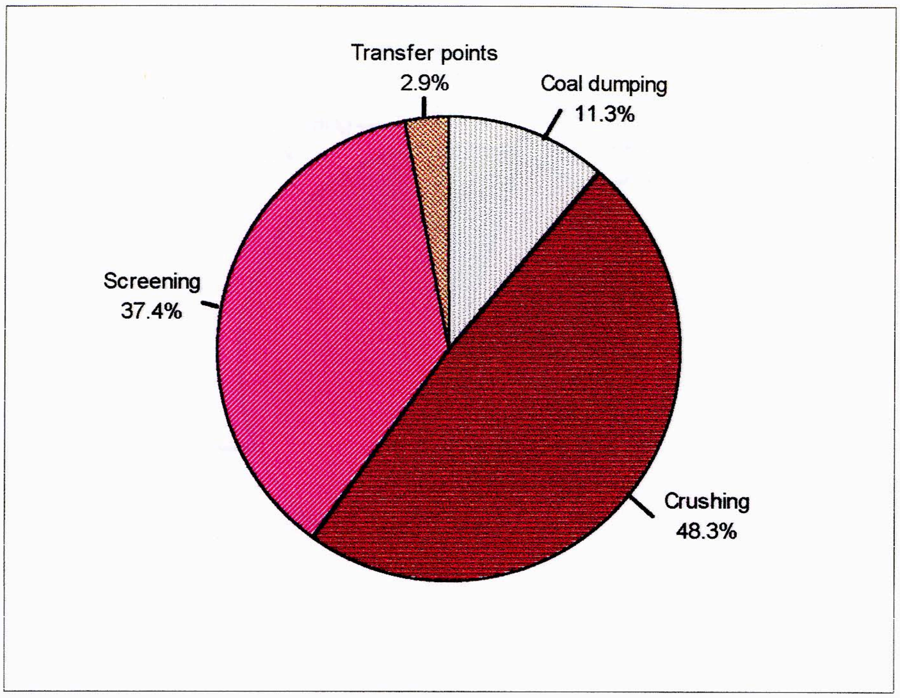


**Fig. 3.5 : Controlled process source emissions**

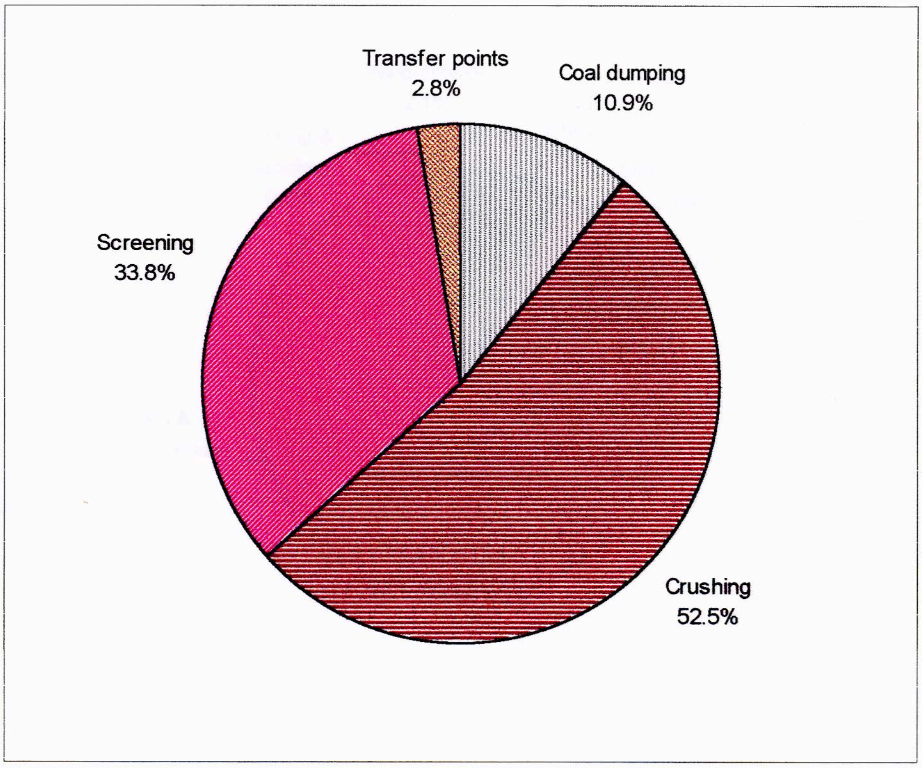


**Fig. 3.6 : Uncontrolled process source emissions**

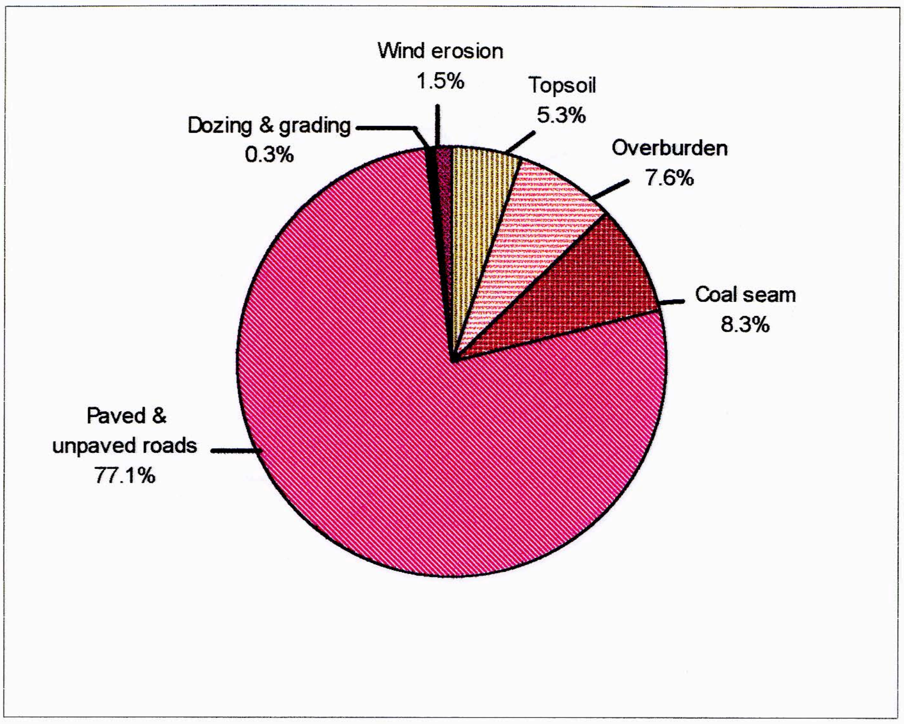


**Fig. 3.7: TSP activity-related controlled emissions**

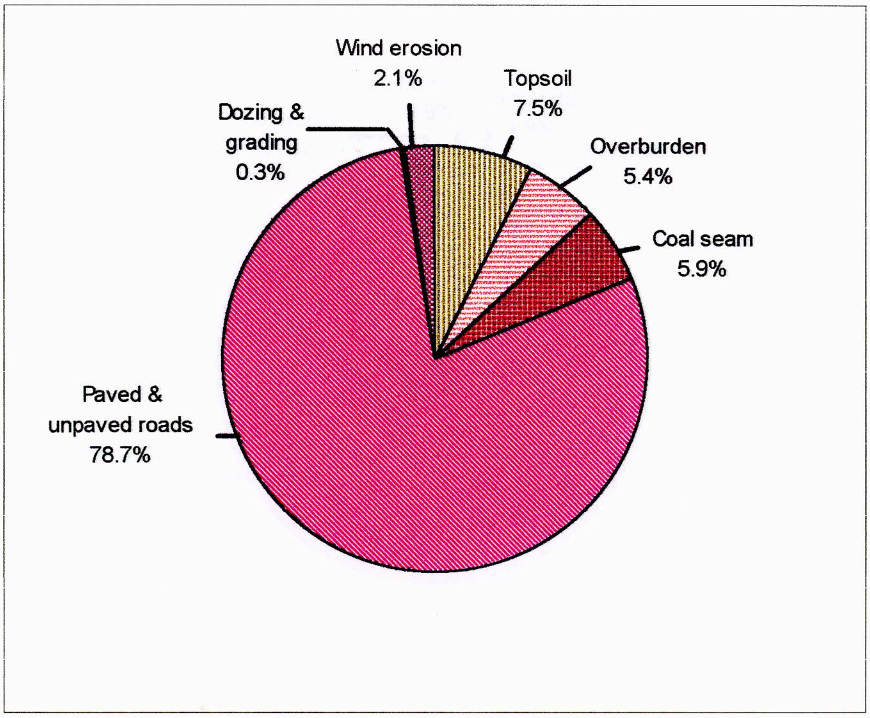


**Fig. 3.8: PM-10 activity-related controlled emissions**

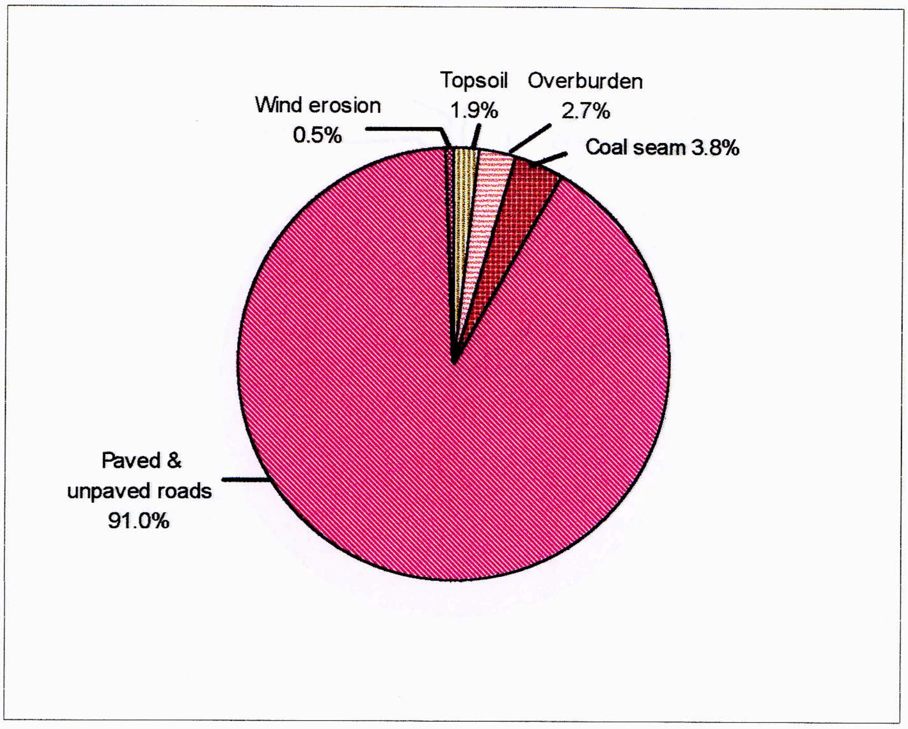


**Fig. 3.9: TSP activity-related uncontrolled emissions**

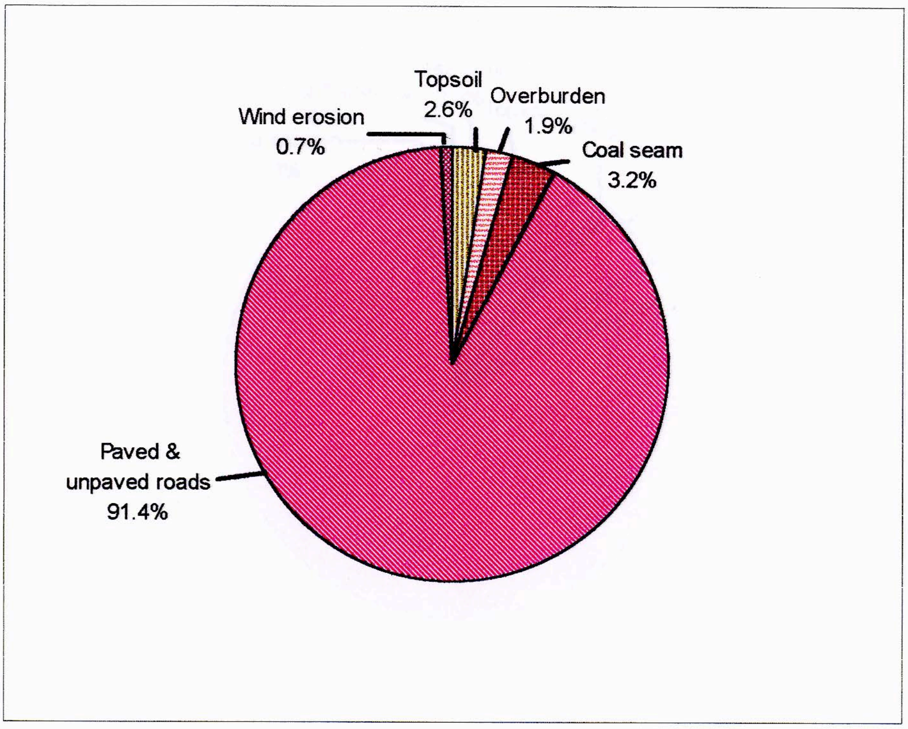


**Fig. 3.10: PM-10 activity-related uncontrolled emissions**

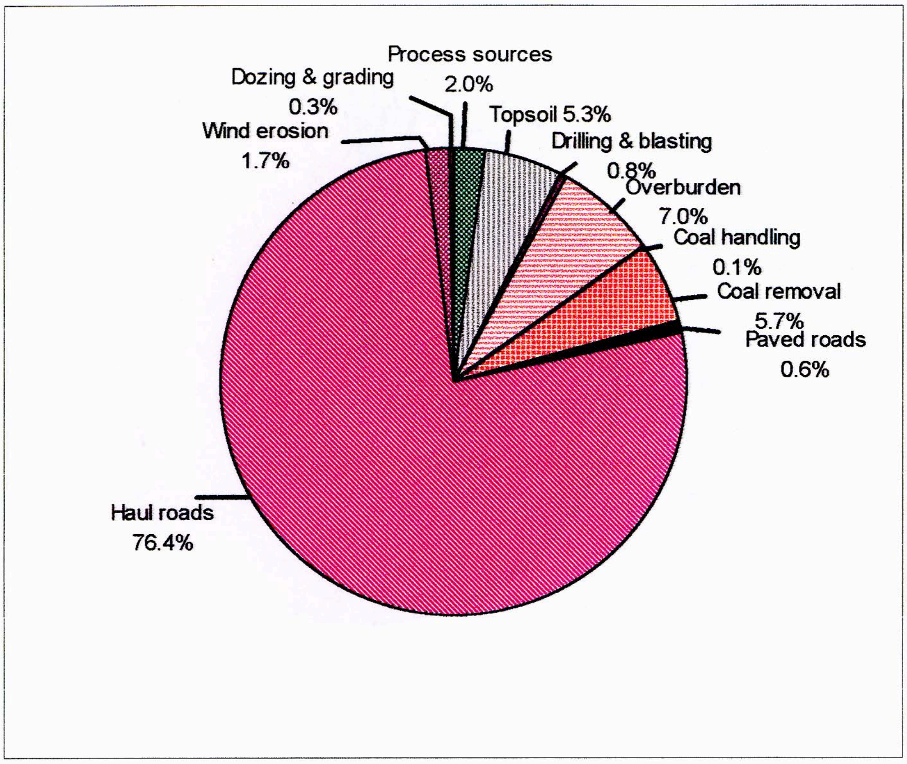


**Fig. 3.11: Total inventory TSP controlled emissions**

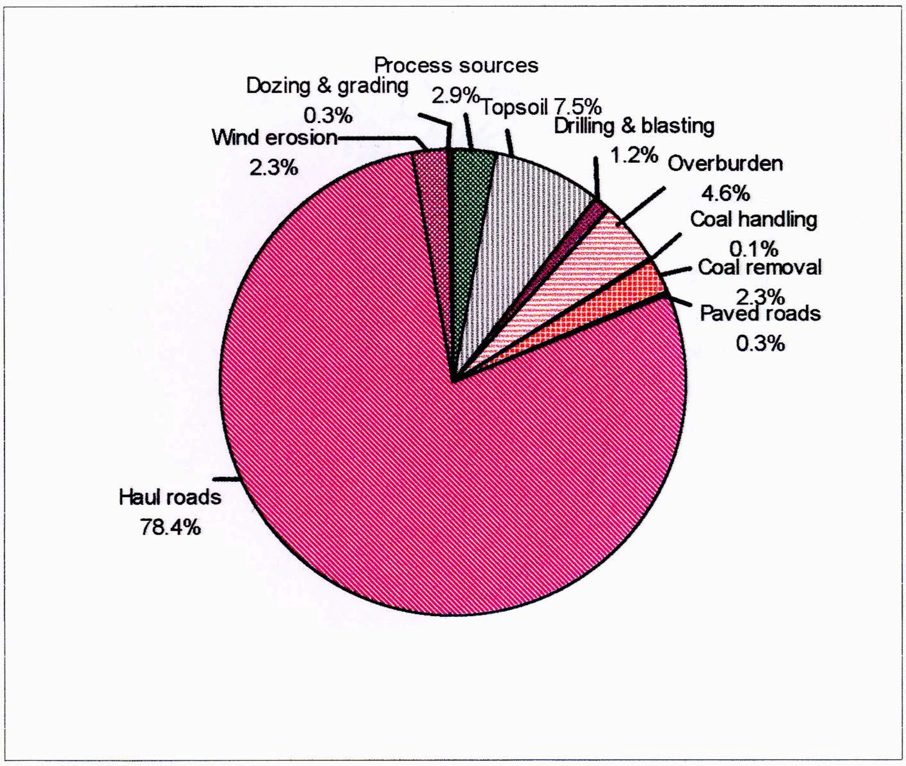


**Fig. 3.12: Total inventory PM-10 controlled emissions**

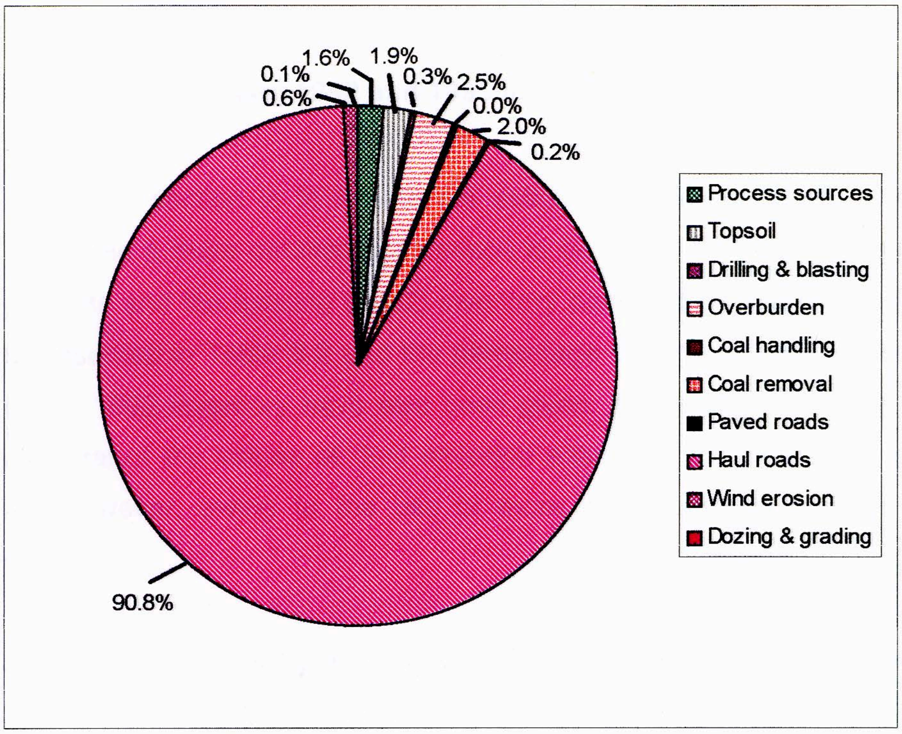


**Fig. 3.13: Total inventory TSP uncontrolled emissions**

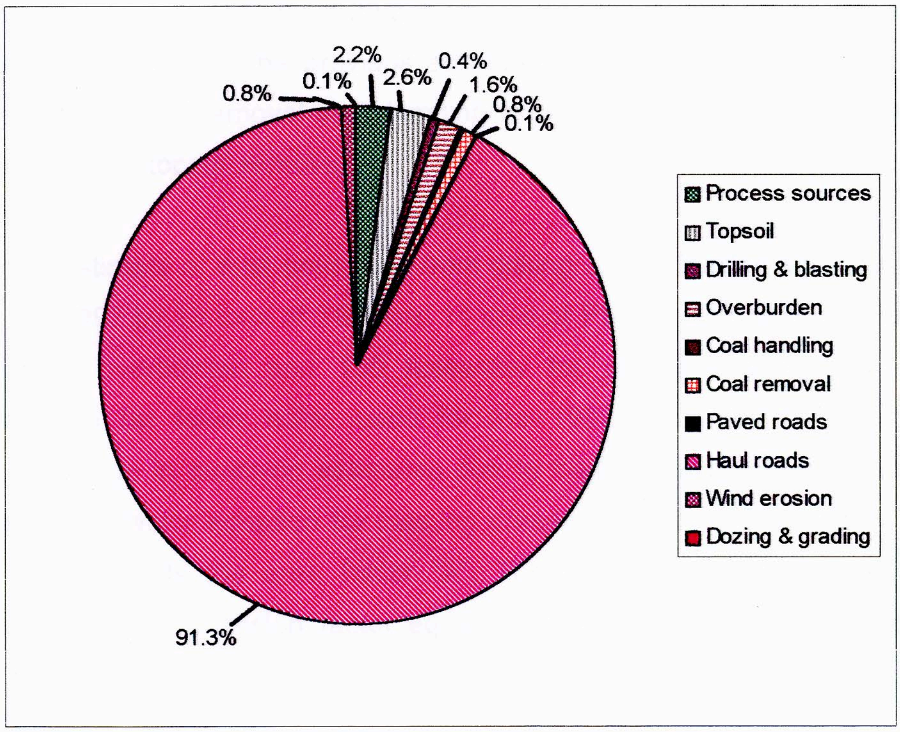


**Fig. 3.14: Total inventory PM-10 uncontrolled emissions**

### 3.2 Comparison between 1992 and 1995 Inventory Results

The focus of this section is to isolate the estimated emission rates of each of the sources to enable a more detailed comparison to be made between the current (1995) inventory results and the existing (1992) inventory compiled by van Nierop (1995). This has been presented in Table 3.2 and the percentage change of revised emission rates relative to the 1992 inventory have also been given. There are substantial differences between several of the values of dust emission estimates for the current and existing inventories, however, owing to the use of more recent activity data in the current estimates.

Investigation conducted during this study indicate that about 3.1 million $m^3$ of topsoil removed during 1992 period resulted in 850 and 298 tons of TSP and PM-10 respectively. The current estimate of emissions due to topsoil related activities was based on 2.1 million $m^3$ of topsoil which was removed and dumped at convenient areas for rehabilitation purposes. This resulted in 597 and 299 tons of TSP and PM-10 respectively which accounts for a 29.8 % decrease in TSP and an increase of 0.3 % of PM-10 as compared with the previous estimates. It must be noted that in the current estimates both topsoil removal and dumping were considered whilst the 1992 estimate only accounted for topsoil removal.

The current estimate of dust emissions from drilling of overburden and coal was greater than that of 1992 by 19 tons of TSP and 14 tons of PM-10. This is due to drilling of 150 holes/day for overburden and 100 holes/day for coal in the current estimate as compared with far fewer holes used for the 1992 estimates. There has been a significant change in emission estimates due to blasting of overburden and coal. The AP-42 emission factor equation for blasting presented in U.S. EPA (1995) contains an error in that it omits the area factor "A". The existing estimate made use of this erroneous published emission factor equation which resulted in a very low emission rate. In the current estimate, the emission factor equation was corrected to take into account the area factor.

**Table 3.2: Comparison between 1992 and 1995 inventory results**

| SOURCE ACTIVITIES | EMISSION RATES (tons/yr) | | | | PERCENTAGE CHANGE | |
|---|---|---|---|---|---|---|
| | 1992 | | 1995 | | | |
| | TSP | PM-10 | TSP | PM-10 | TSP | PM-10 |
| **OPEN DUST SOURCES** | | | | | | |
| Drilling (overburden & coal) | 12 | 1 | 31 | 15 | 158 | 1400 |
| Blasting (overburden & coal) | 1 | 0.5 | 58 | 30 | 5700 | 5900 |
| Topsoil removal & dumping | 850 | 298 | 597 | 299 | -30 | 0 |
| Overburden removal & replacement | 525 | 105 | 795 | 181 | 51 | 72 |
| Coal removal | 234 | 39 | 644 | 93 | 175 | 138 |
| Paved roads | - | - | 71 | 14 | | |
| Haul roads* | 12 015 | 4 325 | 8 662 | 3 118 | -28 | -30 |
| Coal handling (stockpiles) | 1 | 0.5 | 12 | 4 | 1100 | 700 |
| Wind erosion (stockpiles) | - | - | 20 | 10 | | |
| Wind erosion (exposed areas) | 340 | 69 | 170 | 85 | -50 | 23 |
| Dozing & grading | - | - | 35 | 11 | | |
| **TOTAL OPEN DUST** | **13 978** | **4 837** | **11 095** | **3 860** | **-21** | **-20** |
| **PROCESS SOURCES*** | | | | | | |
| Coal dumping | 5 | 2 | 27 | 13 | 440 | 550 |
| Crushing | 13 | 6 | 115 | 58 | 785 | 867 |
| Screening | 104 | 52 | 89 | 44 | -14 | -15 |
| Transfer points | 140 | 70 | 7 | 3 | -95 | -96 |
| **TOTAL PROCESS SOURCES** | **262** | **130** | **238** | **119** | **-9** | **-9** |
| **INVENTORY TOTAL** | **14 240** | **4 968** | **11 333** | **3 979** | **-20** | **-20** |

* **Controlled sources**

The current estimates of emissions due to overburden removal and replacement resulted in a 51 % and 72 % increase in TSP and PM-10 respectively as compared to those of 1992, which involves 24 million $m^3$ of overburden removal by dragline only. The current estimates consist of 33 million $m^3$ of overburden removal by dragline and additional 1.9 million tons of overburden removal and replacement using truck and shovel.

There was a high discrepancy between the current estimate of truck and shovel loading of coal and that of 1992. The increases were 175 % for TSP and 138 % for PM-10. Although the same predictive emission factor was used in the two cases, the 1992 estimate used an AP-42 default value of 17.8 % for the moisture content of coal which resulted in emission factor of 0.018 and 0.003 kg/ton for TSP and PM-10 respectively. The 1992 assumed moisture content of coal was too high as compared with 8.0 % used in the current estimate which resulted in emission factors of 0.048 and 0.007 kg/ton for TSP and PM-10 respectively. It must also be noted that in 1992 the total coal loaded by truck and shovel was 13 million tons as compared with 13.5 million tons loaded in 1995.

Emission rate estimates for existing and current inventories indicate that unpaved haul road emissions are the predominant source of the mine's fugitive dust emissions. The contribution of haul road emissions to the total dust output of the mine was 84 % and 77 % for the existing and current inventories respectively. Comparison of the two results further indicates that current estimates are about 29 % less than the existing estimates because of the site-specific parameter values that were used in the estimation.

For the 1992 estimation, the road surface silt content was assumed to be 8.4 %, based on the default value in AP-42. Data obtained from the questionnaire completed by mine personnel include a VKT of 8 000 per week-day and week-end, an average speed of haul trucks of 40 km/h, and number of days with at least 0.25 mm of precipitation per year was given as 50. It was further assumed that the control efficiency of the watering programme was 70 %, and of the total VKT during the year, 60 % was for haul trucks and 40 % for light and medium duty vehicles.

In the current haul road emission estimates, the road surface silt content from laboratory silt analysis was found to be 5.8 %. The VKT from the traffic count were 15 136 and

10 088 for week-days and week-ends respectively. These were 89 % and 26 % increase over the value used for week-day and week-end respectively in the 1992 estimate. The efficiency of the existing watering of haul roads was calculated to be 70 % using the watering performance model reported in Cowherd *et al.* (1988), the same as the efficiency used for the 1992 estimate.

The use of the AP-42 emission factor equation for the 1992 estimate for stockpile material handling resulted in very high emissions but quality assurance checks performed by van Nierop (1995) led to rejection of these values. Information obtained from the questionnaire completed by mine personnel during the 1992 inventory compilation indicated that 13.3 and 13.0 million tons of coal were stacked and reclaimed respectively at both the ROM stockpile and stockyard. The current estimate took into account stacking and reclaiming of coal at each of the stockpiles. There was an increase of 1100 % in TSP and a 700 % increase of PM-10 over the existing estimates.

The current estimation of emissions due to wind erosion of exposed areas reveals a 50 % decrease in TSP and a 23 % increase in PM-10 as compared to those of 1992. Although TSP estimates in the two cases were based on AP-42 emission factors, the existing estimate for PM-10 employed an emission factor from other literature which gave a PM-10/TSP ratio of 0.2 as compared to 0.5 used in the current estimate due to non-availability of an AP-42 emission factor for PM-10. Almost half of 400 ha open areas that were subject to wind erosion during 1992 have been vegetated hence the decrease achieved in the current estimate of TSP emissions.

One of the limitations of the existing inventory is that certain emission sources, such as emissions from paved areas, wind erosion from material stockpiles, dozing and grading were not quantified. Although the current estimates indicates that emission rates of these sources are not very high, quantification is necessary for a comprehensive source inventory.

There was a high discrepancy in emission rate estimates for process sources due to use of different emission factors in the existing and current estimates. For example, the 1992 estimate for emissions due to conveyor transfer points used a single value factor of 0.1 kg/ton of coal transferred while the current estimate made use of a predictive equation with correction parameters such as wind speed, drop height, coal silt and moisture content taken into consideration. Generally, single-valued emission factors used for coal crushing and screening in the two cases were too high, hence resulting in very high emissions compared to coal dumping at the primary tip.

# CHAPTER 4

# ECONOMIC EVALUATION OF HAUL ROAD DUST CONTROL STRATEGIES

## 4.1 Introduction

Results of the emission inventory indicate that haul road dust emissions represent about 77 % of the total dust output from the colliery. Because haul roads are such a major source of emissions, this source category has been the primary focus of the current dust control cost-effectiveness investigation. This chapter describes a variety of techniques that are used to ensure that the most cost-effective dust controls are identified and quantifies the cost of implementing them.

To begin with, an overview of haul road dust control strategies is presented. An economic model is then developed to take into account the costs and effectiveness of alternative dust control strategies over a range of applications. This model is used to evaluate alternative dust control strategies and the results of the study are presented to show the costs of each strategy at various abatement levels. A sensitivity analysis is undertaken to show the impact of each of the major components on the cost estimate.

## 4.2 Haul Road Dust Control Strategies

There are several options for control of dust emissions from unpaved haul roads. The controls fall into three general categories: source extent reductions, surface improvements, and surface treatment (Cowherd *et al.*, 1988). Although the reduction of source extent by either limiting the amount of traffic on the haul roads or lowering speeds results in a highly predictable reduction in the uncontrolled emission rate (Cowherd, 1993), speed reduction below a certain threshold will inevitably decrease productivity.

The most obvious surface improvement is paving an unpaved road. Haul roads, by their very nature, are not suitable for paving because they are used by very heavy vehicles which cause excessive wear and they are subjected to considerable spillage from haul trucks. Furthermore, the dynamic nature of a strip mine necessitates alteration of road layouts at planned intervals to minimise expensive road hauling costs. Application of gravel on a haul road is a form of stabilisation which physically reduces the emissions potential of a source from either mechanical disturbance or wind erosion. This method may increase road maintenance costs as the new aggregate fractures.

Surface treatment falls into two main categories; namely wet suppression and chemical stabilisation. Wet suppression involves watering, possibly with surfactant or other additives, which keeps the surface wet to control emissions. Chemical stabilisation, on the other hand, attempts to change the physical and hence the emissions characteristics of the roadway (Cowherd *et al.*, 1988). Spraying water onto haul roads at frequent intervals is the most common practical solution for control of dust on the haul roads. The water acts to bind the smaller particles to the larger material by surface tension, thus reducing emissions potential. However, this is only a temporary measure and frequent reapplication is necessary to achieve any substantial level of control efficiency.

Chemical dust suppressants require much less frequent reapplication than water. These suppressants are designed to alter the roadway, such as cementing loose material into a fairly impervious surface (thus simulating a paved surface) or forming a surface which attracts and retains moisture (thus simulating a wet suppression). Chemical dust suppressants are generally applied to the road surface as a water solution of the agent. The degree of control achieved is a direct function of the application intensity, dilution ratio, and frequency of application of the chemical to the surface (Cowherd *et al.*, 1988). The degree of emission control attained also depends on the type and number of vehicles using the road.

## 4.3 Model Development

Development and evaluation of dust control strategies require analysis of the relative costs of alternative options. The key requisite of any evaluation based on cost analysis is a model that provides a rapid means of making a consistent comparison of the real costs of alternative control measures. A spreadsheet cost model has, therefore, been developed to allow comparison of cost and effectiveness of existing and alternative haul road dust controls. Changes in cost of dust control and the reduction in emissions resulting from the introduction of alternative strategies are utilised to evaluate dust control options. This allows the economic implications of the introduction of alternative plans to be expressed in terms of a familiar base case.

The development of the model consists of identification of the key components that affect the overall cost of dust control and development of a spreadsheet based economic model that acknowledges the interrelationship of key components and their effect on the total cost.

### 4.3.1 Components of dust control cost

The major cost elements for dust control techniques of unpaved haul road include capital equipment, operation and maintenance costs. The overall cost of haul road dust control is directly influenced by material cost (e.g., cost of the chemical product, transportation and storage costs) and activity-related costs such as surface preparation, dust palliative application, grading and watering. Other cost elements include equipment downtime and vehicle maintenance costs. These parameters are, in turn, influenced by the selected dust control plan and associated performance characteristics. Evaluation of potential cost savings of haul road dust control strategies is dependent on being able to identify areas in which maximum savings can be gained from changes to dust mitigating practices.

### 4.3.2 Development of costs

The capital and operating costs of a particular dust control option can determine the acceptability of the alternative for a given situation. All dust control programs have certain costs to the mine operator. Cost elements taken into consideration are outlined below.

**Capital costs**

Capital cost estimates may be developed to compare dust control alternatives, to identify major cost items, or to establish a dust control budget. The capital costs of a dust emission control system for a haul road are those direct and indirect expenses incurred up to the date when the control system is placed in operation. These capital costs include actual purchase expenses for control equipment, labour and utility costs associated with the installation of the control system (U.S. EPA, 1987). In general, direct capital costs are the costs of control equipment and the labour, material and utilities needed to install the equipment. Indirect costs are overall costs to the facility incurred by the system but not directly attributable to specific equipment items.

The effect of capital cost of equipment on dust control costs is an area of some debate. In general two schools of thought are encountered (Smith, 1992). The first proposition is that the capital costs of equipment should be amortised over the expected useful life of the equipment and that this amortised amount plus maintenance and operating costs form the basis of the dust control costs. The second approach is that the capital cost of equipment is a once-off expense incurred at the start up of a project and is wholly tax deductible. Consideration is therefore only given to the influence of maintenance and operating costs on total dust abatement costs. This study will base its cost estimates solely on the second option since equipment such as water tankers and graders are already available at the mine and all dust control options will make use of these when the need for implementation arises.

**Operating and maintenance costs**

Operating costs are considered as labour and those costs of consumables required to operate equipment, such as materials and utilities, whilst maintenance costs are expenses associated with equipment maintenance such as routine servicing and overhauls. Operating and maintenance (O&M) costs inputs are required in Rand per operating hour in conjunction with estimates of equipment utilisation (percent during shift).

**Cost estimation**

Calculation of total annual cost of controlling dust emissions from unpaved haul roads can be accomplished in five steps. The first step is the determination of the times between applications and the application intensity. Application parameters are based on chemical vendor's specifications and recommendations to achieve a specified level of control. Information required at this stage includes reapplication intensity and application frequency. The second step involves calculation of the number of annual applications required in order to determine the cost of product for maintaining the road or rejuvenation as the case may be.

The long term performance of unpaved roads is closely related to the continuity of routine maintenance it receives (Department of Transport, 1993). Steps three and four are categorised under road maintenance (watering and grading) cost and is the major cost factor in the maintenance programme. In view of the constant spillage and dust that is generated due to abrasion of the treated surface by traffic, it is necessary to water down the haul road and therefore frequency of watering and application intensity need to be determined to enable watering cost to be estimated. Grading is aimed at levelling out potholes and removing corrugations, ruts and windrows. The type and frequency of grading, which are based on the condition of the haul road, are determined in order to estimate grading cost.

The final step is the calculation of the total annual cost. This involve the sum of all the activity-related costs and the cost of the product used for initial application and subsequent reapplications. Once the best possible cost estimates have been made, however, whether they eventually prove good or bad, they remain the most objective basis on which to base a decision. Great emphasis was therefore placed on securing sufficient data and applying the information carefully in arriving at estimates that are representative of actualities to the highest possible extent.

## 4.4 Model Structure

The model which is structured as a Microsoft Excel, version 5.0, multiple sheet file consists of the cost database, spreadsheets associated with dust control activity-cost centres, the main calculation module, and summary of annual dust control cost for alternative strategies at specified dust reduction levels. This has been illustrated in Appendix I and a software version of the economic evaluation model is included in a magnetic medium as Appendix J.

The purpose of the main module is to recalculate costs due to changes in key parameters. The cost centres were identified by considering the primary activities of dust control of the haul road which involves surface preparation, application of chemical dust suppressant, watering, grading, re-application and maintenance of road surface. In order to determine the total annual cost of dust control, direct costs involving the primary activity related cost centres are collated into a summary which forms the dust control cost summary sub-module.

## 4.5 Criteria for Dust Control Evaluation

Alternative dust control strategies must be evaluated through an orderly process with criteria that provide a means of identifying and comparing the consequences of each. Evaluation in the past was almost entirely based on cost criteria such as capital costs, rate of return, present worth, or benefit-cost ratio (Corbitt, 1990). These procedures lack the wide range of applicability that is necessary for systems analysis procedures (Hay, 1977). A more recent method makes use of cost-effectiveness methods.

Cost-effective evaluation provides a flexible framework for developing information that aids in selecting between alternatives. It permits the use of data from benefit-cost or other economic models but goes beyond these by separating costs from effectiveness (Hay, 1977). The term "cost" includes all of the materials, manpower, equipment, and effort that are required throughout the dust control programme. "Effectiveness" is the degree to which the alternative achieves its objective. It is a measure of the performance of the dust control technique. The decision maker must be informed as to the degree of effectiveness of alternative dust controls and costs of each level of effectiveness.

Once the criteria for economic evaluation for dust control alternatives have been established and a spreadsheet cost model has been developed, control options are selected for evaluation to determine the applicability of the model.

## 4.6 Selection of Dust Palliatives for Evaluation

In selecting dust control options for economic evaluation, an approach was adopted to answer the major technical question guiding the study. That is, which control methods (different chemicals and water) are suitable for dust control on unpaved haul roads? To determine whether or not a proposed dust control measure is economically justified or to find out which of the alternatives will prove the most economically desirable, the method of existing dust control at the mine, which is watering, was used as the *status quo* to which all other selected control options will be compared.

Although many haul road dust control options have been discussed in section 4.2, techniques such as speed reduction, gravelling and paving cannot be considered for evaluation because their disadvantages do not make them technically feasible. Instead, dust palliatives which will reduce dust, lower the erosion potential, reduce road surface material loss and deterioration rates or generally enhance the performance of the haul road will be considered for evaluation.

Different categories of dust palliatives have emerged on the South African market but empirical data were not available to rank the effectiveness of each category of suppressant or to rank the chemicals in each category. Therefore, the economic evaluation was limited to water and three chemical dust suppressants, namely calcium chloride, ligno-sulphonate and a bituminous product. Product data, application data and cost are available locally for all three options. Furthermore, these palliatives are readily available and already in use on local mines. In addition, these products have been found not to cause corrosion to construction equipment nor to vehicles using the roads and they are environmentally safe (Jones, 1996a).

### 4.6.1. Watering

Most of the dust control efforts on haul roads are centred on frequent application of water. Judicious watering helps maintain compaction (and therefore strength) of the wearing course. It also maintains surface shape and reduces the annual loss of surface gravel (Taylor and Hurry, 1986). Although the water itself is usually cheap, equipment and operation costs often escalate the cost of watering programmes.

Water retention on mine haul roads is not very good especially during adverse conditions when high temperature, low humidity and high wind speed are prevalent. This leads to more frequent application of water and increase in cost. Watering of the road about 4-6 times per shift or more is common practice on the South African Highveld especially during dry spells in summer.

### 4.6.2 Calcium chloride

Calcium chloride as a hygroscopic compound attracts moisture from the atmosphere and its surroundings. This property helps to keep unpaved surfaces damp and is effective in binding together fine particles. Furthermore, the product resists evaporation so a single application works for a long time but reapplication is recommended monthly (Polifin Ltd, 1996).

Technical analysis conducted by Jones (1996b) indicates that calcium chloride performs very well on haul roads and minimises the formation of corrugations and ravelling. However, it aggravates slippery conditions when the road is wet owing to its moisture retention properties.

Calcium chloride is applied either directly as a surface spray, or mixed into the material in a rip and recompact operation. The mix-in operation is usually carried out during regravelling operations where the calcium chloride solution is used as a substitute for water during compaction. Spray-on treatments are particularly suitable for already prepared road surfaces since this prevents disturbance of natural compaction. No deleterious environmental effect has been recorded from this product (Department of Transport, 1993).

### 4.6.3 Ligno-sulphonates

Ligno-sulphonates are waste products from the sulphite pulping process commonly used in the pulp and paper industries. In dust palliative form, they glue the particles of the road together, thus preventing them from becoming entrained by vehicles. The product has been shown to be highly effective in controlling dust and at the same time improves the driving surface for extended periods (Jones, 1996a).

Ligno-sulphonate can be sprayed directly onto the road surface or mixed into the surface layer. According to Department of Transport (1993), there can be problems with slipperiness when treated roads are wetted. The product has been found to be highly soluble and tends to leach from the road during heavy rainfall but this does not have adverse consequences on the environment or vegetation (Coetser, 1996).

### 4.6.4 Polymerised bitumen

A bituminous product, a natural petroleum resin emulsion, has the ability to contain dust and, at the same time, create a surface impervious to water. It consists of a semi-liquid with an addition of specially formulated asphaltic-like tackifiers and wetting agents in an aqueous solution. The product is insoluble in water and it has the property of being capable of withstanding heavy loads (Dust-A-Side, 1996). There is no leaching of the product after heavy rain and its application on haul roads minimises grading and watering (South Africa Mining, Coal, Gold and Base Minerals, 1993).

## 4.7. Formulation of Dust Control Programmes

Effective dust control plans are formulated by taking into consideration factors such as control application parameters, certain roadway characteristics, and climatic conditions that affect performance of dust palliatives. The control application parameters are application intensity, application frequency, dilution ratio, and application procedure. The higher the application intensity, the higher the anticipated control efficiency. However this relationship applies only to some extent, because too intense an application will begin to run off the surface.

Because unpaved haul roads are used for the movement of materials and are surrounded by additional unpaved travel areas, spillage and carry-out onto the chemically treated road require periodic housekeeping activities such as sweeping and vacuuming or additional watering to moisten the spilled material. In addition, gradual abrasion of the treated surface by traffic will result in loose material on the surface which should be controlled. Cowherd *et al.* (1988) recommends that dilute applications of the chemical dust suppressants be employed at least every month to control loose surface material. More frequent reapplications would be required if spillage and track-on pose particular problems for the haul road.

The size gradation of the roadway surface is a very important factor because it determines the ability of the road surface to compact and also partially determines the residence time of the dust suppressant in the surface of the road (Department of Transport, 1993). New Vaal Colliery haul roads have some fine material in the wearing surface which is required to provide the chemical binder with the particle surface area necessary for effective interparticle bonding.

Adverse climatic conditions may accelerate the decay of control performance. For example, heavy precipitation washes away water soluble chemical treatments like calcium chloride which in effect renders the programme ineffective. Intense solar radiation dries out watered surface thereby increasing levels of dustiness. On the other hand, light precipitation might improve the efficiency of hygroscopic chemicals like calcium chloride.

### 4.7.1 Watering programme

The empirical model developed by Cowherd *et al.* (1988) for calculating performance of a road watering programme is used to estimate the necessary hourly watering requirements. For example, if a minimum of 75% average control is required on the unpaved haul road and traffic and of the meteorological parameter values shown below are used, this model results in an estimate of the necessary hourly watering requirement as follows:

$$C = 100 - [(0.8 * p * d * t) / i]$$

where: $C$ = average control efficiency, 75 %

$p$ = potential average hourly daytime evaporation rate, 0.28 mm/h

$d$ = average hourly daytime traffic rate, 90 vehicles/hr

$i$ = application intensity, $\ell/m^2$

$t$ = time between applications, hr

$$75 \leq 100 - 0.8*[0.28* 90*t]/ i$$

i.e., $i/t \geq 0.81\ \ell/m^2$ per hour

Thus any watering programme that applies at least 0.81 $\ell/m^2/hr$ of water would result in an estimated average control of at least 75%. Some realistic programmes may be application of 1.62 $\ell/m^2$ every 2 hours, 0.40 $\ell/m^2$ every half an hour or 1.20 $\ell/m^2$ every one and a half hours.

In formulating the watering programme, time between applications was determined using an application intensity of 0.5 $\ell/m^2$ per water tanker pass. This was based on the 80 000 litres of water sprayed by the existing water tanker over 8 km by 20 m section of haul road. Sources of data relating traffic and meteorological parameters are shown in Appendix D.

### 4.7.2 Chemical dust suppressant programme

Investigations conducted during this study indicated that detailed studies have not been done to test the available chemical dust suppressants for control effectiveness over time, by application method (mixed in place or spray-on), or by application rate. Chemical dust control programmes formulated in this section were, therefore, based entirely on practicality (i.e., the application method or rate presently in use at some mines or its feasibility from a cost and operational standpoint) and manufacturer's recommendation (i.e., the application method or rate used was made to conform with the manufacturer's recommended procedures). In addition to these two approaches, discussions with chemical suppressant vendors enabled more realistic dust control plans to be formulated. A summary of chemical application parameters and other related information with regard to housekeeping and road maintenance is shown in Table 4.1. The application method for each of the chemical dust suppressants are briefly discussed below.

**Calcium chloride**

For effective control of dust using calcium chloride on haul roads, the road should be shaped to allow adequate drainage of surface water. The application of the product involves light spraying of water onto the road to assist penetration of the product, followed by a spray-on application of a 38 % solution at an intensity of 2.0 $\ell/m^2$ in a minimum of three applications. In order to prevent puddling or run-off of the product, a suitable interval should be allowed between each application.

**Ligno-sulphonate**

The initial application of Ligno-sulphonate on haul roads consists of two stages involving two products - a ligno-sulphonate powder mixed into the material and a modified ligno-sulphonate solution, "Modlig", sprayed onto the surface. During the first phase, the road surface is ripped to a depth of 50 mm and about 16 tons of ligno-sulphonate powder is dissolved in about 70 000 $\ell$ of water in a tanker (per 1 km length of haul road measuring 20 m in width). The dissolved product is then sprayed onto the road in three applications and thoroughly mixed using a grader. The road is then shaped and compacted. It must be pointed out that additional water may be required to obtain approximately optimum moisture content and to enable adequate compaction. During the second phase, modified ligno-sulphonate (50 per cent solution) is sprayed onto the compacted surface. Subsequent maintenance applications of the modified ligno-sulphonate are as outlined in Table 4.1.

**Polymerised bitumen**

The polymerised bituminous product performs very well when applied by scarifying the surface of the haul road to a depth of about 100 - 150 mm and thoroughly mixing the *in situ* material and aggregate with the product (Dust-A-Side, 1996). The compound is mixed with water then applied to the compacted road surface at an initial application intensity of 3 $\ell/m^2$. The road is maintained every two weeks by spray-on application of a more diluted solution and grading is done about 6 times per year or when deemed necessary (Basson, 1996).

**Table 4.1 : Chemical dust suppressant application parameters**

| CHEMICAL APPLICATION PARAMETERS | TYPE OF CHEMICAL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CALCIUM CHLORIDE | | | | | LIGNO SULPHONATE | | | | | POLYMERISED BITUMEN | | | | |
| | 50 % | 60 % | 70 % | 80 % | 90 % | 50 % | 60 % | 70 % | 80 % | 90 % | 50 % | 60 % | 70 % | 80 % | 90 % |
| Method of application | Spray-on | | | | | Mixed-in (initial application only) | | | | | Mixed-in (initial application only) | | | | |
| Cost of product* | R 1.0 per litre | | | | | R 1.50 per kg (for powder)<br>R 1.80 per litre (for Modlig) | | | | | R 2.0 per litre | | | | |
| Surface preparation | Required | | | | | Required | | | | | Required | | | | |
| **Initial Application** | | | | | | | | | | | | | | | |
| Application intensity ($\ell/m^2$) | 0.6 | 1.0 | 1.5 | 2.0 | 3.0 | 0.5 | 0.8 | 1.0 | 1.5 | 2.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Dilution ratio | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Application frequency | 1 | 2 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **Reapplication** | | | | | | | | | | | | | | | |
| Application intensity ($\ell/m^2$) | 0.4 | 0.5 | 0.8 | 0.8 | 1.0 | 0.4 | 0.6 | 0.6 | 0.8 | 1.0 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 |
| Dilution ratio | 1:5 | 1:3 | 1:3 | 1:2 | 1:1 | 1:3 | 1:3 | 1:2 | 1:2 | 1:1 | 1:5 | 1:5 | 1:4 | 1:4 | 1:3 |
| Frequency of application (per month) | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 |
| **Watering**<br>Frequency per week | 18 | 18 | 18 | 24 | 24 | 18 | 18 | 18 | 24 | 24 | 18 | 18 | 18 | 24 | 24 |
| **Grading**<br>Frequency per month | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

* Cost of product includes actual chemical cost, transport to the mine and storage.

## 4.8 Cost-Effectiveness Analysis

The concept of cost-effectiveness is based on the issue of the cost of different technical options and their effectiveness in terms of reducing dust emissions. It frequently involves an optimisation procedure by finding the least-cost means of meeting a particular standard and its associated cost. Using this cost as a benchmark case, an estimate can be made of how much costs can be expected to increase from this minimum level if policies that are not cost-effective are implemented.

### 4.8.1 The cost-effectiveness approach

There are certain steps that constitute a standardised approach to cost-effectiveness evaluations. These steps, as outlined by Thussen *et al.* (1971), define a systematic methodology for the evaluation of dust control alternatives in economic terms. First, it is essential that the desired goal of the dust control be defined. In this case the ultimate aim is to apply the technique to achieve a specified level of dust reduction. Once this target is set up, alternative dust control concepts and formulations are developed.

Dust control evaluation criteria are established next for both the cost and effectiveness aspects of the alternatives under study. Ordinarily, less difficulty exists in establishing cost criteria than in establishing criteria for effectiveness (Field, 1994). The reason being that the classifications and basis for summarising cost are more commonly understood.

The next step in a cost-effectiveness study is to select the fixed cost or the fixed effectiveness approach. In the fixed cost approach, the basis for selection is the amount of effectiveness obtained at a given cost. The selection criterion in the fixed effectiveness approach is the cost incurred to obtain a given level of effectiveness. As in the case of this study, when dust control alternatives which achieve the same level of dust reduction are to be compared on the basis of cost, the fixed effectiveness approach is employed. In this instance, chemicals and water were compared for specific control levels ranging from 50 to 90 %.

The final step in a cost-effectiveness study involves documentation of the purpose, assumptions, methodology, and conclusions. This is the communication step and it was not treated lightly since rational decision-making on the selection of a particular dust control alternative were based on such information.

### 4.8.2 Assumptions for cost-effectiveness analysis

Assumptions used for the analysis are shown in Table 4.2. The cost figures are not actual values but they are realistic estimates based on the available data obtained from the mine and chemical vendors. These assumptions are based on the following:

- Product costs were obtained from each vendor.

- Labour and equipment costs associated with road surface preparation, chemical application, grading and watering are industry averages obtained from mine personnel and chemical vendors. The rates depend on local contracts, the type and age machinery.

- The cost of water was assumed to be free. This is an inaccurate assumption but no reliable cost data could be found. According to mine personnel, water *per se* is free because it is pumped from mine workings into a dam and later used for watering the haul roads. The cost incurred in the watering programme involves operational and maintenance costs.

- Activity parameters (km graded per hour, etc.) are industry averages. The time for application of suppressants was made identical for all chemicals mixed- in-place, with a second set of activity parameters for spray-on applications.

**Table 4.2 : Assumptions for cost-effective analysis**

| Cost component | Rand/h | Hours/km | | |
|---|---|---|---|---|
| | | Chemicals | | |
| | | Mixed-in | Sprayed-on | Water |
| Surface preparation | 338 | 10.00 | 5.00 | 0.00 |
| Application | 202 | 5.00 | 1.25 | 0.15 |
| Grading | 338 | 2.50 | 2.50 | 2.50 |
| Remaining watering | 428 | 0.15 | 0.15 | 0.15 |

## 4.9 Results of Economic Evaluation of Dust Controls

The results of the economic evaluation have been presented using cost curves as shown in Figure 4.1 for a kilometre length of haul road measuring 20 m in width. Cost curves relate the total cost of a control strategy to the reduction in dust emission levels. Each point on the curve represents a single mitigation strategy that achieves the specific dust reduction. The curves depict a trend of increasing annual cost with increasing emission reduction, showing increasing marginal costs that typify control cost-curves. Among the available strategies the "cost-optimal" strategy is the one that has the lowest cost for a given reduction in dust levels.

The screening curves have clearly indicated that both calcium chloride and ligno sulphonate are more cost-effective approaches than watering for dust reduction within the specified range from 50 - 90 %. A very interesting feature depicted by the cost curves is that water spraying is the most expensive with respect to the other strategies for dust emission reduction above 80 %. The cost curve for water shows sharply increasing cost at higher levels of dust reduction.

The cost implications for the introduction of alternative dust control strategies using water spraying as a base case was investigated. The difference between the cost of watering and the cost of any other control option below the cost curve for water manifests as cost savings.

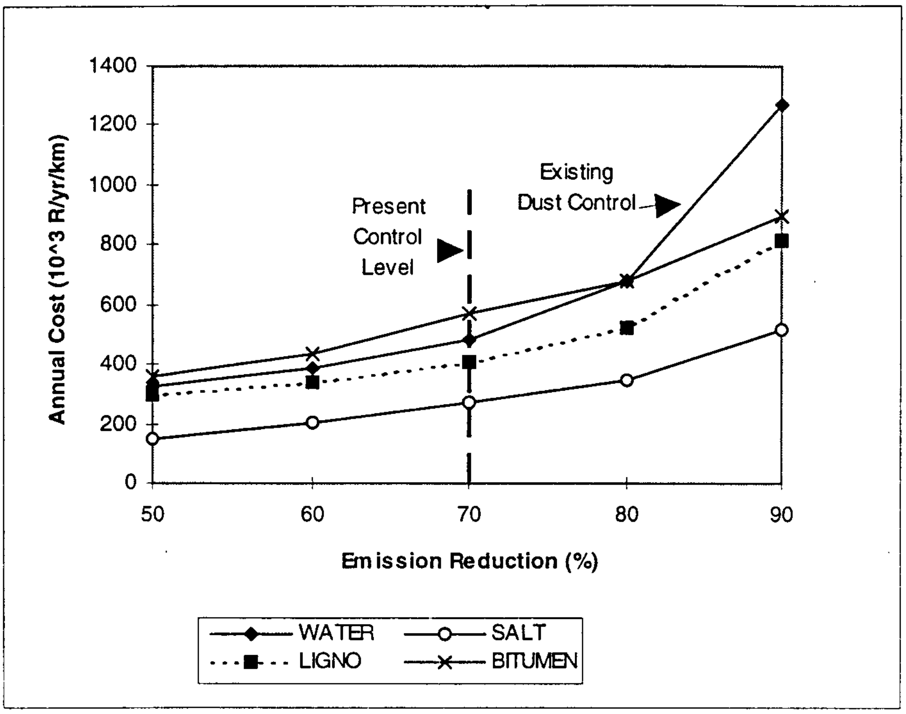


**Figure 4.1 : Dust control screening curves**

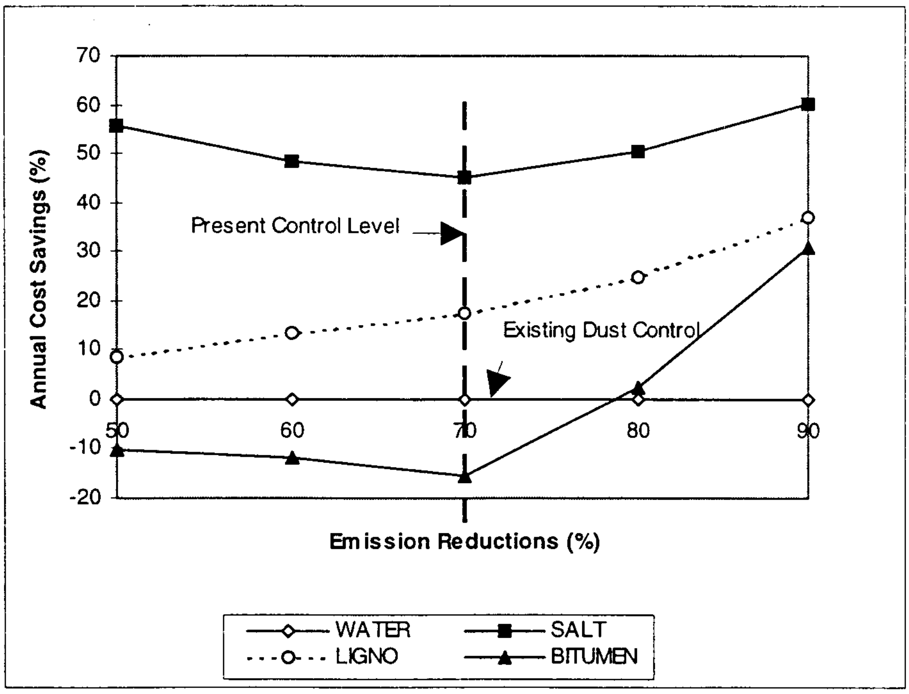


**Figure 4.2 : Percent cost savings versus emission reduction**

Figure 4.2 therefore shows the cost savings of the chemical dust suppressants expressed as a percentage of the total watering cost at various levels of dust mitigation.

Based on the current 70 % dust control efficiency of the existing watering programme, a cost-effectiveness comparison was made for the alternative dust control strategies. The results of the comparison, which have been summarised in Table 4.3, shows that calcium chloride is the most cost-effective strategy, followed by ligno-sulphonates, water spraying and lastly the polymerised bitumen product.

**Table 4.3 : Cost-effectiveness comparison to achieve 70 % control efficiency**

| CONTROL | ANNUAL COST ($10^3$ R/yr/km) | COST SAVINGS ($10^3$ R/yr/km) | TOTAL COST SAVINGS * ($10^3$ R/yr) | PERCENT SAVINGS (%) |
|---|---|---|---|---|
| Water | 483 | - | - | - |
| Calcium Chloride | 270 | 213 | 1 704 | 44 |
| Ligno-sulphonate | 406 | 77 | 616 | 16 |
| Polymerised bitumen | 569 | - 86 | - 688 | - 18 |

* Based on a haul road length of 8 km.

### 4.10 Cost Sensitivity Analysis

Having completed the construction of any basic model, it is always useful to establish how sensitive the result of the model is to changes in the underlying variables or assumptions. As the inputs for any model are based on uncertain future events, some assurance is required before a decision is reached that the result of the model is reasonably dependable. The degree to which such a model can be relied on is determined by relative sensitivity of the result to a change in variables (Correia *et al.*, 1993).

Cost sensitivity analysis is the influence of a specific cost element on the results of the overall cost estimate. According to Corbitt (1990), if an element can be varied over a wide range of values without significantly affecting the overall estimate, the estimate is said to be insensitive to that particular element. In contrast, if a small change in the estimate of one element will substantially modify the overall estimate, the ranking is said to be highly sensitive to that element.

The basic approach in evaluating the cost estimates involves asking "what if" questions in order to assess the degree of reliability of the results and to identify those components that are the most critical to the cost estimation. In an attempt to ascertain the sensitivity of total cost of watering and chemical dust suppression programmes to changes in certain variables, calculation runs were conducted based on 70 % control efficiency (current dust control level) in which a single variable was altered and its influence on overall dust control cost determined. The parameters considered were application intensity, frequency of application of dust palliatives, frequency of watering, daytime average hourly traffic count, and cost of the various chemical dust suppressants.

The change in total annual dust control cost was plotted against the change in value of each variable. The results of the sensitivity analysis have been illustrated graphically in Figures 4.3 - 4.9. Apart from sensitivity analysis of total annual cost with application intensity of water spraying, a plot of each variable against total annual cost results in a straight line. The slope of the resulting line measures how sensitive the cost estimate is to changes in an input variable. A steep slope implies that a small change in the variable leads to a substantial change in the cost estimate. The steeper the resulting line, the greater the sensitivity of the estimated total cost to the variable being investigated (Ross *et al.*, 1995).

Figure 4.3 shows the sensitivity of total annual dust control cost of a watering programme against application intensity. The graph indicates that the annual cost of water spraying is sensitive to application intensity because a small change in the variable causes a considerable change in the cost estimate. It further portray an inverse variation of total cost with the application intensity of water.

Figure 4.4 shows the total annual watering cost against daytime average traffic count. The result shows that the cost estimate is sensitive to average traffic count because of the nature of the slope of the resulting line.

Figure 4.5 depicts the variation of total dust control cost with the frequency of reapplication of chemical dust suppressants. Results indicate that the cost estimate for calcium chloride is moderately sensitive to change in frequency of application. On the contrary, cost estimates for polymerised bitumen and ligno-sulphonate are very sensitive because a slight change in frequency of application results in a substantial change in cost estimates. The polymerised bitumen cost estimate is the most sensitive followed by that of ligno-sulphonate. The calcium chloride cost estimate is the least sensitive.

Sensitivity analysis was conducted to establish the relationship between the total annual dust control cost and the frequency of additional watering. The graph showing this relationship is presented in Figure 4.6. Results indicate that cost estimates are moderately sensitive to frequency of additional watering. The extent of the sensitivity is almost the same for all the dust control alternatives because the slope of their lines is almost equal.

The sensitivity of the total dust control cost for dust suppressants with initial application intensity were explored. The resulting graph is shown in Figure 4.7. It is noted that the total cost estimate is moderately sensitive to changes in application intensity of polymerised bitumen and ligno-sulphonate but not all that sensitive to changes in application intensity of calcium chloride.

Figure 4.8 shows the total control cost versus reapplication intensity of the chemical dust suppressants. The analysis shows that the most sensitive variable is the reapplication intensity of ligno-sulphonate as it has the steepest slope. On the other hand, reapplication intensity of calcium chloride and polymerised bitumen are of the same order of sensitivity since the two lines run almost parallel.

The variation of cost of the chemical dust suppressants with the total annual dust control cost was investigated. The result, which is presented in Figure 4.9, depicts that cost estimates for all dust control alternatives turn out to be sensitive to relatively small changes in cost of chemical dust suppressants. The cost of polymerised bitumen is the most sensitive, with calcium chloride and ligno-sulphonate having the same degree of sensitivity.

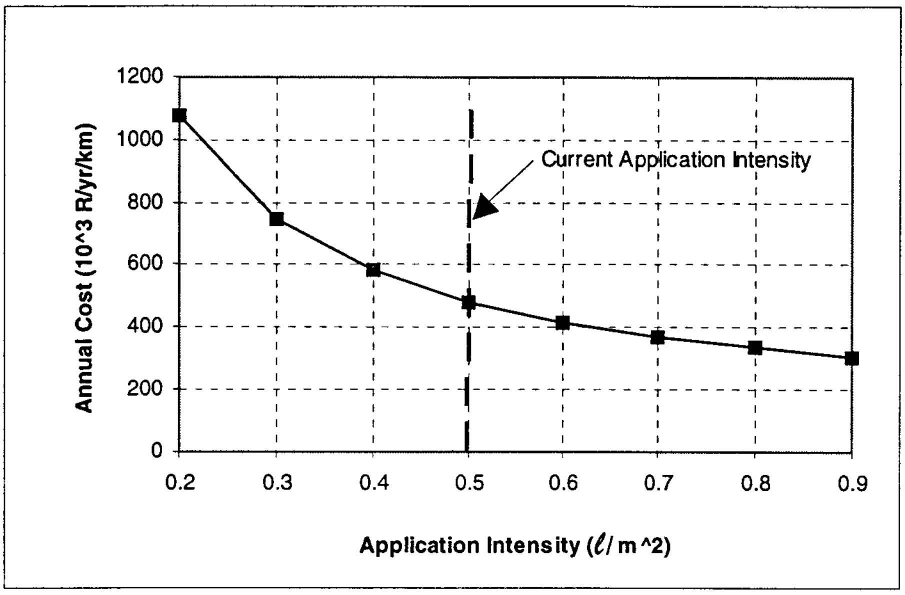


**Figure 4.3: Annual cost versus application intensity of water**

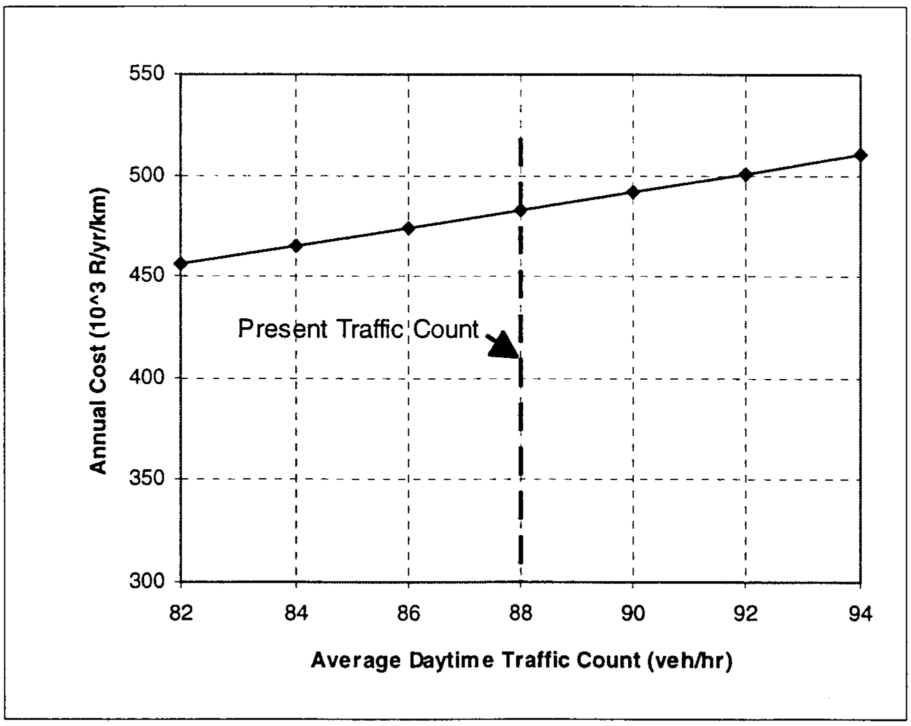


**Figure 4.4: Annual watering cost versus traffic count**

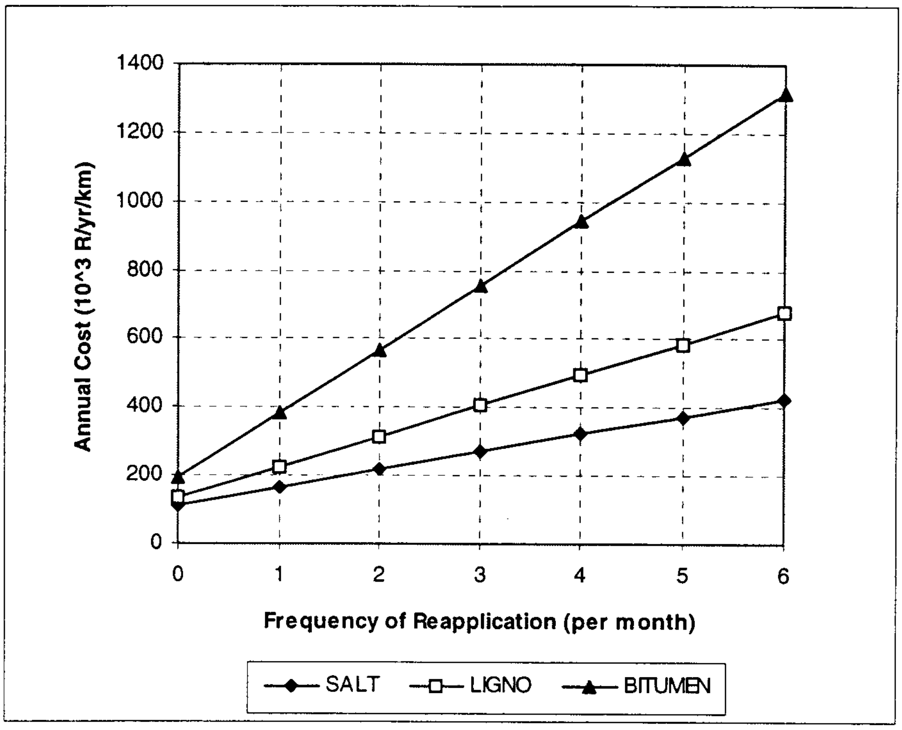


**Figure 4.5 : Annual cost against frequency of reapplication of dust suppressants**

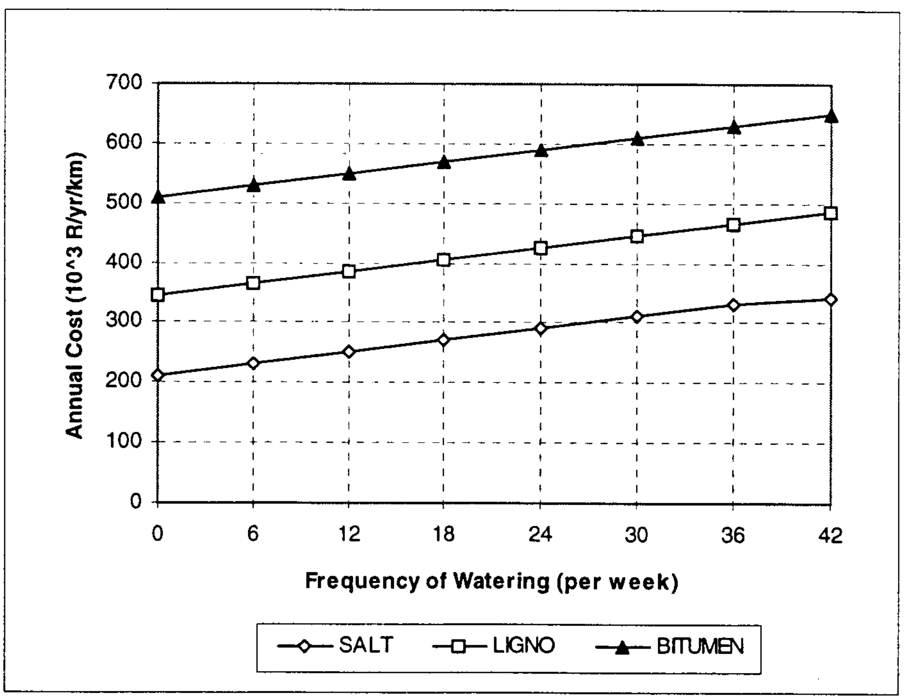


**Figure 4.6 : Annual cost versus frequency of additional watering**

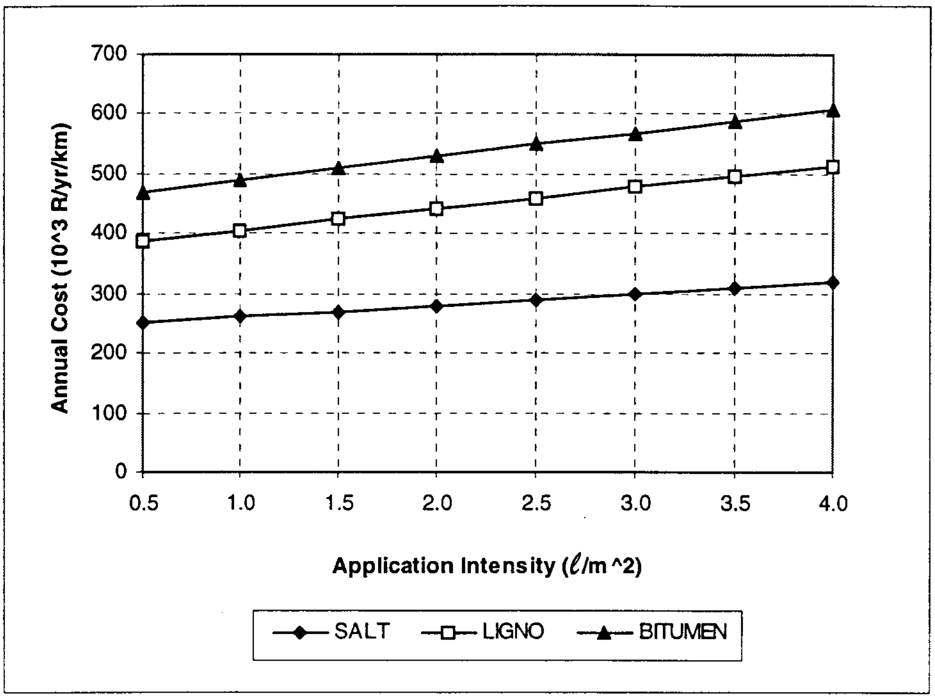


**Figure 4.7 : Annual cost as a function of initial application intensity of dust suppressants**

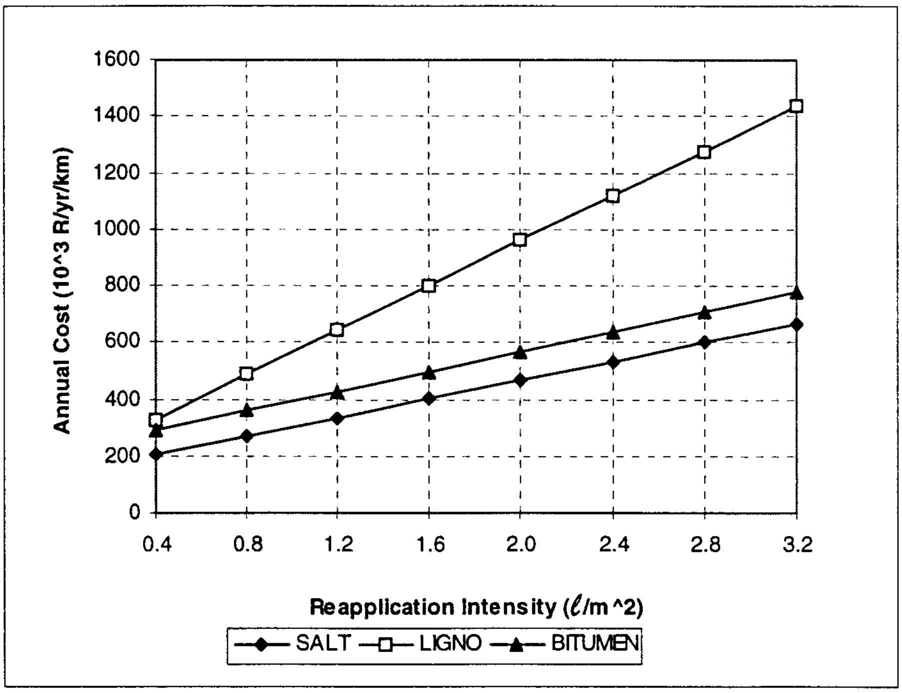


**Figure 4.8 : Annual cost versus reapplication intensity of dust suppressants**

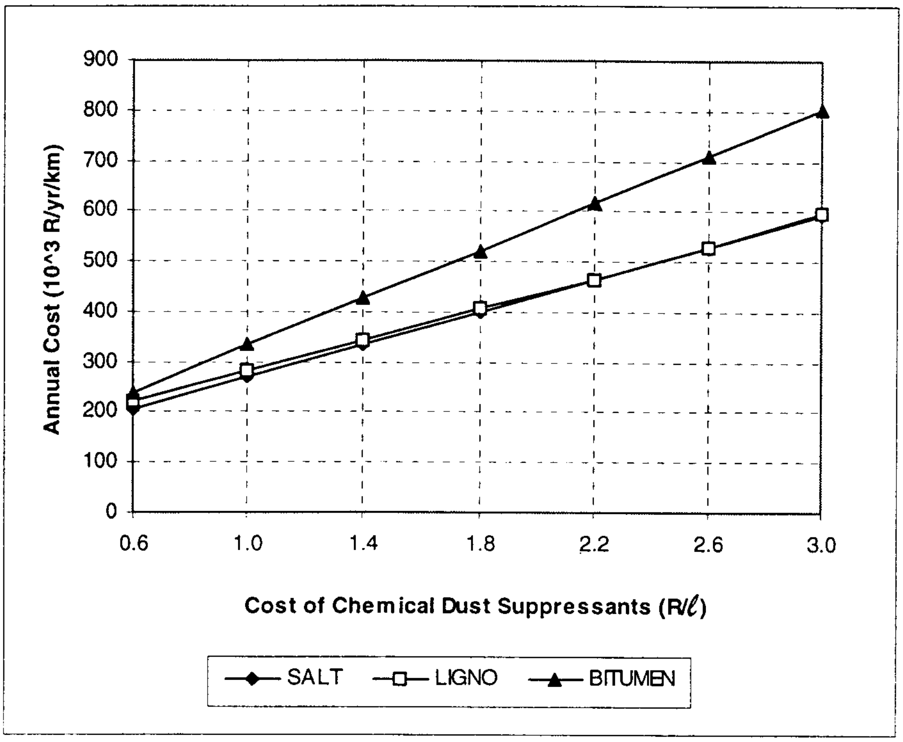


**Figure 4.9 : Annual dust control cost versus cost of chemical products**

As illustrated, sensitivity analysis is particularly useful in pinpointing those variables that are very sensitive and deserve the most attention. The factors that are considered in a sensitivity analysis are the sensitivity of the cost estimate to each major component and the confidence level of the accuracy of each component. According to Corbitt (1990), a high confidence level can be assured if the cost elements which are most sensitive are also very accurate and a lower confidence level is considered for an estimate whose most sensitive components cannot be estimated accurately.

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATIONS

The objective of this project, which is to quantify the cost-effectiveness of dust control strategies, has been accomplished. The ability of the selected dust suppressants to control dust and the cost involved to reduce dust emissions to a specified level have been dealt with in chapter 4. This concluding chapter outlines the implications of the study and gives practical recommendations.

## 5.1 Conclusions

### 5.1.1 Emission inventory

A comprehensive, current and reliable dust emission inventory has been compiled for New Vaal Colliery for the 1995 calendar year using U.S. EPA inventory techniques. The conclusions from the study are:

1. By using site specific data and other physical parameters from the mine, haul road dust emissions emerged as the predominant source of dust emission with the current estimate being about 29 % less than that of 1992 estimate.

2. Comparison of the existing (1992) and current (1995) inventories indicates that there has been a large downward shift in the emission estimates. Overall, total dust emission estimates for 1995 are 20 % less than those of the previous inventory.

3. The inventory has been made more comprehensive by including emission sources such as paved roads, wind blown dust from coal stockpiles, dozing and grading (which were not quantified in the regional inventory of 1992). Although these sources were found to be lesser contributors, their quantification adds credibility to the overall assessment.

4. The inventory has been provided on a spreadsheet to enable easy updating and to simplify any future inventory efforts. A magnetic copy of the inventory, with all calculations, is provided in an Excel spreadsheet in Appendix J.

5. Data sources, methods used, and results of the inventory have been well documented to ensure a technically defensible data base. With such an inventory as a starting point, dispersion and receptor models can be applied to estimate the impacts of various sources on the environment.

6. The emission inventory will serve as a baseline for a control programme because as the inventory is updated annually it is possible to chart the progress of the programme. Additionally, it will serve as a guide in the selection of parameters for monitoring programmes.

### 5.1.2 Cost Model

1. An economic model has been developed so that input parameters can be changed to allow a comparison to be made of costs of alternative dust control methods and their associated emission reduction levels. The model has been tested and found to be effective in evaluating the cost-effectiveness of existing and alternative dust control strategies.

2. To ensure broader acceptance, the model has been structured in a spreadsheet environment, specifically Microsoft Excel version 5.0, as this software and similar packages are used extensively within the mining industry. A software version of the cost model is included in a magnetic medium (1.4 Mb 3.5 stiffy disk) as Appendix J.

3. The model is designed to provide a quick and relatively accurate method of initial assessment of dust control scenarios. It is not designed to replace detailed feasibility studies that are an essential part of scenario evaluation. It does, however, provide quick financial comparisons of alternative scenarios so that choices can be made for further detailed evaluation.

4. Cost estimates of major activity centres and the confidence level of the accuracy of such estimates will be greatly enhanced if detailed capital, operating and maintenance cost data and reliable information on application methods, application intensity, dilution ratio and frequency of application are provided for the dust suppressants available.

### 5.1.3 Cost-effective dust control strategies

1. Situations have been identified where the control of emissions from unpaved haul roads would be very much less expensive than the traditional water spraying. Methods for choosing among dust control options have been outlined.

2. The use of an activity based cost analysis allows the impact of alternatives on the costs of dust control to be evaluated, and identifies areas where maximum savings can be achieved by changes in application method and parameters.

3. Whilst an attempt was made to cover most practical control strategies, several were excluded due to lack of information regarding reliability, effectiveness, cost, and so forth. A more direct means of reducing haul road fugitive dust is to treat the road surface by routine watering and by application of dust suppressing chemicals.

4. Watering is the most commonly used method of dust control and, of course, its effectiveness depends on the frequency of application and on the climate at the mine. Most chemical dust suppressants require special preparation of the road before application, and while chemical dust suppression is initially costly, savings may be realised by the less frequent need to apply water.

5. On the basis of the economic analysis conducted in this study, calcium chloride emerged as the most cost-effective dust control strategy for control efficiencies ranging from 50 % to 90 %. For higher control efficiencies (above 80 %), watering is the least cost-effective method of dust control.

6. Based on a control efficiency of 70 %, which is the effectiveness of the current watering programme, selection of calcium chloride or ligno-sulphonate as an alternative method of dust control will result in cost savings of 44 % and 16 % respectively.

7. Caution is given that factors other than cost-effectiveness, such as slipperiness of treated surfaces, may influence final product selection.

## 5.2 Recommendations

1. Emissions were estimated using existing U.S. EPA inventory techniques and emission factors, which are well established and continuously improved and updated. Some of the emission factors are not appropriate to local conditions, especially those for process sources. There is therefore the need to undertake further research into suitable modifications that will make them appropriate for local conditions.

2. The mining industry should be made aware that an inventory is a sound, quantified decision making tool that can be used to motivate capital expenditure on environmental projects. The mining industry should be provided with technical assistance and training in the use of available emission inventory techniques to enable them take responsibility for future inventory compilations and updates.

3. The magnitude of emissions reported in the emission inventory should not be equated directly with the contribution of sources to ambient air quality, as the impact on ambient air quality is not directly proportional to emissions. The impact of dust emissions on the environment depends on factors such as particle size distribution, release height, spatial distribution and temporal distribution. There is therefore the need for dispersion modelling to be performed using the inventory as an input to quantify the contribution that individual sources make to ambient quality.

4. This study has revealed that detailed studies have not been done to test the available chemical dust suppressants for control effectiveness over time, by

application method and application rate. Cost-effective evaluation of the alternatives was based solely on information gathered during the formulation of dust control plans. Models should be generated to make clear application parameters required to achieve specified levels of dust control.

5. For chemicals, such as hygroscopic compounds, whose dust suppression capacity are often supplemented by some watering, control efficiencies for such control programmes should be estimated by considering the ratio of controlled and uncontrolled road surface moisture content.

6. Average performance curves for chemical dust suppressants that form a hard "cemented" surface will have to be generated. The results of this programme will have to be combined with other test results to develop a model to estimate time-averaged PM-10 control performance. Because suppressants must be applied periodically to the unpaved haul roads, use of time-averaged values would be appropriate.

7. It is also necessary to investigate whether chemical application at more or less frequent intervals, or the cumulative impact of multiple applications, would markedly increase or decrease control effectiveness. Testing for control effectiveness over time and using the results to generate a model would inevitably make the results more reliable.

8. It is recommended that recordkeeping should form a compliance tool for dust control on unpaved haul road. Such recordkeeping, together with traffic records, will allow an estimate of control performance to be made for a variety of control programmes. Level of detail must cover each day/time of application, meteorological conditions, the amount of dust palliative applied, and traffic records. Collection of grab samples for moisture and silt content analysis is recommended.

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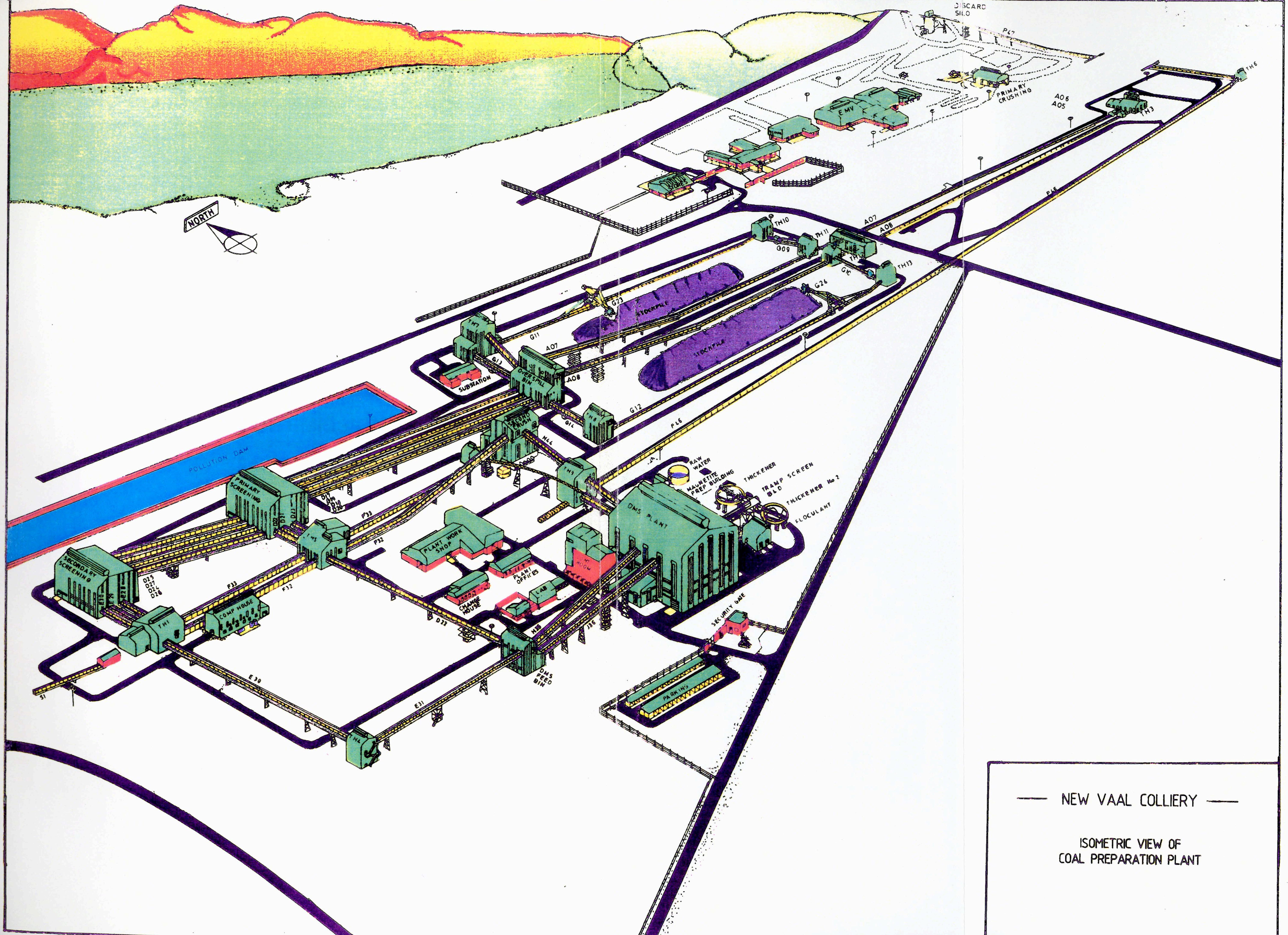
# APPENDIX A

## ISOMETRIC VIEW OF COAL TREATMENT PLANT




NEW VAAL COLLIERY

ISOMETRIC VIEW OF
COAL PREPARATION PLANT

# APPENDIX B

# AP-42 EMISSION FACTORS USED FOR CALCULATION OF EMISSION RATES

| SOURCE | UNCONTROLLED EMISSION FACTOR EQUATIONS | UNITS | EQUATION SYMBOLS |
|---|---|---|---|
| PAVED ROADS | $E = K * [sL/2]^{0.65} * [W/3]^{1.5}$ | g/VKT | E - emission factor<br>sL - surface silt loading, $g/m^2$<br>s - surface silt content, %<br>L - total road surface dust loading, $g/m^2$<br>VKT - vehicle kilometre travelled<br>S - mean vehicle speed, km/h<br>W - mean vehicle weight, Mg or ton<br>w - mean number of wheels<br>p - number of days with at least 0.25 mm of precipitation per year<br>K - particle size multiplier<br>U - mean wind speed, m/s<br>$U_t$ - threshold friction velocity, m/s<br>M - material moisture content, %<br>N - number of disturbances per year<br>$P_i$ - erosion potential corresponding to the observed fastest mile of wind for the $i^{th}$ period between disturbances, $g/m^2$<br>f - percentage of time the wind speed exceeds 5.4 m/s at the mean pile height |
| UNPAVED ROADS | $E = 0.61 * [s/12] * [S/48] * [W/2.7]^{0.7} * [w/4]^{0.5} * [(365-p)/365]$ | kg/VKT | |
| MATERIAL HANDLING | $E = K * (0.0016) * [(U/2.2)^{1.3} / (M/2)^{1.4}]$ | kg/Mg | |
| WIND EROSION (INACTIVE PILES) | $E = K * \sum_{i=1}^{N} P_i$<br>where $P = 58(U-U_t)^2 + 25(U-U_t)$, for $U > U_t$<br>$P = 0$, for $U < U_t$ | $g/m^2$ | |
| WIND EROSION (ACTIVE PILES) | $E = 1.9 * [s/1.5] * [(365 - p)/235] * [f/15]$ | kg/d/ha | |

Table B1 : Emission factor equations for uncontrolled open dust sources

| ACTIVITY | TSP EMISSION FACTOR | PM-10 EMISSION FACTOR | UNITS | RATING | COMMENTS |
|---|---|---|---|---|---|
| TOPSOIL REMOVAL AND DUMPING | E = 0.22 | E = 0.5*TSP | kg/ton | D | by scraper loading |
| | E = 0.02 | E = 0.5*TSP | kg/ton | C | by scraper unloading |
| OVERBURDEN REMOVAL | E = 0.0060 | E = 0.5*TSP | kg/ton | C | overburden replacement |
| | E = 0.018 | E = 0.5*TSP | kg/ton | C | truck & shovel loading |
| | $E = 0.0046 * d^{1.1} * M^{-0.3}$ | $E = 0.0022 * d^{0.7} * M^{-0.3}$ | $kg/m^3$ | B | dragline, d = drop height (m), M = moisture content (%) |
| COAL REMOVAL | $E = 0.58 * M^{-1.2}$ | $E = 0.0447 * M^{-0.9}$ | kg/ton | B | truck & shovel loading of coal M = moisture content (%) |
| DRILLING | E = 0.59 | E = 0.5*TSP | kg/hole | B | overburden |
| | E = 0.10 | E = 0.5*TSP | kg/hole | E | coal |
| BLASTING | $E = 0.00022 * A^{1.5}$ | E = 0.52 * TSP | kg/blast | C | coal and overburden A = horizontal area, with blasting depth ≤ 21.3 m |
| WIND EROSION (exposed areas) | E = 0.85 | E = 0.5 * TSP | tons/ha/yr | C | stripped overburden, graded overburden |
| BULLDOZING | $E = 2.6 * s^{1.2} * M^{-1.3}$ | $E = 0.34 * s^{1.5} * M^{-1.4}$ | kg/hr | B | overburden, s = silt content and M = moisture content (%) |
| GRADING | $E = 0.0034 * S^{2.5}$ | $E = 0.0034 * S^{2.0}$ | kg/VKT | B | S = mean vehicle speed (km/hr) |

**Table B2 : Particulate emission factors for open dust sources**

| ACTIVITY | EMISSION FACTOR | UNITS | COMMENTS |
|---|---|---|---|
| COAL DUMPING INTO HOPPER | $0.002 < E < 0.014$ | kg/ton | Coal, bottom dump truck |
| | $E = 0.004$ | kg/ton | Coal, end dump truck |
| | $E = (5.25 * 10^{-5}) * s U h * M^{-2} * Y^{-0.33}$ where s = silt content, %; U = wind speed, km/h; h = drop height, m; M = moisture content, %; Y = dumping device capacity, $m^3$ | kg/ton | Coal |
| CRUSHING | $E = 0.01$ | kg/ton | Primary coal crushing |
| | $E = 0.03$ | kg/ton | Secondary coal crushing |
| SCREENING | $E = 0.01$ | kg/ton | Primary coal screening |
| | $E = 0.02$ | kg/ton | Secondary coal screening |
| TRANSFER POINTS | $E = (2.9 * 10^{-5}) * s U h * M^{-2}$ where s = silt content, %; U = wind speed, km/h; h = drop height, m ; M = moisture content, % | kg/ton | Coal emissions for each transfer point |

**Table B3 : Particulate (TSP) emission factors for process sources.**

# APPENDIX C

# SAMPLES OF QUESTIONNAIRE USED

# DATA COLLECTION FORM 2A

**TOPSOIL:**

Type of equipment(s) used for removal: ..........................................................

Quantity of topsoil removed ($m^3$/month) :..........................................................

Moisture content (%) : ................... Silt content (%):......................................

Length of conveyor : ..........................................................................................

Dumping height (m) : .........................................................................................

**OVERBURDEN:**

No. of holes drilled per month: ......................................................................

Drilling pattern : ...............................................................................................

Average hole depth (m) : ................ Diameter of hole (m) : ...........................

No. of blasts per month: ...................................................................................

Quantity of overburden removed ($m^3$/month) by truck & shovel: ......................

Quantity of overburden removed ($m^3$/month) by dragline: ................................

Moisture content (%) : ................... Silt content (%): .......................................

Average dragline drop height (m) : ..................................................................

**COAL:**

No. of holes drilled per month: .........................................................................

Drilling pattern : ...............................................................................................

Average hole depth (m) : ................ Diameter of hole (m) : ...........................

No. of blasts per month: ...................................................................................

Quantity of coal removed ($m^3$/month) by truck & shovel: .................................

Moisture content (%) : .................... Silt content (%): .......................................

# DATA COLLECTION FORM 2B

## 1. COAL TIPPING :

Quantity of coal dumped into hopper (tons/month): ......................................

Moisture content (%) : .........................Silt content (%): .........................

Average wind speed (km/h) : ...................Drop height (m) : .........................

Capacity of dump truck : ........................................................................

## 2. CRUSHING & SCREENING :

| SECTION | DUST CONTROL DEVICE | CONTROL EFFICIENCY (%) | EFFICIENCY BASED ON * |
|---|---|---|---|
| 1. PRIMARY TIP | | | |
| | | | |
| | | | |
| | | | |
| 2. CRUSHING | | | |
| | | | |
| | | | |
| | | | |
| 3. SCREENING | | | |
| | | | |
| | | | |
| | | | |
| 4. OTHERS | | | |
| | | | |
| | | | |
| | | | |

* Please state if efficiency is based on actual emissions, intuition, literature source or other.

## 3. COAL TRANSFER POINTS/HOUSES:

| TRANSFER POINTS | DROP HEIGHT (m) | $H_2O$ (%) | SILT (%) | QUANTITY * OF COAL TRANSFER | DUST CONTROL DEVICE | CONTROL EFFICIENCY (%) |
|---|---|---|---|---|---|---|
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* Quantity of coal transferred at each point (tons/month).

$H_2O$ and silt are moisture content and silt content (% of particles with aerodynamic diameter <75 μm) of coal respectively.

# DATA ON COAL STOCKPILES

| PARAMETERS | UNITS | NORTH ROM | SOUTH ROM | LIVE A1 | LIVE A2 & B1 | LIVE B2 & C1 | LIVE C2 | NORTH STRAT | SOUTH STRAT |
|---|---|---|---|---|---|---|---|---|---|
| Length | m | | | | | | | | |
| Width | m | | | | | | | | |
| Height | m | | | | | | | | |
| Surface Area | $m^2$ | | | | | | | | |
| Volume | $m^3$ | | | | | | | | |
| Moisture Content | % | | | | | | | | |
| Silt Content | % | | | | | | | | |
| Particle Size | mm | | | | | | | | |
| Quantity Deposited | tons/month | | | | | | | | |
| Quantity Removed | tons/month | | | | | | | | |

# APPENDIX D

# SOURCES OF INFORMATION

# SOURCES OF INFORMATION

## PARAMETERS FOR CALCULATING EMISSION RATES

### TYPE OF SOURCE : PAVED ROADS

| PARAMETERS | UNITS | ORIGINAL DATA SOURCE |
|---|---|---|
| Paved road emission factor equation | g/VKT | AP-42 (1995), section 13.2.1.3 |
| Particle size multiplier | - | AP-42 (1995), section 13.2.1.3 |
| Surface material silt content | % | Laboratory silt analysis of samples collected from paved areas |
| Surface dust loading | kg/km | Obtained from grab samples from paved areas |
| Average vehicle weight | tons | Site-specific data |
| Vehicle kilometres travelled | VKT | Site-specific traffic count |

### TYPE OF SOURCE : UNPAVED HAUL ROADS

| PARAMETERS | UNITS | ORIGINAL DATA SOURCE |
|---|---|---|
| TSP emission factor | kg/VKT | AP-42 |
| Particle size multiplier | - | AP-42 |
| Road surface material silt content | % | Laboratory silt analysis of samples collected from haul roads |
| Mean vehicle speed | km/hr | Personal communication with mine personnel |
| Mean vehicle weight | tons | New Vaal Colliery (1985) |
| Mean number of wheels | - | Personal observation |
| No. of days of rainfall ≥ 0.25 mm | - | Nefale (1996) |
| Vehicle kilometres travelled | VKT | Site-specific traffic count |
| Control efficiency of water spraying | % | Calculated based on watering performance model, Cowherd *et al.* (1988) |
| Average daytime evaporation rate | mm/hr | Assumption based on AP-42 |
| Average hourly daytime traffic rate | veh/hr | Site-specific traffic count |
| Application intensity | lit/m$^2$ | Calculation based on volume of water used for watering a specified area of haul road |
| Time between applications | hr | Personal observation for a period of time |

**TYPE OF SOURCE : MATERIAL HANDLING OF STOCKPILES**

| PARAMETERS | UNITS | ORIGINAL DATA SOURCE |
|---|---|---|
| TSP emission factor | kg/ton | AP-42, Cowherd *et al.* (1988) |
| Particle size multiplier | - | AP-42 |
| Mean wind speed | m/s | AER |
| Material moisture content | % | New Vaal Colliery (1995) |
| Amount of coal handled | tons | New Vaal Colliery (1995) |

**TYPE OF SOURCE : WIND EROSION OF STOCKPILES AND OPEN AREAS**

| PARAMETERS | UNITS | ORIGINAL DATA SOURCE |
|---|---|---|
| **STOCKPILES** | | |
| TSP emission factor | kg/ha/day | Cowherd (1993) |
| Silt content of coal | % | Laboratory silt analysis of samples collected from coal stockpiles |
| No. of days with rainfall ≥ 0.25 mm | - | Nefale (1996) |
| Percentage of times wind speed > 5.4 m/s | % | AER |
| Surface area of stockpiles | ha | Questionnaire, Form 2B |
| Number of disturbances per year | - | Questionnaire, Form 2B |
| **EXPOSED AREAS** | | |
| TSP emission factor | tons/ha/day | AP-42, section 11.9.2, Table 11.9.4 |
| Area exposed | ha | New Vaal Colliery (1994) |

**TYPE OF SOURCE : OTHER OPEN DUST SOURCES**

| PARAMETERS | UNITS | ORIGINAL DATA SOURCE |
|---|---|---|
| **TOPSOIL** | | |
| TSP emission factor (removal) | kg/ton | AP-42, section 11.9.2, Table 11.9.4 |
| TSP emission factor (dumping) | kg/ton | AP-42, section 11.9.2, Table 11.9.4 |
| Amount of topsoil removed/dumped | tons | New Vaal Colliery (1995) |
| **OVERBURDEN** | | |
| TSP emission factor, drilling | kg/hole | AP-42, section 11.9.2, Table 11.9.4 |
| TSP emission factor, blasting | kg/blast | AP-42, section 11.9.2, Table 11.9.4 |
| Number of holes drilled | - | Questionnaire, Form 2A |
| Burden & spacing | m | Questionnaire, Form 2A |
| Number of blasts/yr | - | Questionnaire, Form 2A |

**TYPE OF SOURCE : OTHER OPEN DUST SOURCES (continued)**

| PARAMETERS | UNITS | ORIGINAL DATA SOURCE |
|---|---|---|
| Removal (T&S), emission factor | kg/ton | AP-42, section 11.9.2, Table 11.9.4 |
| | | |
| Removal (dragline), emission factor | kg/ton | AP-42, section 11.9.2, Table 11.9.1 |
| Dragline drop distance | m | AP-42, section 11.9.2, Table 11.9.3 |
| Amount removed | tons, $m^3$ | New Vaal Colliery (1995) |
| Replacement (T&S), emission factor | kg/ton | AP-42, section 11.9.2, Table 11.9.4 |
| **COAL** | | |
| TSP emission factor, drilling | kg/hole | AP-42, section 11.9.2, Table 11.9.1 |
| Number of holes drilled | - | Questionnaire, Form 2A |
| Burden & spacing | m | Questionnaire, Form 2A |
| TSP emission factor, blasting | kg/blast | AP-42, section 11.9.2, Table 11.9.1 |
| Number of blast per year | - | Questionnaire, Form 2A |
| Coal loading (T&S), emission factor | kg/ton | AP-42, section 11.9.2, Table 11.9.1 |
| Amount of coal removed | tons | New Vaal Colliery (1995) |
| Bulldozing, TSP & PM-10 emission factors | kg/hr | AP-42 (1995), section 11.9.2, Table 11.9.1 |
| Total time used for bulldozing | hrs/ha/yr | New Vaal Colliery (1994) |
| Grading, TSP emission factor | kg/VKT | AP-42 (1995), section 11.9.2, Table 11.9.1 |

**CATEGORY OF SOURCE : PROCESS SOURCES**

| PARAMETERS | UNITS | ORIGINAL DATA SOURCE |
|---|---|---|
| TSP emission factor, coal dumping | kg/ton | AP-42, section 11.9.2, Table 11.9.4 |
| Amount of coal processed | tons | Questionnaire, Form 2B |
| TSP emission factor, primary crusher | kg/tons | Cole and Kerch (1990) |
| TSP emission factor, secondary crusher | kg/tons | Cole and Kerch (1990) |
| Amount of coal processed | tons | Questionnaire, Form 2B |
| Control efficiencies of all devices | % | Questionnaire, Form 2B |
| TSP emission factor, primary screening | kg/ton | Cole and Kerch (1990) |
| TSP emission factor, secondary screening | kg/ton | Cole and Kerch (1990) |
| Amount of coal screened | tons | Questionnaire, Form 2B |
| TSP emission factor, Transfer points | kg/ton | Cole and Kerch (1990) |
| Amount of coal transferred | tons | Questionnaire, Form 2B |
| Moisture content of coal | % | New Vaal Colliery (1995) |
| Silt content of coal | % | Laboratory silt analysis |
| Average drop height of coal | m | Assumption based on AP-42 |

# APPENDIX E

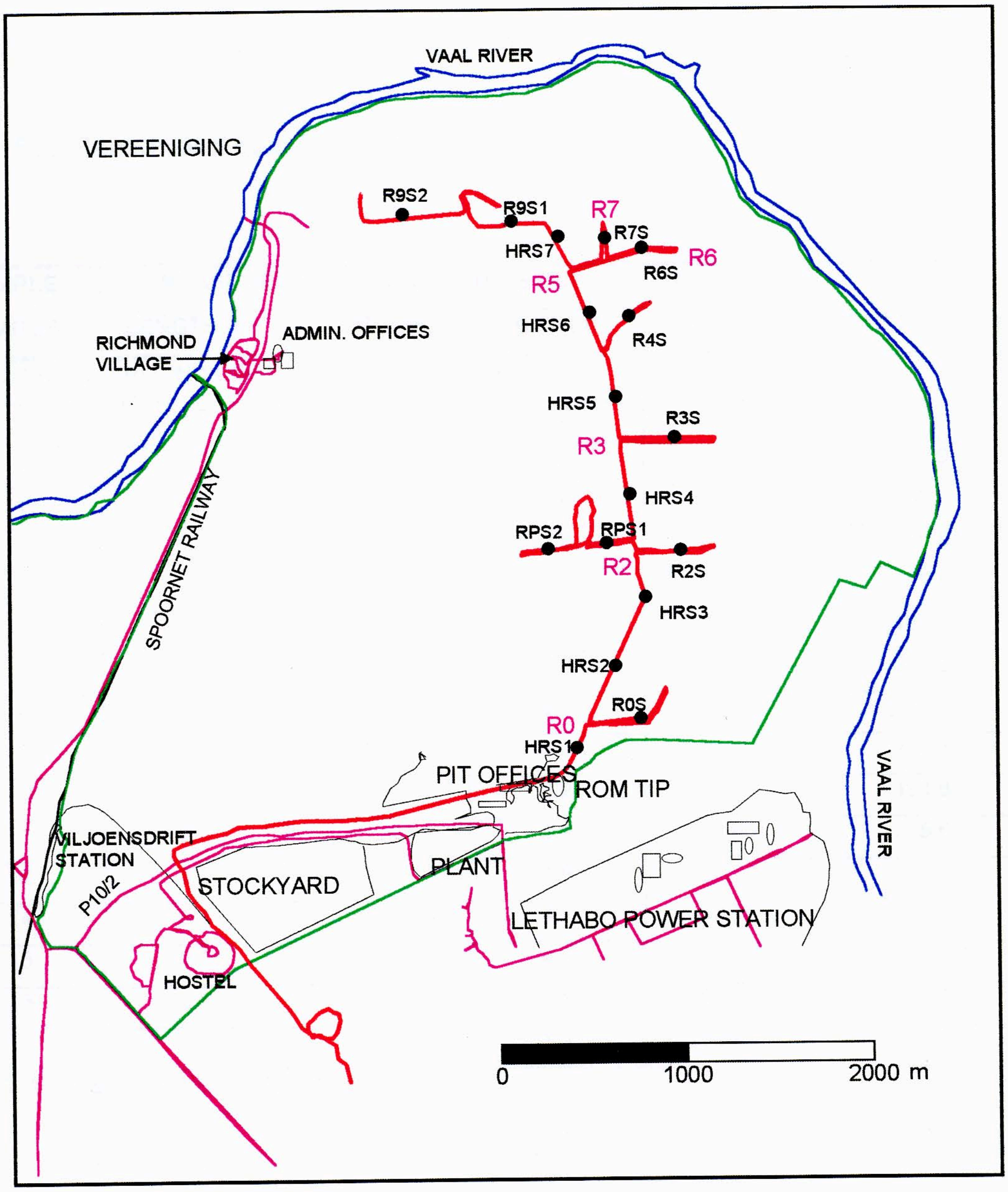


**Fig. E1 : LOCATION OF HAUL ROAD SAMPLING POINTS**
**Source: New Vaal Colliery (1994)**

# APPENDIX F

## PAVED ROAD SURFACE DUST AND SILT LOADINGS

Table F1 gives an idea of the extent of road surface dust loading at different sampling locations at the Plant and the Pit Offices.

**Table F1: Paved road dust loadings**

| SAMPLE NUMBER | MEASUREMENT OF SAMPLING STRIP | | | MASS OF SAMPLE (g) | DUST LOADING ($g/m^2$) |
|---|---|---|---|---|---|
| | LENGTH (m) | WIDTH (m) | AREA ($m^2$) | | |
| **PAVED AREAS AROUND COAL PROCESSING PLANT** | | | | | |
| PVP 1 | 6.0 | 0.7 | 4.2 | 121.8 | 29.0 |
| PVP 2 | 6.0 | 0.7 | 4.2 | 83.5 | 19.9 |
| PVP 3 | 3.4 | 0.7 | 2.4 | 127.1 | 53.4 |
| PVP 4 | 2.8 | 1.0 | 2.8 | 253.7 | 90.6 |
| PVP 5 | 3.4 | 1.2 | 4.1 | 308.1 | 75.5 |
| PVP 6 | 4.0 | 2.0 | 8.0 | 1 017.2 | 127.2 |
| PVP 7 | 4.6 | 1.3 | 6.0 | 1 500.0 | 250.8 |
| PVP 8 | 5.6 | 1.7 | 9.5 | 1 114.0 | 117.0 |
| PVP 9 | 5.4 | 1.3 | 7.0 | 1 652.0 | 235.3 |
| PVP 10 | 5.6 | 1.1 | 6.2 | 1 200.0 | 194.8 |
| PVP 11 | 3.0 | 1.4 | 4.2 | 863.5 | 205.6 |
| PVP 12 | 3.0 | 1.6 | 4.8 | | |
| PVP 14 | 3.6 | 1.3 | 4.7 | 460.0 | 48.5 |
| PVP 13 | 3.0 | 1.5 | 4.5 | 1 098.1 | 244.0 |
| PVP 15 | 5.6 | 1.4 | 7.8 | 303.6 | 38.6 |
| PVP 16 | 5.9 | 1.0 | 5.9 | 629.9 | 106.8 |
| **PAVED AREAS AROUND PIT OFFICES** | | | | | |
| PVPO 1 | 5.2 | 0.3 | 1.6 | 560.0 | 359.0 |
| PVPO 2 | 5.7 | 0.3 | 1.7 | 600.0 | 350.9 |
| PVPO 3 | 4.5 | 0.3 | 1.4 | 2 420.0 | 1 792.6 |
| PVPO 4 | 5.7 | 0.3 | 1.7 | 2 650.0 | 1 549.7 |
| PVPO 5 | 6.5 | 0.3 | 2.0 | 940.0 | 482.1 |
| PVPO 6 | 7.4 | 0.3 | 2.2 | 1 200.0 | 540.5 |
| PVPO 7 | 6.1 | 0.2 | 1.2 | 640.0 | 524.6 |

**Table F2 : Mean values of dust and silt loadings**

| LOCATION | DUST LOADING ($g/m^2$) RANGE | DUST LOADING ($g/m^2$) MEAN | SILT CONTENT (%) | SILT LOADING ($g/m^2$) |
|---|---|---|---|---|
| (PAVED ROADS) PLANT | 20 - 251 | 122 | 15.7 | 19.2 |
| (PAVED ROADS) PIT OFFICES | 351 - 1 793 | 800 | 8.2 | 65.6 |
| (PAVED ROAD) P10/2 | - | - | - | 0.5 |

A silt loading of 0.5 $g/m^2$ was assumed for road P10/2 by taking into consideration the high traffic volume and the type of vehicles that travel on the road.

# APPENDIX G

## RESULTS OF TRAFFIC COUNT

### PAVED ROAD TRAFFIC COUNT

Results of the traffic count are presented in Table G1. The total number of traffic passes during the period of traffic count was 2 059, thus giving an average hourly traffic count of 147.

**Table G1 : Traffic count along P1O/2 paved road**

| DURATION | TYPE OF VEHICLES | | | | | | TOTAL |
|---|---|---|---|---|---|---|---|
| | CARS | BAKKIES | MINI-BUSES | BUSES | TRUCKS 1 < w <10 t | HEAVY VEHICLES | |
| 05:00 - 06:00 | 96 | 30 | 20 | 3 | 0 | 2 | 151 |
| 06:00 - 07:00 | 90 | 82 | 25 | 4 | 1 | 0 | 202 |
| 07:00 - 08:00 | 84 | 74 | 19 | 4 | 5 | 0 | 186 |
| 08:00 - 09:00 | 46 | 64 | 20 | 2 | 11 | 1 | 144 |
| 09:00 - 10:00 | 40 | 41 | 11 | 0 | 0 | 0 | 92 |
| 10:00 - 11:00 | 38 | 38 | 9 | 1 | 1 | 1 | 88 |
| 11:00 - 12:00 | 36 | 40 | 13 | 2 | 0 | 0 | 91 |
| 12:00 - 13:00 | 50 | 36 | 15 | 2 | 0 | 0 | 103 |
| 13:00 - 14:00 | 92 | 67 | 22 | 6 | 13 | 8 | 208 |
| 14:00 - 15:00 | 68 | 51 | 37 | 11 | 7 | 6 | 180 |
| 15:00 - 16:00 | 113 | 60 | 14 | 7 | 11 | 1 | 206 |
| 16:00 - 17:00 | 100 | 44 | 18 | 6 | 0 | 0 | 168 |
| 17:00 - 18:00 | 93 | 50 | 14 | 0 | 0 | 0 | 157 |
| 18:00 - 19:00 | 70 | 10 | 3 | 0 | 0 | 0 | 83 |
| **TOTAL** | **1016** | **687** | **240** | **48** | **49** | **19** | **2059** |
| **PERCENT** | **49** | **33** | **12** | **2** | **2** | **1** | **100** |

The following deductions emerged from the traffic count:

- Results of the count indicates that of all the vehicles that use the P10/2 road, 30% turn off to the pit offices, 7% to coal processing plant and 63% continue to Eskom's Lethabo power station.

- New Vaal Colliery operates on three working shifts; namely morning (06:00 - 14:00), afternoon (14:00 - 22:00) and night (22:00 - 06:00). Peak traffic volume occur about half an hour before and after change of shift.

- All cars belonging to employees and visitors are left at the parking areas just before the security gates at the plant and the pit offices.

- Based on personal observation, it was assumed that the average hourly traffic rate from 19:00 to 05:00 will be about 10 % of that during the day. Thus the total number of vehicle passes per day was calculated to be 2 206.

- The length of P10/2 was found to be about 4 km, therefore, the VKT per day along P10/2 was estimated to be about 8 824 by multiplying length of road by daily traffic count.

Considering the traffic flow around the plant and the pit offices, the vehicle kilometres travelled on the paved roads at these two areas were assumed to be 250 and 600 per day respectively. This assumption is based on personal observation of traffic movement on paved roads at the plant and pit offices.

## HAUL ROAD TRAFFIC COUNT

The vehicle kilometre travelled on the haul road was obtained by conducting traffic count. The results of the count is shown in Table G2.

**Table G2: Haul road traffic count**

| TYPE OF VEHICLE | DURATION | | | | | | TOTAL | % |
|---|---|---|---|---|---|---|---|---|
| | 08:00 - 09:00 | 09:00 - 10:00 | 10:00 - 11:00 | 11:00 - 12:00 | 12:00 - 13:00 | 13:00 - 14:00 | | |
| BAKKIES | 30 | 47 | 43 | 39 | 47 | 74 | 281 | 52 |
| BUSES | - | - | - | - | - | 2 | 2 | 0 |
| WATER TANKERS | 3 | - | 3 | 5 | 2 | 3 | 16 | 3 |
| TRUCKS 1 < W < 10 tons | 6 | 5 | 8 | 12 | 9 | 11 | 51 | 9 |
| DUMP TRUCKS (EMPTY) | 15 | 20 | 16 | 9 | 16 | 11 | 87 | 16 |
| DUMP TRUCKS (LOADED) | 18 | 19 | 13 | 15 | 16 | 3 | 84 | 16 |
| GRADERS | 2 | 2 | 3 | 1 | 2 | 3 | 13 | 2 |
| F. E. LOADERS | - | 1 | 1 | 2 | 2 | 2 | 8 | 2 |
| **TOTAL** | **74** | **94** | **87** | **85** | **94** | **110** | **542** | **100** |

Due to time constraints it was not possible to conduct the count for 24 hours. The following assumptions were made to enable realistic estimate of VKT to be made:

- Although the traffic count missed peak activity period (06:00 - 08:00), hourly traffic count of 120 was assumed for this period. This assumption together with the results of the traffic count gave total traffic count for the 8-hour morning shift as 728.

- Production for the three shifts continues at the same rate and therefore the number of passes of haul trucks was assumed to be the same for the three shifts. On the average, hourly haul truck passes was estimated to be 28.

- Based on the results of the traffic count and the first assumption, hourly traffic count for light/medium vehicles was found to be 69.

- Other supporting services are reduced during afternoon and night shifts. It was therefore assumed that hourly traffic count of light/medium duty vehicles for these two shifts will be about 60 % that of the morning shift. This assumption was based on discussion with mine personnel.

- There are two shifts on Saturdays and no production on Sundays. Traffic count during the week-end was assumed to be 2/3 of that of a week-day.

- Daytime hourly traffic rate was calculated to be 88 veh/hr by considering traffic volume from 06:00 - 18:00.

Based on the traffic count and the above assumptions, the total traffic volume per week-day and week-end was found to be 1 892 and 1 261 respectively. The total length of haul road was found to be about 8 km by adding together the length of the main haul road and the ramps. The annual VKT was calculated by multiplying the total length of haul roads by total number of traffic passes per year and this was found to be 4 459 936.

# APPENDIX H

# SPREADSHEET FOR DUST EMISSION ESTIMATION

# TABLE H1: ESTIMATION OF EMISSIONS FROM PAVED ROADS

AP-42 predictive emission equation for paved road is given by:

E = K(sL/2)^0.65 * (W/3)^1.5

where: E = particulate emission factor (g/m^2)

K = base emission factor for particle size

sL = silt loading (g/m^2)

W = average weight of vehicles travelling on the road (tons)

| | | LOCATION | | | |
|---|---|---|---|---|---|
| PARAMETERS | | PLANT | PIT OFFICE | P10/2 | |
| VEHICLE WEIGHT (tons) | | 3 | 3 | 3 | |
| SILT CONTENT % | | 15.7 | 8.2 | 1.6 | |
| DUST LOADING (g/m^2) | | 122.47 | 799.78 | 19.23 | |
| SILT LOADING (g/m^2) | | 19.23 | 65.58 | 0.31 | |
| LENGTH OF ROAD (m) | | | | 4 | |
| NO. OF VEHICLES/DAY | | | | 2206 | |
| VKT PER DAY | | 250 | 600 | 8824 | |
| VKT/year | 660 | 78000 | 187200 | 2753088 | |
| | K fact ( g/VKT) | | | | |
| TSP emission factor (g/VKT) | 24 | 104.50 | 231.98 | 7.11 | |
| PM -10 (g/VKT) | 4.6 | 20.03 | 44.46 | 1.36 | |
| AP42 1995 SECTION 13.2.1.3 | | | | | |
| | | | | | |
| **UNCONTROLLED** | | | | | **TOTAL** |
| **TSP EMISSIONS (tons/year)** | | **8.15** | **43.43** | **19.57** | **71.15** |
| **PM-10 EMISSIONS (tons/year)** | | **1.56** | **8.32** | **3.75** | **13.64** |

## TABLE H2: ESTIMATION OF DUST EMISSIONS FROM HAUL ROAD

| | TYPE OF VEHICLE | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| PARAMETERS | BAKKIES | BUSES | W/TANK | TRUCKS | EMPTY T | LOADED T | GRADERS | FE LOAD | |
| SILT CONTENT (%) | 5.8 | 5.8 | 5.8 | 5.8 | 5.8 | 5.8 | 5.8 | 5.8 | |
| SPEED (km/hr) | 65 | 60 | 35 | 45 | 40 | 35 | 40 | 40 | |
| WEIGHT (tons) | 3 | 11 | 209 | 8 | 196 | 350 | 21 | 78 | |
| WHEELS | 4 | 6 | 6 | 6 | 6 | 6 | 6 | 4 | |
| NO. OF PPT > 0.25 mm | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | |
| CONTROL EFFICIENCY (%) | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | |
| E FACTOR | 1.020623 | 2.8651 | 13.1275 | 1.719446 | 14.3434 | 18.8333955 | 3.0034918 | 6.144599 | **TOTAL** |
| TOTAL VKT/ yr (for 3 shifts/ /week-day + 2 shifts/saturday) = 52 weeks/yr X 8840 veh/week X 8 km length haul road | | | | | | | | | 4459936 |
| % PASSES | 51.8 | 0.4 | 3 | 9.4 | 16 | 15.5 | 2.4 | 1.5 | |
| VKT /yr | 2310247 | 17840 | 133798 | 419234 | 713589.8 | 691290.08 | 107038.46 | 66899.04 | |
| CONTROL TERM | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | |
| | **CONTROLLED EMISSION RATES** | | | | | | | | |
| TSP (kg/yr) | 707368 | 15334 | 526932 | 216255 | 3070592 | 3905802 | 96447 | 123320 | **8662049** |
| PM-10 kg/yr) | 254652 | 5520 | 189696 | 77852 | 1105413 | 1406089 | 34721 | 44395 | **3118338** |
| | | | | | | | | | |
| **TSP (tons/yr)** | **707** | **15** | **527** | **216** | **3071** | **3906** | **96** | **123** | **8662** |
| **PM-10 (tons/yr)** | **255** | **6** | **190** | **78** | **1105** | **1406** | **35** | **44** | **3118** |
| | | | | | | | | | |
| | **UNCONTROLLED EMISSION RATES (tons/yr)** | | | | | | | | |
| **TSP** | **2358** | **51** | **1756** | **721** | **10235** | **13019** | **321** | **411** | **28873** |
| **PM-10** | **849** | **18** | **632** | **260** | **3685** | **4687** | **116** | **148** | **10394** |

# TABLE H3: EMISSIONS FROM COAL HANDLING OF STOCKPILES

| | NAME OF STOCKPILE | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **PARAMETER** | **N/ROM** | **S/ROM** | **A1** | **A2** | **B1** | **B2** | **C1** | **C2** | **N/STRAT** | **S/STRAT** | |
| | | | | | | | | | | | |
| WIND SPEED (m/s) | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | |
| MOISTURE (%) | 8.3 | 8.3 | 8.3 | 8.3 | 8.3 | 8.3 | 8.3 | 8.3 | 8.3 | 8.3 | |
| COAL HANDLED t/yr | 993624 | 993624 | 4599996 | 4599996 | 4599996 | 4599996 | 4599996 | 4599996 | 3720000 | 3720000 | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| TSP FACTOR kg/t/yr | 0.000327 | 0.000327 | 0.000327 | 0.000327 | 0.000327 | 0.000327 | 0.000327 | 0.000327 | 0.000327 | 0.000327 | |
| | | | | | | | | | | | |
| | | | | | | | | | | | **TOTAL** |
| TSP EMISSION kg/yr | 324 | 324 | 1502 | 1502 | 1502 | 1502 | 1502 | 1502 | 1215 | 1215 | 12092 |
| PM-10 (kg/yr) | 114 | 114 | 526 | 526 | 526 | 526 | 526 | 526 | 425 | 425 | 4232 |
| | | | | | | | | | | | |
| **TSP (tons/yr)** | **0.32** | **0.32** | **1.50** | **1.50** | **1.50** | **1.50** | **1.50** | **1.50** | **1.21** | **1.21** | **12.09** |
| **PM-10 (tons/yr)** | **0.11** | **0.11** | **0.53** | **0.53** | **0.53** | **0.53** | **0.53** | **0.53** | **0.43** | **0.43** | **4.23** |

# TABLE H4: WIND EROSION FROM ACTIVE STOCKPILES AND OPEN AREAS

| PARAMETER | NAME OF STOCKPILE | | | | | | | | TOTAL | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N/ROM | S/ROM | A1 | A2&B1 | B2&C1 | C2 | N/STRAT | S/STRAT | (tons/yr) | PIT AREA |
| SILT CONTENT (%) | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | | |
| FREQ OF U >5.4m/s (% | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | | |
| SURFACE AREA (ha) | 0.6865 | 0.6865 | 3.8012 | 6.0254 | 6.0254 | 3.8012 | | | | 200 |
| DAYS PPT>0.25 mm | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | | |
| E FACTOR (kg/ha/day) | 3.129116 | 3.129116 | 3.129116 | 3.129116 | 3.129116 | 3.129116 | | | | |
| DAYS OF DISTURB/yr | 300 | 300 | 300 | 300 | 300 | 300 | 180 | 180 | | |
| TSP kg/yr | 644 | 644 | 3568 | 5656 | 5656 | 3568 | | | 19738 | |
| PM-10 (kg/yr) | 322 | 322 | 1784 | 2828 | 2828 | 1784 | | | 9869 | |
| E FACTOR (Mg/ha/yr) | | | | | | | | | | 0.85 |
| | | | | | | | | | | |
| **TSP (tons/yr)** | **0.64** | **0.64** | **3.57** | **5.66** | **5.66** | **3.57** | | | **20** | **170** |
| **PM-10 (tons/yr)** | **0.32** | **0.32** | **1.78** | **2.83** | **2.83** | **1.78** | | | **10** | **85** |

# TABLE H5: OTHER OPEN DUST EMISSIONS

| | EMISSION | | | SOURCE | EMISSIONS (tons/yr) | | |
|---|---|---|---|---|---|---|---|
| SOURCE ACTIVITY | FACTOR | UNITS | RATING | EXTENT | UNITS | TSP | PM-10 |
| **TOPSOIL** | | | | | | | |
| REMOVAL (TSP) | 0.22 | kg/ton | D | 2488675 | tons/yr | 548 | 274 |
| DUMPING | 0.02 | kg/ton | C | 2488675 | tons/yr | 50 | 25 |
| **TOPSOIL TOTAL** | | | | | | **597** | **299** |
| **OVERBURDEN** | | | | | | | |
| **DRILLING & BLASTING** | | | | | | | |
| **AP-42 predictive equation for blasting is given by the expression;** | | | | | | | |
| **E (TSP) = 0.00022*A^1.5 kg/blast** | | where A = horizontal area (m^2) | | | | | |
| **E (PM-10) = 0.52* E (TSP)** | | | | | | | |
| Blast hole drilling pattern of 7.5 m x 9.0 m giving an area A = | | | | | | 67.5 | m^2/hole |
| No. of holes drilled/day = | | 150 | | (holes are drilled 6 days/week for 52 weeks /yr) | | | |
| No of holes drilled/yr = | | 46800 | | | | | |
| No. of working areas blasted/day = | | 3 | (for 6 days/week for 52 weeks/yr) | | | | |
| Total no. of blasts/yr = | | 936 | | | | | |
| No. of holes/blast = | | 50 | holes/blast | | | | |
| Area per blast = | | 3375 | m^2/blast | (i.e. used as horizontal area in the emission factor equatio | | | |
| DRILLING | 0.59 | kg/hole | B | 150 | holes/day | 28 | 14 |
| BLASTING | 43.14 | kg/blast | C | 936 | blast/yr | 40 | 21 |
| **REMOVAL & REPLACEMENT** | | | | | | | |
| REMOVAL (T & S) | 0.018 | kg/ton | C | 1927944 | tons/yr | 35 | 17 |
| REMOVAL (dragline) | | | | | | | |
| (a) drop height (m) = | 7.5 | | | | | | |
| (b) Moisture cont (%) = | 7.9 | | | | | | |
| (TSP) | 2.27E-02 | kg/m3 | B | 32966078 | m3/yr | 748 | |
| (PM-10) | 4.79E-03 | kg/m3 | B | 32966078 | m3/yr | | 158 |
| REPLACEMENT (T&S) | 0.006 | kg/ton | C | 1927944 | tons/yr | 12 | 6 |
| **OVERBURDEN TOTAL** | | | | | | **863** | **216** |
| **COAL** | | | | | | | |

## TABLE H5: OTHER OPEN DUST EMISSIONS(continued)

| | EMISSION | | | SOURCE | EMISSIONS (tons/yr) | | |
|---|---|---|---|---|---|---|---|
| **SOURCE ACTIVITY** | **FACTOR** | **UNITS** | **RATING** | **EXTENT** | **UNITS** | **TSP** | **PM-10** |
| **DRILLING & BLASTING** | | | | | | | |
| **AP-42 predictive equation for blasting is given by the expression;** | | | | | | | |
| **E (TSP) = 0.00022*A^1.5 kg/blast** | | where A = horizontal area (m^2) | | | | | |
| **E (PM-10) = 0.52* E (TSP)** | | | | | | | |
| | | | | | | | |
| Blast hole drilling pattern of 7.62 m x 7.62 m giving an area A = | | | | | | 58.0644 | m^2/hole |
| No. of holes drilled/day = | | 100 | | (holes are drilled 6 days/week for 52 weeks /yr) | | | |
| No of holes drilled/yr = | | 31200 | | | | | |
| No. of working areas blasted/day = | | 3 | (for 6days/week for 52 weeks/yr) | | | | |
| Total no. of blasts/yr = | | 936 | | | | | |
| No. of holes/blast = | | 33.33 | holes/blast | | | | |
| Area per blast = | | 1935.48 | m^2/blast | (i.e. used as horizontal area in the emission factor equatio | | | |
| DRILLING | 0.1 | kg/hole | B | 100 | holes/day | 3 | 2 |
| BLASTING | 18.73 | kg/blast | C | 936 | blast/yr | 18 | 9 |
| | | | | | | | |
| **REMOVAL** | moisture content of coal= | | 8 | | | | |
| REMOVAL (TSP) | 4.78E-02 | kg/ton | B | 13467084 | tons/yr | 644 | |
| (PM-10) | 6.88E-03 | kg/ton | B | 13467084 | tons/yr | | 93 |
| | | | | | | | |
| **COAL TOTAL** | | | | | | **665** | **103** |
| | | | | | | | |
| **DOZING & GRADING** | | | | | | | |
| | | (emission factor equations from Table 11.9.1 of AP-45, 1995) | | | | | |
| **SPOILS DOZING** | | | | | | | |
| | | E (TSP) = 2.6 * s^1.2/M^1.3 kg/hr | | | | | |
| | | E (PM-10) = 0.75 * (0.45 * s^1.5/M^1.4) kg/hr | | | | | |
| s = silt content (%) of overburden = | | 6.9 | | | | | |
| M = moisture content (%) = | | 7.9 | | | | | |

## TABLE H5: OTHER OPEN DUST EMISSIONS(continued)

| | EMISSION | | | SOURCE | EMISSIONS (tons/yr) | | |
|---|---|---|---|---|---|---|---|
| **SOURCE ACTIVITY** | **FACTOR** | **UNITS** | **RATING** | **EXTENT** | **UNITS** | **TSP** | **PM-10** |
| Total area leveled per yr | = | 70 | ha | | | | |
| No. of dozer hrs/ha | = | 170 | | | | | |
| Total no. of dozer hrs/yr | = | 11900 | hrs | | | | |
| EMISSIONS (TSP) | 1.80 | kg/hr | B | 11900 | hrs/yr | 21 | |
| EMISSIONS (PM-10) | 0.34 | kg/hr | B | 11900 | hrs/yr | | 4 |
| | | | | | | | |
| **GRADING** | | | | | | | |
| | | (emission factor equations from Table 11.9.1 of AP-45, 1995) | | | | | |
| | | E (TSP) = 0.0034 * (S)^2.5 | | | kg/VKT | | |
| S = mean vehicle speed (km/hr) | = | 10 | | | | | |
| No. of hrs grader is used/day | = | 12 | hrs/day | (5 days /week for 52 weeks) | | | |
| No. of grading hours per yr | | 3120 | hrs/yr | | | | |
| No. of graders in a fleet | | 4 | | | | | |
| Total no. of grading hrs | | 12480 | hrs/yr | | | | |
| | | | | | | | |
| EMISSIONS | 1.08 | kg/hr | B | 12480 | hrs/yr | 13.42 | 6.71 |
| | | | | | | | |
| **DOZING/GRADING TOTAL** | | | | | | 35 | 11 |
| | | | | | | | |
| **OVERALL TOTAL** | | | | | | **2160** | **629** |

# TABLE H6: SUMMARY OF OPEN DUST EMISSION RATES

| | CONTROLLED EMISSIONS (tons/yr) | | | | UNCONTROLLED EMISSIONS (tons/yr) | | | |
|---|---|---|---|---|---|---|---|---|
| **SOURCE ACTIVITY** | **TSP** | **%** | **PM-10** | **%** | **TSP** | **%** | **PM-10** | **%** |
| DRILLING (overb/coal) | 31 | 0.3% | 15 | 0.4% | 31 | 0.1% | 15 | 0.1% |
| BLASTING (overb/coal) | 58 | 0.5% | 30 | 0.8% | 58 | 0.2% | 30 | 0.3% |
| TOPSOIL REMOV/DUMP | 597 | 5.4% | 299 | 7.7% | 597 | 1.9% | 299 | 2.7% |
| OVERBURDEN REMOV/REPL | 795 | 7.2% | 181 | 4.7% | 795 | 2.5% | 181 | 1.6% |
| COAL REMOVAL | 644 | 5.8% | 93 | 2.4% | 644 | 2.1% | 93 | 0.8% |
| PAVED ROADS | 71 | 0.6% | 14 | 0.4% | 71 | 0.2% | 14 | 0.1% |
| HAUL ROADS | 8662 | 78.1% | 3118 | 80.8% | 28873 | 92.2% | 10394 | 93.3% |
| COAL HANDLING (stockpiles) | 12 | 0.1% | 4 | 0.1% | 12 | 0.0% | 4 | 0.0% |
| W/EROSION (stockpiles) | 20 | 0.2% | 10 | 0.3% | 20 | 0.1% | 10 | 0.1% |
| W/EROSION (exposed areas) | 170 | 1.5% | 85 | 2.2% | 170 | 0.5% | 85 | 0.8% |
| DOZING & GRADING | 35 | 0.3% | 11 | 0.3% | 35 | 0.1% | 11 | 0.1% |
| | | | | | | | | |
| **TOTAL** | **11095** | 100.0% | **3860** | 100.0% | **31306** | 100.0% | **11136** | 100.0% |

# TABLE H7: ESTIMATION OF PROCESS EMISSIONS

| ESTIMATION OF EMISSION RATES FOR PROCESS SOURCES | | | | | EMISSION RATES (tons/yr) | | | |
|---|---|---|---|---|---|---|---|---|
| | E FACTOR | QTY OF COAL | CONTROL DEVICE | CTRL | CONTROLLED | | UNCONTROLLED | |
| SOURCE | (kg/ton) | (ton/month) | USED | % | TSP | PM-10 | TSP | PM-10 |
| **COAL DUMPING** | 0.004 | 1122257 | Dust scrubber | 50 | **27** | **13** | **54** | **27** |
| | | | | | | | | |
| **CRUSHING** | | | | | | | | |
| Primary | 0.01 | 897806 | Dust Scrubber | 50 | 54 | 27 | 108 | 54 |
| Secondary | 0.03 | 427000 | Dust Scrubber | 60 | 61 | 31 | 154 | 77 |
| **TOTAL CRUSHING** | | | | | **115** | **58** | **261** | **131** |
| | | | | | | | | |
| **SCREENING** | | | | | | | | |
| Primary | 0.01 | 897806 | Sonicore Spray | 40 | 65 | 32 | 108 | 54 |
| Secondary | 0.02 | 250000 | Sonicore Spray | 60 | 24 | 12 | 60 | 30 |
| **TOTAL SCREENING** | | | | | **89** | **44** | **168** | **84** |
| | | | | | | | | |
| **TRANSFER POINTS** | | | | | | | | |
| | (emission factor used was from Cole and Kerch (1990) | | | | | | | |
| | E (TSP) = | 2.9E-05 *s * U * h * /M^2 | kg/ton where | | | | | |
| **s = silt content (%) =** | | 1.4 | | | | | | |
| **U = wind speed (km/hr) =** | | 10.8 | ( 1 m/s = 3.6 km/hr) | | | | | |
| **h = drop height (m) =** | | 5 | | | | | | |
| **M = moisture cont (%) =** | | 8 | | | | | | |
| | | | | | | | | |
| Tip | 3.426E-05 | 1122257 | Sprays & Scrubbers | 50 | 2.31E+00 | 1.15E+00 | 4.61E+00 | 2.31E+00 |
| ROM | 3.426E-05 | 1122257 | Scrubber | 60 | 1.85E+00 | 9.23E-01 | 4.61E+00 | 2.31E+00 |
| DMS | 3.426E-05 | 200000 | Scrubber | 60 | 3.29E-01 | 1.64E-01 | 8.22E-01 | 4.11E-01 |
| Screens | 3.426E-05 | 897806 | Sprays | 40 | 2.21E+00 | 1.11E+00 | 3.69E+00 | 1.85E+00 |
| **TOTAL TRANSFER POINTS** | | | | | **7** | **3** | **14** | **7** |
| | | | | | | | | |
| **TOTAL PROCESS EMISSION RATES** | | | | | **238** | **119** | **497** | **248** |

# TABLE H8: SUMMARY OF PROCESS SOURCE EMISSION RATES

| | CONTROLLED EMISSIONS (tons/yr) | | | | UNCONTROLLED EMISSIONS (tons/yr) | | | |
|---|---|---|---|---|---|---|---|---|
| **ACTIVITY** | **TSP** | **%** | **PM-10** | **%** | **TSP** | **%** | **PM-10** | **%** |
| COAL DUMPING | 27 | 11.3% | 13 | 11.3% | 54 | 10.8% | 27 | 10.8% |
| CRUSHING | 115 | 48.5% | 58 | 48.5% | 261 | 52.6% | 131 | 52.6% |
| SCREENING | 89 | 37.3% | 44 | 37.3% | 168 | 33.8% | 84 | 33.8% |
| TRANSFER PTS | 7 | 2.8% | 3 | 2.8% | 14 | 2.8% | 7 | 2.8% |
| | | | | | | | | |
| **TOTAL** | **238** | **100.0%** | **119** | **100.0%** | **497** | 100.0% | **248** | 100.0% |

# TABLE H9: RESULTS OF 1995 EMISSION INVENTORY

| | | | EMISSION RATES (tons/yr) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CONTROL | CONTROL | CONTROLLED | | | | UNCONTROLLED | | | |
| SOURCE ACTIVITIES | DEVICE/METHOD | EFFICIENCY (%) | TSP | % | PM-10 | % | TSP | % | PM-10 | % |
| **OPENDUST SOURCES** | | | | | | | | | | |
| DRILLING (overb + coal) | | | 31 | 0.3 | 15 | 0.4 | 31 | 0.1 | 15 | 0.1 |
| BLASTING (overb + coal) | | | 58 | 0.5 | 30 | 0.8 | 58 | 0.2 | 30 | 0.3 |
| TOPSOIL REMOV/DUMP | | | 597 | 5.3 | 299 | 7.5 | 597 | 1.9 | 299 | 2.6 |
| OVERB REMOV/REPLAC | | | 795 | 7.0 | 181 | 4.6 | 795 | 2.5 | 181 | 1.6 |
| COAL REMOVAL | | | 644 | 5.7 | 93 | 2.3 | 644 | 2.0 | 93 | 0.8 |
| PAVED ROADS | | | 71 | 0.6 | 14 | 0.3 | 71 | 0.2 | 14 | 0.1 |
| HAUL ROADS | Watering | 70 | 8662 | 76.4 | 3118 | 78.4 | 28873 | 90.8 | 10394 | 91.3 |
| COAL HANDLING (stockpiles) | | | 12 | 0.1 | 4 | 0.1 | 12 | 0.0 | 4 | 0.0 |
| WIND EROSION (stockpiles) | | | 20 | 0.2 | 10 | 0.2 | 20 | 0.1 | 10 | 0.1 |
| W/EROSION (exposed areas) | | | 170 | 1.5 | 85 | 2.1 | 170 | 0.5 | 85 | 0.7 |
| DOZING & GRADING | | | 35 | 0.3 | 11 | 0.3 | 35 | 0.1 | 11 | 0.1 |
| **PROCESS SOURCES** | | | | | | | | | | |
| COAL DUMPING | Dust scrubber | 50 | 27 | 0.2 | 13 | 0.3 | 54 | 0.2 | 27 | 0.2 |
| PRIMARY CRUSHING | Dust scrubber | 50 | 54 | 0.5 | 27 | 0.7 | 108 | 0.3 | 54 | 0.5 |
| SECONDARY CRUSHING | Dust scrubber | 60 | 61 | 0.5 | 31 | 0.8 | 154 | 0.5 | 77 | 0.7 |
| PRIMARY SCREENING | Sonicore spray | 40 | 65 | 0.6 | 32 | 0.8 | 108 | 0.3 | 54 | 0.5 |
| SECONDARY SCREENING | Sonicore spray | 60 | 24 | 0.2 | 12 | 0.3 | 60 | 0.2 | 30 | 0.3 |
| TIP TRANSFER POINT | Sprays & scrubbers | 50 | 2 | 0.0 | 1 | 0.0 | 5 | 0.0 | 2 | 0.0 |
| ROM TRANSFER POINT | Dust scrubber | 60 | 2 | 0.0 | 1 | 0.0 | 5 | 0.0 | 2 | 0.0 |
| DMS TRANSFER POINT | Dust scrubber | 60 | 3.29E-01 | 0.0 | 1.64E-01 | 0.0 | 8.22E-01 | 0.0 | 4.11E-01 | 0.0 |
| SCREENS TRANSFER PT | Sonicore sprays | 40 | 2 | 0.0 | 1 | 0.0 | 4 | 0.0 | 2 | 0.0 |
| **TOTAL INVENTORY** | | | **11332** | **100.0** | **3979** | **100.0** | **31803** | **100.0** | **11384** | **100.0** |

# APPENDIX I

# STRUCTURE OF SPREADSHEET COST MODEL

# CHEMICAL DUST SUPPRESSANT APPLICATION PARAMETERS

| CHEMICAL APPLICATION PARAMETERS | TYPE OF CHEMICALS | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CALCIUM CHLORIDE | | | | | LIGNO SULPHONATE | | | | | POLYMERISED BITUMEN | | | | |
| | 50 % | 60 % | 70 % | 80 % | 90 % | 50 % | 60 % | 70 % | 80 % | 90 % | 50 % | 60 % | 70 % | 80 % | 90 % |
| Method of application | Spray-on | | | | | Mixed-in (initial application only) | | | | | Mixed-in (initial application only) | | | | |
| Cost of product | R 1.0 per litre | | | | | R 1.50 per kg (for powder)<br>R 1.80 per litre (for modified) | | | | | R 2.0 per litre | | | | |
| Surface preparation | Required | | | | | Required | | | | | Required | | | | |
| **Initial Application** | | | | | | | | | | | | | | | |
| Application intensity ($\ell/m^2$) | 0.6 | 1.0 | 1.5 | 2.0 | 3.0 | 0.5 | 0.8 | 1.0 | 1.5 | 2.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Dilution ratio | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Application frequency | 1 | 2 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **Reapplication** | | | | | | | | | | | | | | | |
| Application intensity ($\ell/m^2$) | 0.4 | 0.5 | 0.8 | 0.8 | 1.0 | 0.4 | 0.6 | 0.6 | 0.8 | 1.0 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 |
| Dilution ratio | 1:5 | 1:3 | 1:3 | 1:2 | 1:1 | 1:3 | 1:3 | 1:2 | 1:2 | 1:1 | 1:5 | 1:5 | 1:4 | 1:4 | 1:3 |
| Frequency of application (per month) | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 |
| **Watering**<br>Frequency per week | 18 | 18 | 18 | 24 | 24 | 18 | 18 | 18 | 24 | 24 | 18 | 18 | 18 | 24 | 24 |
| **Grading**<br>Frequency per month | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

## COST ESTIMATES FOR ANALYSIS

| ACTIVITY | COST Rand/hour | HOURS/KILOMETRE Mixed | Topical | Water |
|---|---|---|---|---|
| Surface prep | 338 | 10 | 5 | 0 |
| Application | 202 | 5 | 1.25 | 0.15 |
| Grading | 338 | 2.5 | 2.5 | 2.5 |
| Remaining watering | 428 | 0.15 | 0.15 | 0.15 |

## COST- EFFECTIVE ANALYSIS
## (To achieve 50 % control efficiency)

| COST ELEMENTS | CALCIUM CHLORIDE | LIGNO-SULPHONATE | POLYMERISED BITUMEN |
|---|---|---|---|
| Surface prep (Rand/applic.) | 1690 | 3380 | 3380 |
| Application (Rand/occur.) | 253 | 1010 | 1010 |
| Cost of ligno powder (R/km) | | 24150 | |
| Cost of chemical (R/ℓ) | 1 | 1.8 | 2 |
| Applic intensity (ℓ/$m^2$) | 0.6 | 0.5 | 3 |
| Dilution ratio (chem) | 0 | 0 | 0 |
| Dilution ratio (water) | 0 | 0 | 0 |
| Litres of chem required/km | 12000 | 10000 | 60000 |
| Cost of chem (for 20000 $m^2$) | 12000 | 42150 | 120000 |
| **MAINTENANCE** | | | |
| Frequency of application | 3/month | 3/month | 2/month |
| Application intensity (ℓ/$m^2$) | 0.4 | 0.4 | 1 |
| Dilution (chem) | 1 | 1 | 1 |
| Dilution (water) | 5 | 3 | 5 |
| No. of reapplications/yr | 33 | 33 | 22 |
| Chem. cost (R/occurrence) | 1333 | 3600 | 6667 |
| Chem. cost (R/yr) | 44000 | 118800 | 146667 |
| Reapplication cost (R/yr) | 8333 | 66660 | 22220 |
| **Total mainten. cost (R/yr)** | 52333 | 185460 | 168887 |
| **WATERING** | | | |
| Frequency of watering/week | 18 | 18 | 18 |
| **Watering cost/yr** | 60091 | 60091 | 60091 |
| **GRADING** | | | |
| Frequency of grading/month | 2 | 1 | 1 |
| **Grading cost (R/yr)** | 20280 | 10140 | 10140 |
| **TOTAL ANNUAL COST (R)** | **146646** | **302231** | **363508** |

## COST- EFFECTIVE ANALYSIS
## (To achieve 60 % control efficiency)

| COST ELEMENTS | CALCIUM CHLORIDE | LIGNO-SULPHONATE | POLYMERISED BITUMEN |
|---|---|---|---|
| Surface prep (Rand/applic.) | 1690 | 3380 | 3380 |
| Application (Rand/occur.) | 505 | 1010 | 1010 |
| Cost of ligno powder (R/km) | | 24150 | |
| Cost of chemical (R/ℓ) | 1 | 1.8 | 2 |
| Applic intensity (ℓ/$m^2$) | 1 | 0.8 | 3 |
| Dilution ratio (chem) | 0 | 0 | 0 |
| Dilution ratio (water) | 0 | 0 | 0 |
| Litres of chem required/km | 20000 | 16000 | 60000 |
| Cost of chem (for 20000 $m^2$) | 20000 | 52950 | 120000 |
| **MAINTENANCE** | | | |
| Frequency of application | 3/month | 3/month | 2/month |
| Application intensity (ℓ/$m^2$) | 0.5 | 0.6 | 1.5 |
| Dilution (chem) | 1 | 1 | 1 |
| Dilution (water) | 3 | 3 | 5 |
| No. of reapplications/yr | 33 | 33 | 22 |
| Chem. cost (R/occurrence) | 2500 | 5400 | 10000 |
| Chem. cost (R/yr) | 82500 | 178200 | 220000 |
| Reapplication cost (R/yr) | 16665 | 33330 | 22220 |
| **Total mainten. cost (R/yr)** | 99165 | 211530 | 242220 |
| **WATERING** | | | |
| Frequency of watering/week | 18 | 18 | 18 |
| **Watering cost/yr** | 60091 | 60091 | 60091 |
| **GRADING** | | | |
| Frequency of grading/month | 2 | 1 | 1 |
| **Grading cost (R/yr)** | 20280 | 10140 | 10140 |
| **TOTAL ANNUAL COST (R)** | **201731** | **339101** | **436841** |

## COST- EFFECTIVE ANALYSIS
## (To achieve 70 % control efficiency)

| COST ELEMENTS | CALCIUM CHLORIDE | LIGNO-SULPHONATE | POLYMERISED BITUMEN |
|---|---|---|---|
| Surface prep (Rand/applic.) | 1690 | 3380 | 3380 |
| Application (Rand/occur.) | 758 | 1010 | 1010 |
| Cost of ligno powder (R/km) | | 24150 | |
| Cost of chemical (R/ℓ) | 1.0 | 1.8 | 2 |
| Applic intensity (ℓ/$m^2$) | 1.5 | 1 | 3 |
| Dilution ratio (chem) | 0 | 0 | 0 |
| Dilution ratio (water) | 0 | 0 | 0 |
| Litres of chem required/km | 30000 | 20000 | 60000 |
| Cost of chem (for 20000 $m^2$) | 30000 | 60150 | 120000 |
| **MAINTENANCE** | | | |
| Frequency of application | 3/month | 3/month | 2/month |
| Application intensity (ℓ/$m^2$) | 0.8 | 0.6 | 2 |
| Dilution (chem) | 1 | 1 | 1 |
| Dilution (water) | 3 | 2 | 4 |
| No. of reapplications/yr | 33 | 33 | 22 |
| Chem. cost (R/occurrence) | 4000 | 7200 | 16000 |
| Chem. cost (R/yr) | 132000 | 237600 | 352000 |
| Reapplication cost (R/yr) | 24998 | 33330 | 22220 |
| **Total mainten. cost (R/yr)** | 156998 | 270930 | 374220 |
| **WATERING** | | | |
| Frequency of watering/week | 18 | 18 | 18 |
| **Watering cost/yr** | 60091 | 60091 | 60091 |
| **GRADING** | | | |
| Frequency of grading/month | 2 | 1 | 1 |
| **Grading cost (R/yr)** | 20280 | 10140 | 10140 |
| **TOTAL ANNUAL COST (R)** | **269816** | **405701** | **568841** |

# COST- EFFECTIVE ANALYSIS
## (To achieve 80 % control efficiency)

| COST ELEMENTS | CALCIUM CHLORIDE | LIGNO-SULPHONATE | POLYMERISED BITUMEN |
|---|---|---|---|
| Surface prep (Rand/applic.) | 1690 | 3380 | 3380 |
| Application (Rand/occur.) | 758 | 1010 | 1010 |
| Cost of ligno powder (R/km) | | 24150 | |
| Cost of chemical (R/ℓ) | 1 | 1.8 | 2 |
| Applic intensity (ℓ/$m^2$) | 2 | 1.5 | 3 |
| Dilution ratio (chem) | 0 | 0 | 0 |
| Dilution ratio (water) | 0 | 0 | 0 |
| Litres of chem required/km | 40000 | 30000 | 60000 |
| Cost of chem (for 20000 $m^2$) | 40000 | 78150 | 120000 |
| **MAINTENANCE** | | | |
| Frequency of application | 3/ month | 3/month | 2/month |
| Application intensity (ℓ/$m^2$) | 0.8 | 0.8 | 2.5 |
| Dilution (chem) | 1 | 1 | 1 |
| Dilution (water) | 2 | 2 | 4 |
| No. of reapplications/yr | 33 | 33 | 22 |
| Chem. cost (R/occurrence) | 5333 | 9600 | 20000 |
| Chem. cost (R/yr) | 176000 | 316800 | 440000 |
| Reapplication cost (R/yr) | 24998 | 33330 | 22220 |
| **Total mainten. cost (R/yr)** | 200998 | 350130 | 462220 |
| **WATERING** | | | |
| Frequency of watering/week | 24 | 24 | 24 |
| **Watering cost/yr** | 80122 | 80122 | 80122 |
| **GRADING** | | | |
| Frequency of grading/month | 2 | 1 | 1 |
| **Grading cost (R/yr)** | 20280 | 10140 | 10140 |
| **TOTAL ANNUAL COST (R)** | **343847** | **522932** | **676872** |

## COST- EFFECTIVE ANALYSIS
## (To achieve 90 % control efficiency)

| COST ELEMENTS | CALCIUM CHLORIDE | LIGNO-SULPHONATE | POLYMERISED BITUMEN |
|---|---|---|---|
| Surface prep (Rand/applic.) | 1690 | 3380 | 3380 |
| Application (Rand/occur.) | 758 | 1010 | 1010 |
| Cost of ligno powder (R/km) | | 24150 | |
| Cost of chemical (R/ℓ) | 1 | 1.8 | 2 |
| Applic intensity (ℓ /$m^2$) | 3 | 2 | 3 |
| Dilution ratio (chem) | 0 | 0 | 0 |
| Dilution ratio (water) | 0 | 0 | 0 |
| Litres of chem required/km | 60000 | 40000 | 60000 |
| Cost of chem (for 20000 $m^2$) | 60000 | 96150 | 120000 |
| **MAINTENANCE** | | | |
| Frequency of application | 3/ month | 3/month | 2/month |
| Application intensity (ℓ /$m^2$) | 1 | 1 | 3 |
| Dilution (chem) | 1 | 1 | 1 |
| Dilution (water) | 1 | 1 | 3 |
| No. of reapplications/yr | 33 | 33 | 22 |
| Chem. cost (R/occurrence) | 10000 | 18000 | 30000 |
| Chem. cost (R/yr) | 330000 | 594000 | 660000 |
| Reapplication cost (R/yr) | 24998 | 33330 | 22220 |
| **Total mainten. cost (R/yr)** | 354998 | 627330 | 682220 |
| **WATERING** | | | |
| Frequency of watering/week | 24 | 24 | 24 |
| **Watering cost/yr** | 80122 | 80122 | 80122 |
| **GRADING** | | | |
| Frequency of grading/month | 2 | 1 | 1 |
| **Grading cost (R/yr)** | 20280 | 10140 | 10140 |
| **TOTAL ANNUAL COST (R)** | **517847** | **818132** | **896872** |

# COST- EFFECTIVE ANALYSIS
# WATERING PROGRAMME

Control efficiency of watering programme is given by AP-42 as follows:

C = 100 - [(0.8*p*d*t)/i]

where:

p = average daytime evaporation rate in mm/hr
d = average daytime traffic rate in no. of veh/hr
t = time between applications in hrs
i = application intensity in lit/m^2

| PARAMETER | VALUE | UNITS |
|---|---|---|
| p | 0.21 | mm/hr |
| d | 88 | veh/hr |
| i | 0.5 | lit/m^2 |
| No. of hours/day | 20 | |
| Time for watering = | 0.15 | (hr/km) |
| Cost of watering = | 428 | (Rand/hr) |

GRADING COST PARAMETERS

| | |
|---|---|
| Grading cost (Rand/hr) = | 338 |
| Time for grading (hr/km) = | 2.5 |
| No. of grading per week = | 2 |

| CONTROL EFFICIENCY (%) | TIME BETWEEN APPLICATIONS (hrs) | NO. OF TIMES (per day) | NO. OF HRS (per day) | COST Rand/day | COST Rand/week | COST Rand/yr | GRADING COST | ANNUAL COST | TOTAL COST (Rand x 10^3) |
|---|---|---|---|---|---|---|---|---|---|
| 50 | 1.69 | 11.83 | 1.774 | 759 | 4556 | 236904 | 87880 | 324784 | 325 |
| 60 | 1.35 | 14.78 | 2.218 | 949 | 5695 | 296129 | 87880 | 384009 | 384 |
| 70 | 1.01 | 19.71 | 2.957 | 1 266 | 7593 | 394839 | 87880 | 482719 | 483 |
| 80 | 0.68 | 29.57 | 4.435 | 1 898 | 11390 | 592259 | 87880 | 680139 | 680 |
| 90 | 0.34 | 59.14 | 8.870 | 3 797 | 22779 | 1184518 | 87880 | 1272398 | 1272 |

## DUST CONTROL COST SUMMARY SUB-MODULE

| CONTROL EFFICIENCY (%) | DUST CONTROL COST (Rand/yr/km) | | | |
|---|---|---|---|---|
| | WATER | CALCIUM CHLORIDE | LIGNO-SULPHONATE | POLYMERISED BITUMEN |
| 50 | 325 | 147 | 302 | 364 |
| 60 | 384 | 202 | 339 | 437 |
| 70 | 483 | 270 | 406 | 569 |
| 80 | 680 | 344 | 523 | 677 |
| 90 | 1 272 | 518 | 818 | 897 |

## COST IMPLICATIONS

| CONTROL EFFICIENCY (%) | PERCENTAGE COST SAVINGS (%/yr/km) | | | |
|---|---|---|---|---|
| | WATER | CALCIUM CHLORIDE | LIGNO-SULPHONATE | POLYMERISED BITUMEN |
| 50 | - | 55 | 7 | - 12 |
| 60 | - | 47 | 12 | - 14 |
| 70 | - | 44 | 16 | - 18 |
| 80 | - | 49 | 23 | 0 |
| 90 | - | 59 | 36 | 30 |

# APPENDIX J

1.4 Mb MAGNETIC DISK CONTAINING
EXCEL VERSION 5.0 SPREADSHEETS
OF APPENDICES H AND I.