
THE ESTIMATED ENVIRONMENTAL COST OF SASOL FERTILIZER

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PREAMBLE

I would like to use this opportunity to thank Prof. Braam de Villiers for his commitment towards this project, as well as his enthusiasm towards the continuation of this study in order to extend the existing knowledge base of environmental cost accounting.

I would also like to thank Frikkie Botha for his initial support and approval of the concept of this study.

My sincerest thanks goes also to everybody else that helped, guided and spent some valuable time with me on this project. These people include Barend Bredenkamp and other personnel from Sasol Fertiliser, Prof. Johan Nel and Hendriko Veldman.

Finally I would like to thank my family (Lizelotte and Berno) for their support.

OPSOMMING

In hierdie studie is sowel die omgewings en sosiale koste van Sasol Kunsmis ondersoek. Koste is gekategoriseer as primêre en sekondêre koste en daarna ingesluit in 'n kosteberaming model, wat ook metodes en prosedures insluit vir gebruik in die uitvoer van algemene omgewingskoste bepaling studies.

'n Beskrywing van die omgewing, sowel die kunsmis vervaardigingsproses is bespreek. Die belangrike omgewings en sosiale koste van Sasol Kunsmis is geïdentifiseer en geld waardes toegeken waar moontlik. Hierdie studie stel toepaslike en bestaande koste bepaling prosedures asook spesialis studies voor vir toekomstige navorsing in 'n Suid Afrikaanse konteks. Tipiese studies sluit sogenaamde “bereidwilligheid om te betaal”, asook “ bereidwilligheid om vergoed te word” ondersoek in.

Die totale omgewingskoste vir Sasol Kunsmis is bepaal as 'n minimum van ongeveer R50 miljoen. Hierdie bedrag sluit die meeste van die sekondêre koste soos geïdentifiseer uit, maar sluit belangrike remedieerings koste in terme van grond en grondwater besoedeling en verlies aan plantegroei in. Laastens is bevind dat die primêre omgewingskoste van Sasol Kunsmis tans groter is as die bekende sekondêre koste, gebaseer op beskikbare koste waardes.

Toekomstige studies word benodig om die huidige kennisbasis van algemene omgewingskoste bepaling in Suid Afrika uit te brei.

SUMMARY

This study investigated the main environmental and social cost of Sasol Fertiliser. This cost was categorised as primary and secondary in nature and was described as part of a cost estimation model, including a number of procedures and methods that can be followed for general environmental cost estimation studies.

A description of the receiving environment, as well as the fertiliser production process was presented. The main environmental and social cost for Sasol Fertiliser was identified and monetary values assigned to this cost where possible. This study recommended suitable existing cost estimating procedures or specialist studies for future research in South Africa, including “Willingness to Pay” and “Willingness to be Compensated” studies.

The total environmental cost for Sasol Fertiliser was found to be in the order of a minimum of R50 million. This amount excluded most of the secondary cost identified, but included the remediation cost in terms of soil and groundwater contamination and loss of vegetation. It was found that the primary environmental cost of Sasol Fertiliser outweighed its known secondary environmental cost, based on the cost values obtained.

Future studies are required to expand the current knowledge base of general environmental cost accounting in South Africa.

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LIST OF ABBREVIATIONS

AN	Ammonium Nitrate
B/C	Benefit/Cost
CAA	Clean Air Act
CEPPPO	Chemical Emergency Preparedness and Prevention Office
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CO ₂	Carbon dioxide
DAP	Di-Ammonium Phosphate
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
FAO	Food and Agricultural Organisation of the United Nations
H ₂ S	Hydrogen Sulphite
HNO ₃	Nitric Acid
IFA	International Fertiliser Association
IFDC	International Fertiliser Development Centre
J&W	Jones and Wagener Consulting Civil Engineers (Pty) Ltd.
KAN	Potassium Ammonium Nitrate
Km	Kilometre
LCA	Life Cycle Assessment
MAP	Mono Ammonium Phosphate
mm	Millimetres
m/s	Meters per second
mS/m	Milli Siemens per meter
N	Nitrogen
Na	Sodium
NH ₃	Ammonia
NH ₄	Ammonium
NO _x	Various forms of Nitrous Oxide
NO ₃	Nitrate
NPK	Fertilisers containing Nitrates, Phosphates and Potassium
ppm	Parts per million

RESM	Receiving Environmental Surface Monitoring
SIA	Social Impact Assessment
SRK	Steffan, Robertson and Kirstein Consulting Engineers and Scientists (Pty) Ltd.
SO ₂	Sulphur Dioxide
SO ₄	Sulphate
tds	Total Dissolved Solids
TEKS	Trichardt, Evander, Kinross and Secunda
tpd	Tons per day
tph	Tons per hour
UNEP	United Nations Environment Program
UNIDO	United Nations Industrial Development Organisation
USA	United States of America
USEPA	The United States Environmental Protection Agency
WHO	World Health Organisation
WMB	Wates, Meiring and Barnard Consulting Engineers (Pty) Ltd.
WTC	Willingness to be Compensated
WTP	Willingness to Pay

CHAPTER 1: INTRODUCTION

1.1 Introduction

Environmental cost accounting is a new developing scientific field in South Africa. In this study, an attempt is made to estimate the existing and continuing environmental cost of a fertiliser production facility in order to provide guidelines for future approaches that can be generally used in this exciting study field.

The inclusion of environmental cost in the normal economic affairs of any business that has the potential to pollute the environment is becoming increasingly important. Unfortunately, this seems to require the marriage of the fields of the physical sciences and economics where people with knowledge of both fields are scarce to find.

A good starting point on the economic side of this marriage is the consideration of the typical cost-benefit analysis performed for most business decisions. This method provides the starting point or framework for this study with the main focus on the cost side of the research problem.

1.2 Cost-benefit analysis

The purpose of an economic evaluation is to determine whether any project or investment is financially desirable. During such an analysis, a number of questions are addressed namely “is any individual project worthwhile?” asking if the project meets minimum economic standards. A second question is “given a list of projects, which is the best?” That is, how does each project rank or compare to the others on the list?

In practice, economic evaluations are difficult to perform correctly. This is mostly due to the fact that those responsible for carrying out the analysis necessarily have a limited view of their organisation’s activities and cannot realistically take all the appropriate factors into account. The result is that most evaluations are done on the basis of assumptions often out of date or otherwise inaccurate for the situation at hand (Shtub, Bard & Globerson, 1994:46).

Again, the method often used to reach a decision is known as cost-benefit analysis. In the private sector, the company generally pays all the cost and receives all the benefits, both

quantitative and qualitative. Replacing an outdated piece of equipment is an example where the returns are measurable, while constructing a new company cafeteria illustrates the opposite case. In the case of normal government, quite a different situation arises. Revenues are received through various forms of taxation and are supposed to be “spent in the public interest”. Thus, a government pays but receives very few, if any benefits. In such a case, the measurement of benefits is normally very difficult due to wide disbursement.

In cost-benefit (B/C) analysis, where B/C ratios is used to rank competing projects, there may be legitimate ambiguity in deciding what goes in the numerator and what goes in the denominator of the ratio (Shtub *et al.*, 1994:117). Benefits and cost can be broken down into four classes: (1) primary, (2) secondary, (3) external and (4) intangible. Primary refers to benefits and cost that are a direct result of a particular project. Secondary benefits and cost are not those that are less important, but rather the marginal benefits and cost that accrue when an imperfect market mechanism is at work. In such instances, the market price of a project’s final goods and services do not reflect the “true” price. External benefits and cost are those that arise when a project produces a spill over effect on someone other than the intended group. Intangible benefits and cost are those that are difficult, if not impossible to measure on a monetary scale.

After categorising the benefits and cost in this manner, they are normally allocated to various project time periods during which they are expected to occur. These periods include the planning stage, the implementation stage, the operation stage and the closeout stage (Shtub *et al.*, 1994: 125).

Cost-benefit analysis is therefore not restricted to the feasibility and basic engineering phase of a project only. It can even be applied to an accident situation during normal operation, using the outcome to decide whether further operation would be worthwhile. All mentioned *cost categories* were encountered during an explosion at a fertiliser manufacturing plant in the United States of America (USA).

At approximately 6 minutes past 6 on the morning of 13 December 1994, an explosion occurred in the ammonium nitrate plant at the Terra International Inc., Port Neal Complex. Four persons were killed as a direct result of the explosion and 18 were injured and required hospitalisation. The explosion resulted in the release of approximately 5 700 tons of anhydrous ammonia to the air and secondary containment, approximately 25 000 gallons of nitric acid to the ground and

lined chemical ditches and sumps, as well as liquid ammonium nitrate solution into secondary containment. The release of off-site ammonia continued for approximately six days following the explosion. Chemicals released as a result of the explosion have resulted in contamination of the groundwater under the facility (CEPPO, 1996).

The USA Environmental Protection Agency's (EPA) Region 7, settled charges against Terra Industries Inc. in Sergeant Bluff, Iowa, for allegedly violating the Clean Air Act (CAA), the Emergency Planning and Community Right-to-Know Act (EPCRA), and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA).

Under the settlement, which was lodged with the U.S. District Court for the Northern District of Iowa Western Division, Terra Industries had to pay a civil penalty of \$500 000 and spent approximately \$100 000 on various supplemental environmental projects beneficial to the local community (*primary unforeseen cost*). These projects included improving hazardous materials planning and preparedness projects in the Sergeant Bluff area, such as installing emergency sirens and equipping local fire departments with anhydrous ammonia monitors (*secondary unforeseen cost*). The ammonium nitrate manufacturer had to pay another \$150 000 to reimburse past response cost (USEPA, 1998).

External cost can be seen to include the loss of life due to the "spill over" effects of the accident. Personnel died, while the shareholders (company beneficiaries) of the company did loose share value but not their lives. *Intangible unforeseen cost* can for example be related to grieve and emotional loss experienced by the family members of those personnel who died in the explosion.

At this time, environment seems to be a buzzword. The fact of the matter is that there is much more to the environment than just the physical environment. Two additional well-known environments are that of the social and economical environments. When combined with the physical environment, it is often referred to as the triple bottom line concept (including environment as the third bottom line). From the example above, it is realised that the type of impacts experienced after the explosion were more than just physical environmental impacts.

A fertiliser company influences its immediate surroundings. There could be pollution due to effluents and emissions, while the health of people in the surrounding area can be affected, as well as bio-diversity etc. There are also benefits in terms of job opportunities and increased crop

yields due to land application of fertiliser (Anon., 1997:15). Sometimes, an inquisitive environmental orientated mind might wonder if the benefits of inorganic fertiliser really outweigh its cost, especially if annual profit figures are published without consideration of the environment. The current South African average profit of the fertiliser industry is very low (approximately 2.5%) while globally, fertiliser profits are under pressure (Jarvis, 2000:3). These profits do not necessarily reflect the “true” environmental profit margin or triple bottom line (Maritz, 2000). Asked differently, is B divided by C really greater than 1?

Cost-benefit analysis provides a method that can be used to decide whether a certain project is worthwhile. As mentioned, such an analysis can be completed during any phase of a project. However, there are a number of shortcomings with B/C methodology. The use of the benefit/cost ratio to rank or ascertain the best alternative can be deceptive because it disguises the problem of scale. Another problem is that the analysis normally possesses a high degree of subjectivity, leaving room for both conscious and unacknowledged bias leading to further shortcomings.

The most significant shortcoming of interest is the need and general failure to evaluate those aspects that are seemingly non-quantifiable in monetary terms. The type of question that continually gets raised is *“how do you measure the value of harmony between labour and management?”* or *“what is the value of a pollution free environment?”* The developments of indicators other than those that reflect monetary value directly, present a considerable challenge to analysts. They then normally depart from the familiar criteria of economic efficiency as a prime mechanism of evaluation and venture into the unknown areas of social and environmental concerns (Shtub *et al.*, 1994:126).

This departure from the familiar economic techniques finds the analyst normally using a multi-attribute-scoring model. These scoring models are used increasingly in planning studies. As an example, a New York utility company Niagara Mohawk developed a scoring form based on environmental aspects. The outcome of the model as applied to project alternatives, is used to screen possible project sites and decide which site to select. All procedures and the methodology used for assigning points are then normally mentioned on the form.

A typical rationale for the interest shown by regulatory commissions is offered by Mintzer (as quoted by Shtub *et al.*, 1994) who asserts that the “scaled scoring models are easy to use,

facilitate comparisons of environmental impacts measured in different units and are *more comprehensive* than economic analysis. In addition, they prove a rank from the lowest to the highest cost on the basis of all economic, environmental and social factors that can be quantified.” These are very impressive claims, but unfortunately, many of the applications reported have paid little attention to methodological issues, with the consequences that the validity of the results are highly uncertain (Shtub *et al.*, 1994:117).

1.3 Problem statement, hypothesis and research questions

Environmental accounting can be defined as a process of applying selected scientific methods or procedures in order to estimate the monetary value of quantifiable and seemingly non-quantifiable aspects of a pollution free (taking natural background values into account) physical environment, on which environmentally sustainable business decisions can be based. In current practice, environmental aspects are mainly accounted for using subjective scoring models when seeming difficult to obtain their economic value. For instances where economic values were obtained, very little or no thought went into the methodology and procedures used to obtain these values.

Project decisions based on monetary values for environmental cost are substantially less subjective when the methodology and procedures for estimating these values are well described and the assumptions used, well defined. No such generally used methods and procedures exist for Sasol Fertiliser.

The hypothesis to be proven for this study is that the main, seemingly non-quantifiable environmental cost of Sasol Fertiliser can be expressed in terms of monetary value. Stated in the form of a research question, the study problem is as follows: *what are the monetary values of the main environmental cost of Sasol Fertiliser?*

In order to answer this main question, the following sub questions must also be considered:

- How is fertiliser produced? (General process description, flow diagram and mass balance information).
- What are the main relevant environmental aspects of the production of fertiliser?
- Are any monetary values for environmental cost available in published literature?

- If no values are available, can procedures to estimate this cost be identified, obtained or developed?
- How do the identified cost values compare with each other?

The questions listed presents a significant task that requires set strategy and study goals.

1.4 Study goals and strategy

This study is focused on using this mini-dissertation to introduce scientific concepts of environmental cost accounting to Sasol Fertiliser by identifying the main environmental aspects of the factory operating at Secunda, expressing these impacts in terms of economic values and report on the methodology used to estimate these values. These general goals were derived from the study hypothesis and research questions, but can be expanded by listing the following sub goals for this study:

- To describe the physical and social environment of the Secunda Sasol Fertiliser factory.
- To identify the main environmental cost of the Sasol Fertiliser factory at Secunda by studying the manufacturing process.
- To categorise the identified environmental cost using the categories used in cost-benefit analysis.
- To report on possible procedures that can be followed to obtain monetary cost estimates for the environmental cost.
- To rank the monetary values of the environmental cost.
- To identify areas of future recommended study applicable to environmental cost estimation.

As part of the study strategy to prove the hypothesis as well as to provide answers to the research questions and goals, identified sources of information include the information obtained from published literature (indirect observation / secondary sources). Furthermore, information regarding the Sasol Fertiliser factory will be obtained through interviews with plant personnel, reviewing operation manuals and other published reports, while estimating procedures will be discussed referring to information and methods also published in literature.

1.5 Dissertation structure

This mini-dissertation is structured to provide a description of the general receiving environment of the Sasol Fertiliser factory in Chapter 2. This description includes typical aspects of the physical environment and the social environment. The main environmental impacts of Sasol Fertiliser are identified in Chapter 3, using the process description and plant mass balance information to identify all possible environmental impacts. Included are a list and evaluation of these impacts against typical environmental and social aspects, as well as the categorising of possible unforeseen cost that may result from these impacts (if values are available) in terms of cost-benefit analysis terminology.

Chapter 4 contains the procedures for estimating economic values of environmental cost. This information includes procedures for estimating economic values, as found in literature and as discussed and proposed during this study. The environmental cost values identified are also ranked. Finally, Chapter 5 contains the conclusions of this study and Chapter 6 the recommendations for future study, expanding the scope of methodology used during environmental accounting.

CHAPTER 2: THE RECEIVING ENVIRONMENT OF SASOL FERTILISER

2.1 Introduction

This chapter describes the receiving environment of Sasol Fertiliser in terms of the physical and social environments. When the physical environment is considered, aspects included are *air, water, soil* and bio-diversity in terms of *plants and animals*.

People are normally related to the social side of impact assessment. In this field of impact assessment, social aspects include issues related to the physical environment as well as to those aspects that could be broadly related to logistic arrangements or input cost. Job opportunities, salaries and general benefits related to the Sasol Fertiliser operation falls into this category.

Burge (1990:93) listed a number of social-logistical variables typically used in Social Impact Assessment (SIA). Examples of these variables are the influx or out-flux of temporary workers, presence of seasonal residents, relocation of individuals and families, dissimilarity of age, gender, racial and ethnic composition, formation of attitudes toward a project, interest group activity, alteration in the size and structure of local government, to name but a few. Other examples of identified SIA variables also include relocated populations, historical experience with change, distribution of power and authority, identification of stakeholders and perceptions of risk. Also health and safety, attitudes toward the policy/project and change in community infrastructure can be named in this list (Burge & Vanday, 1995:44).

This chapter focuses on the environmental aspects relevant to the social-environmental (physical environment) issues of the receiving environment of Sasol Fertiliser. As related to environmental cost, this mainly includes those attributes that could contribute to increased cost to the community in terms of health, safety and direct increased household cost as a result of the pollution of the physical environment.

An integrated approach is followed in the description of the receiving environment, including possible social impacts with the description of the physical environment. Maps are presented to identify those communities in the direct vicinity of the Sasol Fertiliser factory.

2.2 Location of the Sasol Fertiliser factory

The Sasol Secunda Complex is located in the centre of the Highveld Ridge region, in the south-western portion of Mpumalanga (SRK, 2000:4). The Highveld Ridge has been modified by mining, industrial activities related to coal and gold mining, power generation and agriculture. In turn, the land-use in the Secunda region has changed significantly over the last 50 years from a rural agricultural setting to being highly industrialised.

The first industrial developments occurred in the early 1950's with the establishment of gold mining in the area and the development of small towns to service the needs of the mining industry. Based on the coal reserves in the Secunda region, the construction of the Sasol Industrial Complex commenced in the late 1970's. Over the following two decades the complex doubled its petrochemical production capacity and added further industries such as those associated with fertiliser and explosives production.

Although the existence of the complex and the mining in the region has changed the land use character substantially, mixed farming with arable production still plays an important regional role. The various industrial activities, such as coal and gold mining, petrochemical, fertiliser and explosives production undertaken over the past 30 to 50 years, present a multitude of actual and potential contamination sources that have impacted onto the environment in the Secunda region for an extended period of time.

The Secunda Industrial Complex occupies an area of approximately 9 km² and is located 5 km south-west of the town of Secunda (*population: 44 753*; See Figure 2.1). Approximately 7 km to the west of the complex is the Embalenhle Township (*population: 210 000*). Additional settlements in close proximity to the complex include the towns of Trichardt (10 km north north-east, *population: 3 939*), Evander (10 km north-west, *population: 11 232*) and Charl Cilliers (15 km south, *population: 196*). Large towns in the vicinity are Standerton, approximately 60 km to the south of Secunda and Bethal that is located 25 km east of Trichardt. This study does not include the towns of Standerton or Bethal (*population: 15 172* and Enzinoni Township with a population of *109 057*) and is mainly concerned with the area within the boundaries of Charl Cilliers, Embalenhle, Evander Secunda and Trichardt, also known as the TEKS area.

There are a number of mines in the immediate area surrounding the complex, with the closest being the Middelbult main shaft, approximately 2 km to the east.

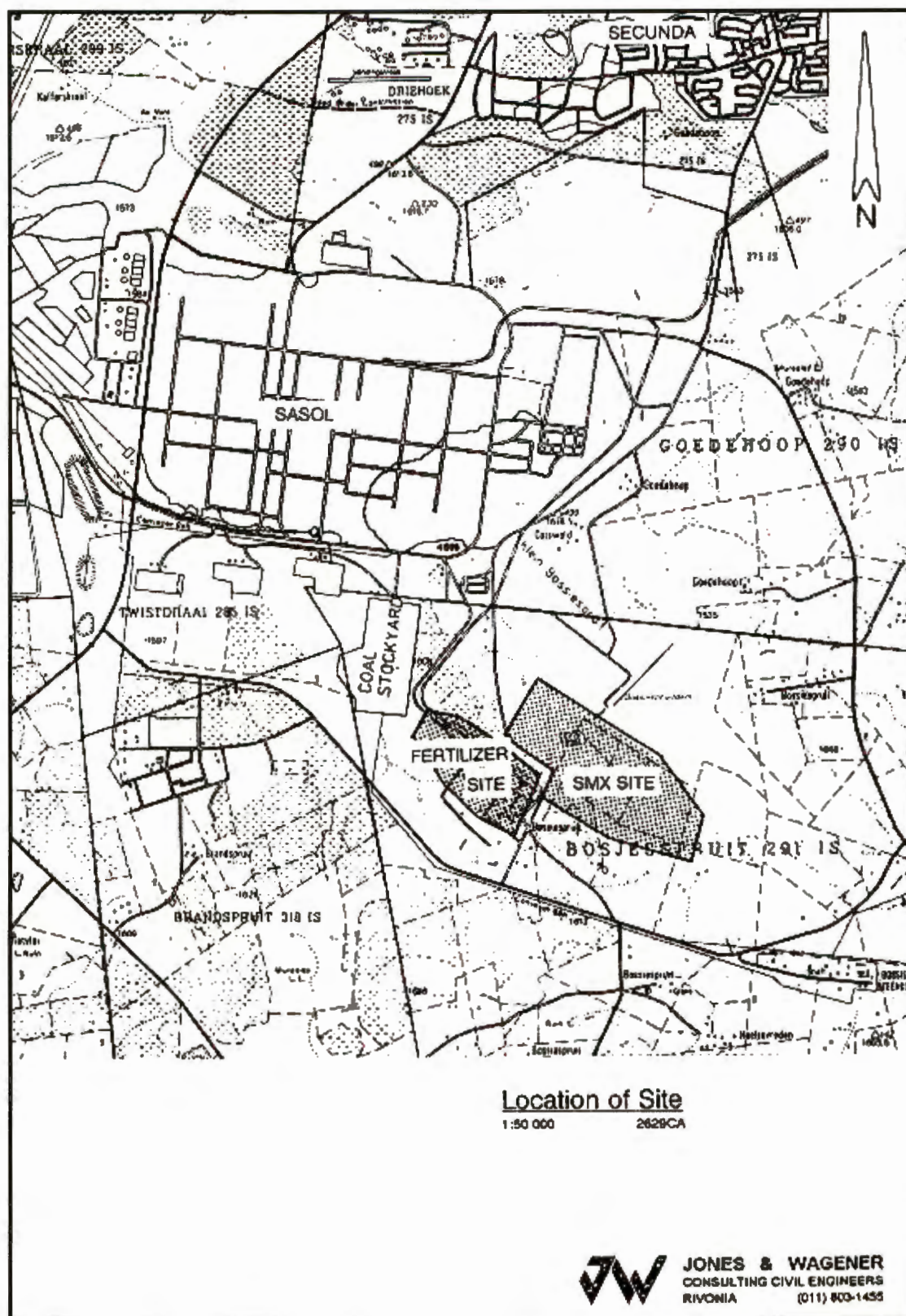


Figure 2.1: Location of the Sasol Fertiliser site relative to the main Secunda Sasol complex (Source: Jones and Wagener Consulting Civil Engineers (Pty) Ltd. (J&W, 1994)).

2.3 Surface water characteristics

The Sasol Industrial Complex is located within the Waterval River catchment. Ecoserv Closed Corporation, on behalf of Wates, Meiring and Barnard Consulting Engineers (Pty) Ltd. has undertaken a recent study of the surface water systems as a specialist study as part of the Sky High Project Environmental Impact Assessment (EIA). The information mentioned below was extracted from this study by an anonymous author employed by Steffan, Robertson and Kirstein Consulting Engineers and Scientists (Pty) Ltd. (SRK, 2000:8).

The ecological status of the Waterval River catchment was investigated, with emphasis on the aquatic systems that may be affected by the Sasol Industrial Complex. The eco-toxicity of various effluents having the potential of seeping or overflowing /decanting, was evaluated in terms of the possible effects on the receiving surface water environment. The major impacts within the area appeared to result from industrial activities and urban developments within the upper parts of the Waterval River catchment. The activities and developments caused large-scale alterations in water quality and hydrological patterns, which had an adverse effect on the riverine habitats directly adjacent to and downstream from where they are situated.

More specific to the Sasol Fertiliser, the site is located in a sub-catchment of the Waterval River comprising the following tributaries, i.e. the Klein Bossiespruit, the Groot Bossiespruit, the lower reaches of the Klipspruit and the lower reaches of the Trichardtspruit (see Figure 2.2). The Groot Bossiespruit is in close proximity of the fertiliser factory and flows in a westerly direction towards the Klein Bossiespruit from where it flows into the Trichardtspruit. The Klipspruit flows in a westerly direction north of the complex and joins the Trichardtspruit at monitoring point 2 (Receiving Environmental Surface Monitoring). From monitoring point 1 or RESM 1, the Trichardtspruit flows through the Embalenhle Township. Thus, the fertiliser factory has the potential of not just polluting some of the surface waterways of the physical environment, but also causing increased social cost to Embalenhle and communities down the Trichardtspruit.

This sub-catchment as a whole contains the most heavily impacted riverine habitats within the Waterval catchment and modifications to the habitats within some segments of the sub-catchment have reached a critical level. Large-scale industrial activity is widespread throughout most of this sub-catchment, e.g. the Sasol Industrial Complex, as well as various gold and coalmines.

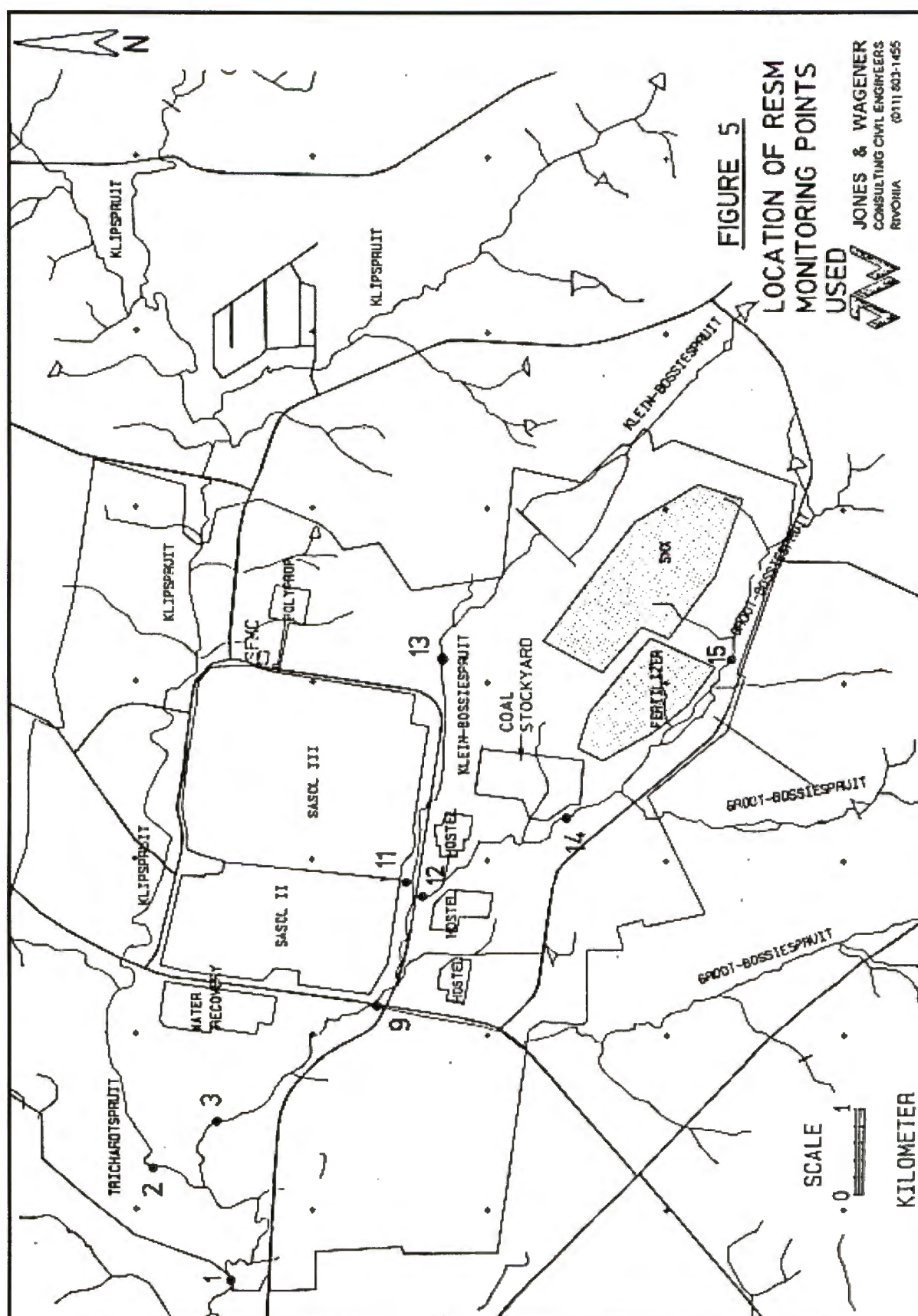


Figure 2.2: Map of all rivers and sampling points (Source: Jones and Wagener Consulting Civil Engineers (Pty) Ltd. (J&W, 1994)).

The sub-catchment is also likely to have been affected by impacts caused by upstream activities, i.e. agricultural activities and limited number of industrial activities occurring in upstream areas (SRK, 2000:8).

Two monitoring points exist in the Groot Bossiespruit, namely points 14 and 15. RESM 15 is upstream from the Sasol Fertiliser factory, while RESM 14 is downstream. *RESM 14 provides the background values for any environmental cost related estimation. RESM 1 provides the dilution factor and actual concentrations of chemicals flowing through the middle of Embalenhle.*

Data from these points are available and was used by Jones and Wagener Consulting Civil Engineers (Pty) Ltd. (J&W, 1994:10) to study fertiliser related chemicals in the Groot Bossiespruit, released by possible seepage from the site. The parameters studied were total dissolved solids (tds), nitrates (NO_3 as N), ammonium (NH_4 as N), sodium (Na) and sulphates (SO_4). A number of effluent treatment dams are contained within the Sasol Fertiliser site and the possibility of overflow of effluents containing these chemicals into the spruit is possible during extended raining periods. Seepage and spillage occurred in the past as confirmed by Jones and Wagener Consulting Civil Engineers (Pty) Ltd. (J&W, 1994:20).

Eigenhuis (1999a:9) discussed the drinking water standard for human usage as published by the World Health Organisation (WHO) and included some of the chemicals mentioned above. These concentration limits are listed in Table 2.1.

Contamination of groundwater is also an environmental aspect with social consequence, but due to the fact that groundwater is moving very slow in comparison with surface water, this issue will be noted but addressed as less significant in this study. Groundwater contamination impacts has long delay periods before the impact thereof is experienced and is a very complicated subject due to the lack of geo-hydrological data. Monitoring boreholes exist in the vicinity of the Sasol Fertiliser site.

The Secunda complex is underlain by the Karoo Aquifer, which is represented by the geological units constituting the Vryheid Formation as detailed below.

Table 2.1: Drinking water and other standards as published by the World Health Organisation (Source: Eigenhuis (1999a:9)).

Chemical (contaminant)	Human usage	Irrigation purposes	Animals
Al (mg/l)	0.15	5	5
Ca (mg/l)	32	-	1000
Cl (mg/l)	100	1	3000
Mg (mg/l)	30	-	500
NO ₃ (mg/l)	6	0.5	100
K (mg/l)	50	70	-
Na (mg/l)	100	-	2000
NH ₄ (mg/l)	-	-	-
SO ₄ (mg/l)	200	6.5 – 8.4	1000

2.4 Geological and soil characteristics

The Secunda complex is underlain by the Vryheid Formation of the Karoo Super Group sequence, which comprises a succession of alternative layers of sandstone and silt stone, intruded by dolerite sills and dykes (SRK, 2000:4). The Vryheid Formation consists of the following sedimentary sequences from the surface downwards:

- A highly weathered zone of sandstone and /or silt stone extending to depths ranging between 4 m and 30 m deep below the surface;
- A 20 m thick laminated to fine bedded silt stone/shale layer, underlying alternating layers of sandstone.

Jones and Wagener Consulting Civil Engineers (Pty) Ltd. (J&W, 1994:4) confirms that the factory and storage dam complex of the fertiliser factory is located on a deeply weathered dolerite sill. The base of the sill outcrops on the hillside between the dams and the Groot Bossiespruit and having a dip towards the south, i.e. down the slope towards the Groot Bossiespruit. As the dolerite is underlain by sedimentary sandstone and silt stones with low vertical permeability, it can be reasonably assumed that the dolerite sill is the major water bearing formation in the area and as such represents the most likely path for groundwater seepage. Sasol Fertiliser dug a cut-off trench south of the treatment dams to provide a catchment

area for seepage. This trench drains back into Dam 8, from where the content of the dam is treated again.

Another aspect of importance is the soil found in the area. As a supporting study to a study completed for Sasol Fertiliser by the Institute of Soil Climate and Water in Pretoria, Eigenhuis (1999a:5) reported the physical characteristics of two soils found in the TEKS area. The soils investigated were a sandy and a clay loam. Typical bulk density of the sandy loam was approximately 1.45 g/cm^3 , while the clay loam reported at a value of 1.42 g/cm^3 . Of further importance is the measured saturated hydraulic conductivity of 0.029 and 0.018 cm/min respectively. The sandy loam conducts more water per minute than the typical clay loam found in the Sasol Fertiliser area. Jones and Wagener Consulting Civil Engineers (Pty) Ltd. (J&W, 1994:25) dug 19 test pits on the Sasol Fertiliser site and reported on the soil profiles found. Low spatial variability of soils in the area was found, ranging from sandy clays at 1.1 m to 3.4 m (averaging 2.6 m in soil depth) below the soil surface to silty clay and sandy silty clays. The main type of soil found in the area is the mentioned clay loam.

Eigenhuis (1997b) presented a very comprehensive explanation of the factors influencing contaminant movement in soils. Water and other liquids are responsible for the movement of contaminants through soil. The interaction between chemicals or contaminants and soil can be described by six kinetic reaction namely adsorption, desorption, mobilisation, immobilisation, precipitation and dissolution (Eigenhuis, 1997b:2.34), meaning that chemicals can be periodically or permanently bonded to the soil particle surface or washed out of the system.

Since the transport of soils (and possible permanently associated chemicals) by human intervention, water or air (resulting in the contamination of the extended area surrounding the Sasol Fertiliser site) are the only mechanisms for further contamination, the *localised nature of this type of contamination* is of major importance. Eigenhuis (1999a:3) also reported kinetic constants for all the chemicals as studied by Jones and Wagener Consulting Civil Engineers (Pty) Ltd. at RESM 14, applicable to the modelling of the movement of fertiliser associated chemicals through soils found in the Sasol Fertiliser area.

2.5 Climate characteristics

Secunda is located on the Mpumalanga Highveld region approximately 100 km south-east of Johannesburg (SRK, 2000:6). The average elevation of the area is 1600 m above sea level. Consequently, altitude as well as the presence of a semi-permanent anticyclone and its north-south seasonal displacement determines the climate of Secunda.

In summer, the anticyclone is situated over the Indian Ocean at about 35°S and is replaced by a trough of low pressure over the interior. Convective mixing occurs in the lower atmosphere and afternoon thunderstorms frequently occur. This circulation regime is interrupted when the South Atlantic anticyclone ridges eastwards to the south of Africa and over the north-eastern interior, resulting in a south-easterly to easterly airflow over Mpumalanga.

During winter, the anticyclone is situated at approximately 25°S over the plateau area of Southern Africa and is manifested by the generally light winds and clear conditions experienced during winter months (SRK, 2000:6)

According to Burger and Coetzee (2000:3.1), meteorological mechanisms govern the dispersion, transformation and eventual removal of pollutants from the atmosphere. The extent to which pollution will accumulate or disperse in the atmosphere is dependent on the degree of thermal and mechanical turbulence within the earth's boundary layer. Dispersion comprises vertical and horizontal components of motion. The stability of the atmosphere and the depth of the mixing layer define the vertical component. The horizontal dispersion of pollution in the boundary layer is primarily a function of the wind field. The wind speed determines both the distance of downwind transport and the rate of dilution as a result of plume 'stretching'. The generation of mechanical turbulence is similarly a function of the wind speed, in combination with the surface roughness. The wind direction and the variability in wind direction, determine the general path pollutants will follow, and the extent of crosswind spreading. ***Pollution concentration levels therefore fluctuate in response to changes in atmospheric stability, to concurrent variations in the mixing depth, and to shifts in the wind field.***

Spatial variations and diurnal and seasonal changes in the wind field and stability regime are functions of atmospheric processes operating at various temporal and spatial scales (Goldreich & Tyson, 1988). Atmospheric processes at macro- and meso-scales need therefore be taken into account in order to parameterise the atmospheric dispersion potential of a particular area

accurately. A qualitative description of the synoptic systems determining the macro-ventilation potential of the region may be provided based on the review of pertinent literature. Meso-scale systems may be investigated through the analysis of meteorological data observed for the region (Burger & Coetzee, 2000:3.1).

The wind field over the region generally reflects the synoptic scale circulation. The flow field of the region is dominated by north-westerly to north north-westerly winds due to continental high pressure that prevails over the interior throughout the year. During winter months, the northward shift of the high-pressure belt and the enhanced influence of westerly wave disturbances (e.g. cold fronts) give rise to an increase in the frequency of south-westerly winds. Summer months are characterised by the weakening and southward shift of the anticyclonic belt that allows tropical easterly flow to resume its influence over the region. An increase in the frequency of north-easterly winds during summer months and the continued prevalence of north-westerly airflow reflects the combined influence of anticyclonic subsidence and tropical easterly wave systems (Preston-Whyte & Tyson, 1988).

Calm wind conditions occur less frequently at 350 m above ground level (~3%) than at the surface (~20%). The average surface wind speeds are in the range of 1.5 m/s to 5 m/s, whereas stronger wind speeds of above 10 m/s occur mainly from the east. These can be observed from the wind roses constructed from a year's hourly average wind data for 1999 at Secunda (Figure 2.3). Wind roses represent wind frequencies for the 16 cardinal wind directions. The length of the shaft indicates frequencies when compared to the circles drawn to represent a 5% frequency of occurrence. Hence, for the annual average wind rose, easterly winds may be identified as occurring 5% of the time. Wind speed classes are assigned to illustrate the frequencies with high and low winds occurring for each wind vector. The frequencies of calms, defined as periods for which wind speeds are below 1 m/s, are indicated in the centre of the wind rose. The predominant winds are from the eastern sector (~38%) and north north-western sector (~15%), with calm periods occurring about 20% of the year (Burger & Coetzee, 2000:3.1).

Distinct spatial variations in day and night time wind patterns can also clearly be observed. More calm conditions occur during the night (~28%) than the day (~14%). Furthermore, winds from the eastern sector are more pronounced during the day than night time.

Atmospheric calmness / stability is frequently categorised into one of six stability classes. These are briefly described in Table 2.2.

Table 2.2: Atmospheric stability classes (Source: Burger & Coetzee (2000)).

A	Very unstable	Calm wind, clear skies, hot daytime conditions
B	Moderately unstable	Clear skies, daytime conditions
C	Unstable	Moderate wind, slightly overcast daytime conditions
D	Neutral	High winds or cloudy days and nights
E	Stable	Moderate wind, slightly overcast night time conditions
F	Very stable	Low winds, clear skies, cold night time conditions

Figure 2.4 depicts the atmospheric stability for each wind direction. The stable (Classes E and F) characteristic of the easterly night time breezes is clearly evident. Since these winds are characterised by weak vertical mixing and low wind speeds, this wind component impedes dispersion while effectively transporting pollutants in a concentrated plume. This wind sector also produces a high frequency of convective conditions (very unstable, Class A). This occurs during the midday period and is characterised by clear skies and calm wind conditions.

Sasol air emissions monitoring stations monitor levels of H₂S (Rosebank, Johannesburg), SO₂, ozone, NO, NO₂ and normal meteorological conditions at Langverwagt (Embalenhle Township), Sasol Secunda Club and the Bossiespruit mine. A new air emission monitoring station is envisaged between the towns of Ermelo and Amersfoort. In terms of normal meteorological measurements, the annual average Secunda rainfall of 747 mm falls as the thunderstorms during the summer months from October to April, with the highest rainfall of 134 mm occurring during January. June is the driest month of the year with an average mean rainfall of 7 mm. Corrosion experiments are also being done at the Sasol Secunda Club monitoring station.

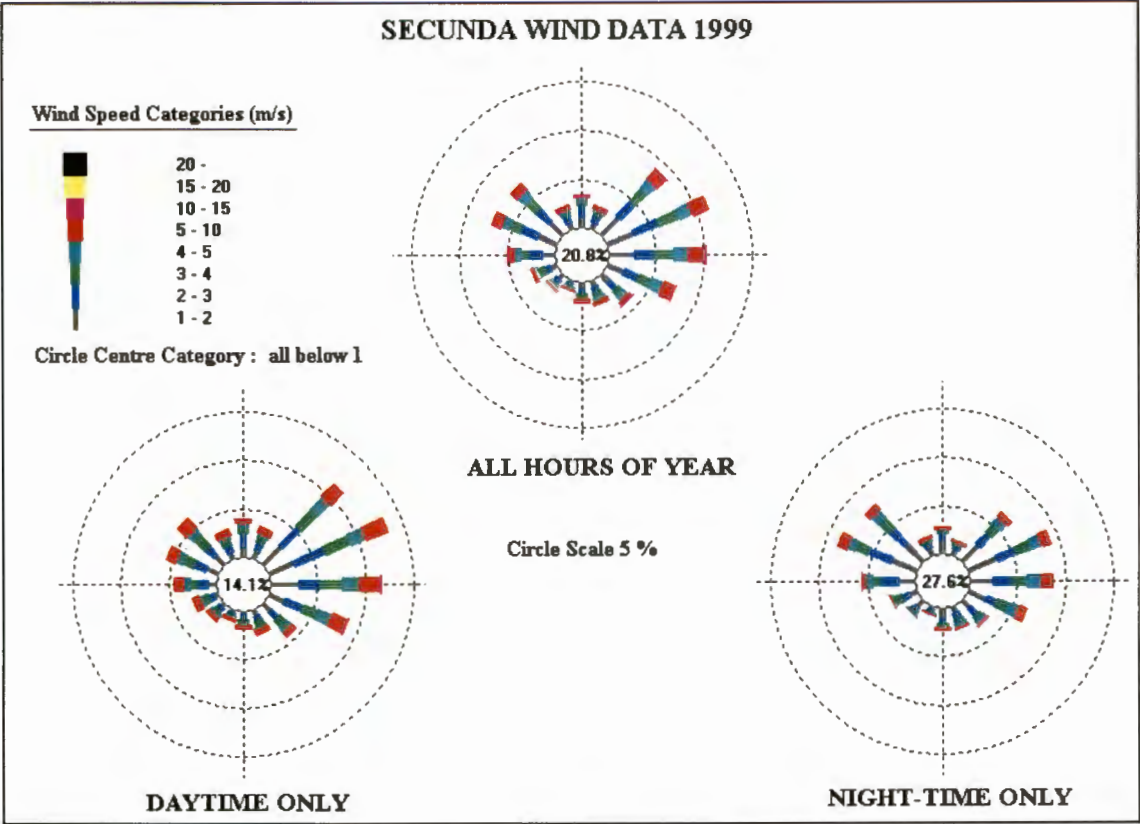


Figure 2.3: The 1999 wind rose for Secunda (*Source: Burger & Coetzee (2000)*).

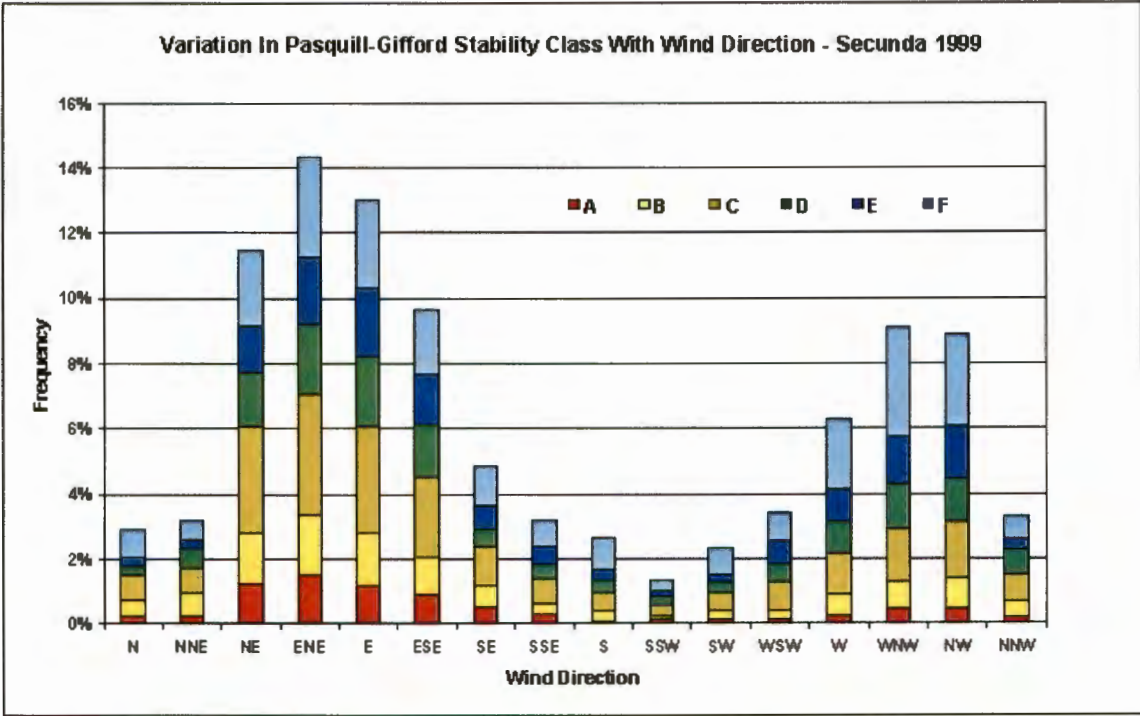


Figure 2.4: Frequency distribution of Pasquill Stability Classes for each wind direction for Secunda (1999) (*Source: Burger & Coetzee (2000)*).

2.6 Bio-diversity characteristics

Recently, Davies and Jacobsen (2000) completed a bio-diversity assessment for a proposed fine ash dam within the Secunda Industrial Complex. The bio-diversity study was based on a site survey, review of literature and expert knowledge of the Highveld region. During the site survey, ninety-one plant species were found, twenty-one of which were exotic.

The site is a very species-poor flora and reflects the semi-transformed state of the area. Eleven mammal species, thirty-seven bird species and three frog species were found on site. A further two mammal, seventeen reptile (five lizard and twelve snake) and six frog species are expected to inhabit the site. In all thirteen red data book plant and animal species were expected on the site, but only one namely the Brown-hyena *Hyaena brunnea* (listed as rare) was found.

Of the medium-sized mammals identified from spoor, probable residents on the site included clawless Otter *Aonyx capensis*, Porcupine *Hystrix africae-australis*, Water mongoose *Atilax paludinosus*, Yellow mongoose *Cynictis penicilata* and Grey duiker *Sylvicapra grimmia*, while Brown hyena, Black-backed jackal *Canis mesomelas* and Cape fox *Vulpes chama* are likely to be transient visitors.

The specific site studied by Davies and Nielson has been substantially altered from its natural state, which is classified as *Themeda* Veldt or Moist Clay Highveld Grassland. The flora and fauna of the site are impoverished as a result of past and present land uses (crop farming, livestock grazing and coal mining). Despite the paucity of species, the site still represents an important part of the natural environment with its own specific plant and animal communities. It forms one element in a network of semi-natural areas, through which wide-ranging species such as Brown hyena can move, maintaining the contact between populations and individuals that is essential for genetic interchange.

Themeda trianda grassland or *Themeda* Veldt is one of the least protected and most heavily transformed vegetation types in South Africa. ***These grasslands have a particular high forage value and thus are valuable for livestock production.*** Typical impacts for this type of veldt is ploughing, the spread of weeds and ruderals, planting of maize, monotypic pasture grasses and exotic trees, overgrazing, construction of tarred roads and other earth works. Despite most of these impacts, this type of veldt can normally be rehabilitated to become representative of *Themeda* Veldt. Such sites are also valuable as a habitat corridor for medium-sized mammals (Davies & Jacobsen (2000:14)). Sasol created a game park in the northern secondary area of the

complex. The primary area contains the main Sasol East and Sasol West factories and is situated approximately in the centre of the complex. This game park however is quite removed from the fertiliser factory.

In order to assess the degradation of bio-diversity, a baseline assessment is required. Ecosun Closed Corporation performed such an assessment for Wates, Meiring and Barnard Consulting Engineers (Pty) Ltd., who reported on the evaluation of the effect of the Sasol Secunda Industrial Complex and the proposed Sky High Project on the receiving aquatic ecosystem. Wates, Meiring and Barnard Consulting Engineers (Pty) Ltd. (WMB, 1999:114) also proposed the development of a biological monitoring program at new RESM sites, including activities such as definite toxicity bioassays (on a monthly basis) and habitat assessment, determining sediment contaminant levels and *in situ* water quality (on a quarterly basis). Annual monitoring activities are to include fish, metal bio-accumulation and aquatic and Riparian Vegetation.

The report by Wates, Meiring and Barnard Consulting Engineers (Pty) Ltd. presents a very thorough baseline including the bio-diversity found on the Sasol Secunda site. This baseline information was only made available as recently as 1999 and the short operational period of the proposed biological monitoring program after implementation did not produce any useful records on the degradation of bio-diversity up to date. Due to the lack of data, bio-diversity will fall outside the scope of this study, but mention will be made of important aspects where relevant.

2.7 Conclusion

Various aspects and components of the receiving environment were presented in this chapter. These included the physical location of the Sasol Fertiliser factory, population data and the immediate towns surrounding the Sasol Industrial Complex. The aquatic environment, soil and geological characteristics, climate and bio-diversity were also discussed.

This chapter allowed the identification of the mechanisms of general pollution and potential pollution pathways, away from the Sasol Fertiliser factory towards the receiving environment. The impacts of fertiliser related chemicals were found to be possible through transport of these chemicals by water and air. The Trichardtspruit, flowing through Embalenhle was identified as a pollution pathway, while general wind directions were identified in which air emissions could be dispersed. Wind direction and the whole science behind air dispersion modelling are very

complex. Fortunately, air emissions monitoring stations exist in the area and useful concentration data are available. The data from these stations can be used as a starting point for estimating secondary environmental cost to the local society.

Soil pollution was found to be reversible through desorption and other mechanisms in a watery medium, while irreversible soil pollution constituted only a localised clean-up cost. Irreversible soil pollution is therefore ranked lower than air and water pollution due to the lack of soil movement. The possibility of soil clean up through washing is an interesting option that will be considered later as part of the cost estimation procedures.

Bio-diversity was excluded from the scope of this study due to the lack of biological monitoring data available. However, Wates, Meiring and Barnard Consulting Engineers (Pty) Ltd. completed a very comprehensive aquatic ecosystem study in 1999. The report included baseline data on plants and animal species found in the Secunda Industrial Complex.

Finally, it is realised that pollution related volumes and concentrations (mass balance information) form the basis of any environmental cost estimating procedure where soil, air and water are considered.

CHAPTER 3: THE ENVIRONMENTAL AND SOCIAL IMPACTS OF SASOL FERTILISER

3.1 Introduction

A specific introduction to the Sasol Fertiliser production factory at Secunda is provided in this chapter. The purpose is to focus directly on the microenvironment of Sasol Fertiliser in terms of technical and environmental issues, in order to compile a list of the main aspects for which cost values could be estimated.

Typical fertiliser production processes vary in accordance with the nutrients produced. The various chemicals and sources used in the manufacture of finished fertiliser products, from raw materials through intermediate products, are shown in Figure 3.1 (IFA, 1999).

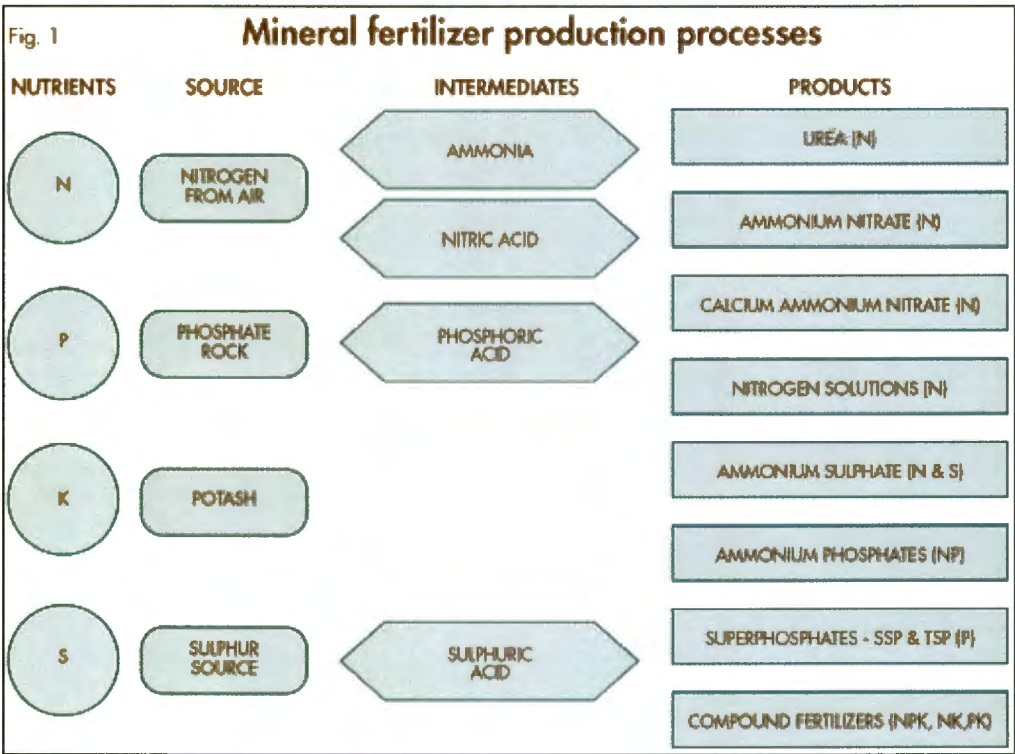


Figure 3.1: Chemicals used in the production of different fertiliser products (*Source: IFA (1999)*).

The Sasol Fertiliser plant at Secunda is capable of running in different modes of operandi, producing various compound fertilisers using the existing plant equipment. A general overview of the site, equipment typical to fertiliser production and similar to the equipment used by Sasol

Fertiliser forms a framework for the identification of potential sources of emissions and pollution. No specific attention will therefore be given to the production process of one specific compound fertiliser, while information obtained from literature, site visits and interviews with plant personnel will be presented.

3.2 Sasol Fertiliser site and process description

The Sasol Fertiliser factory was designed and built during an era of political unrest and terrorist attacks. Main buildings and plants were therefore placed far apart in order to prevent the total destruction of the plant in the event of a possible attack. This current layout is a possible cause for inefficient energy utilisation, but was required in terms of risk management of the facility at the time (Bredenkamp, 2000).

The Sasol Fertiliser factory site layout is shown in Figure 3.2, while flow diagrams of the typical processes used is shown in Figures 3.3 to 3.6. The production facility consists of a number of main areas namely:

- **Plant areas:** nitric acid, pipe reactor, granulation.
- **Process utility areas:** cooling towers and compressor houses.
- **General infrastructure:** mechanical workshops, garages, restrooms, administrative buildings, parking, dispatch office, clock station and contract cabin.
- **Storage areas:** raw materials store, final product store, sand store, diesel store tanks etc.
- **Loading bays:** phosphoric offloading station, raw material off loading.
- **Product handling:** bagging and transport loading, as well as conveyer system areas.
- **Storm water runoff:** “Clean” and “Dirty” runoff areas of which some areas are covered with cement slabs.
- **Evaporation dams:** Various evaporation dams (just off-site from the main factory site).

When these listed areas are considered, the plant areas need further explanation. In comparison, it is perceived that the possible environmental impacts emanating from the mechanical workshops, garages, and general office areas are much less than that emitted from the plant. Plant areas of interest are the nitric acid plant, pipe reactor, granulation facility as well as the bulk handling section.

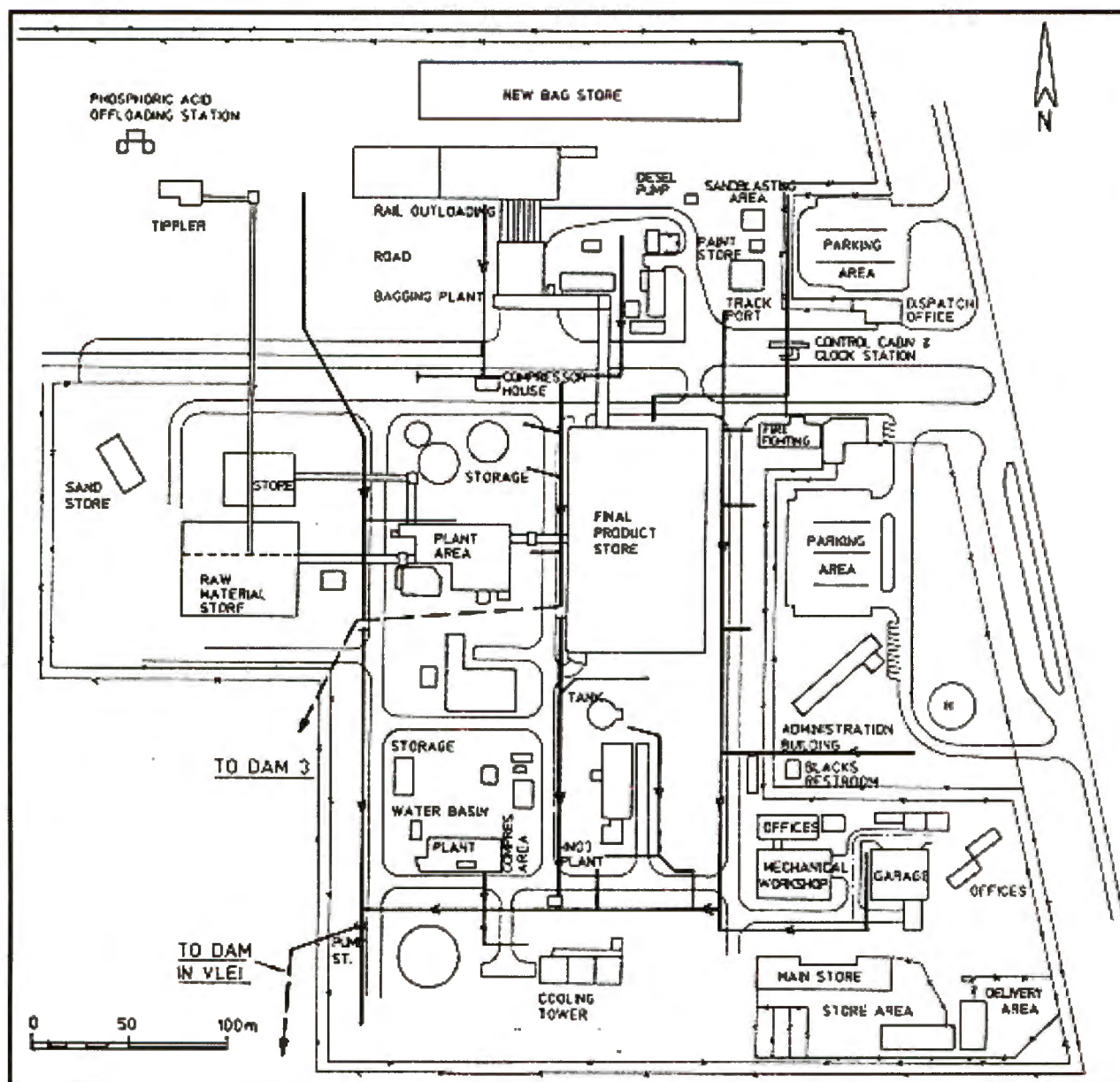


Figure 3.2: Layout of the Sasol Fertiliser Site (*Source: Jones and Wagener Consulting Civil Engineers (Pty) Ltd. (J&W, 1994).*)

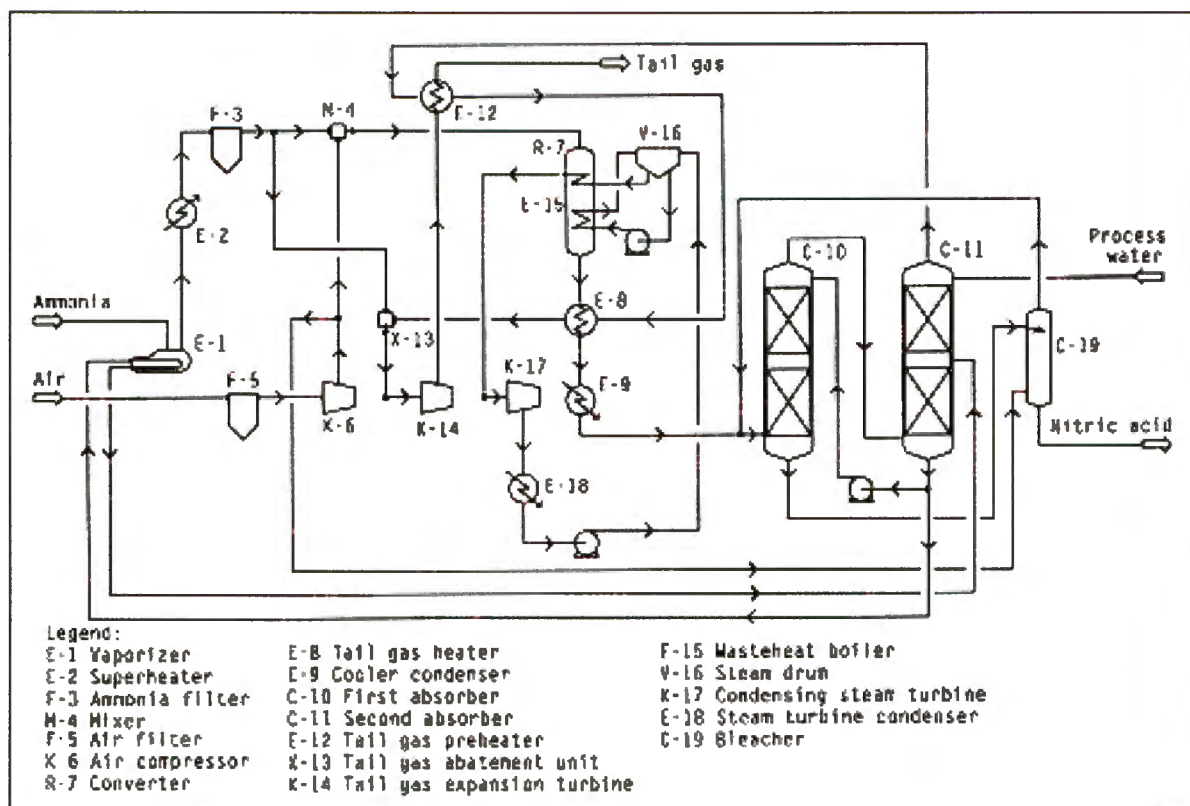
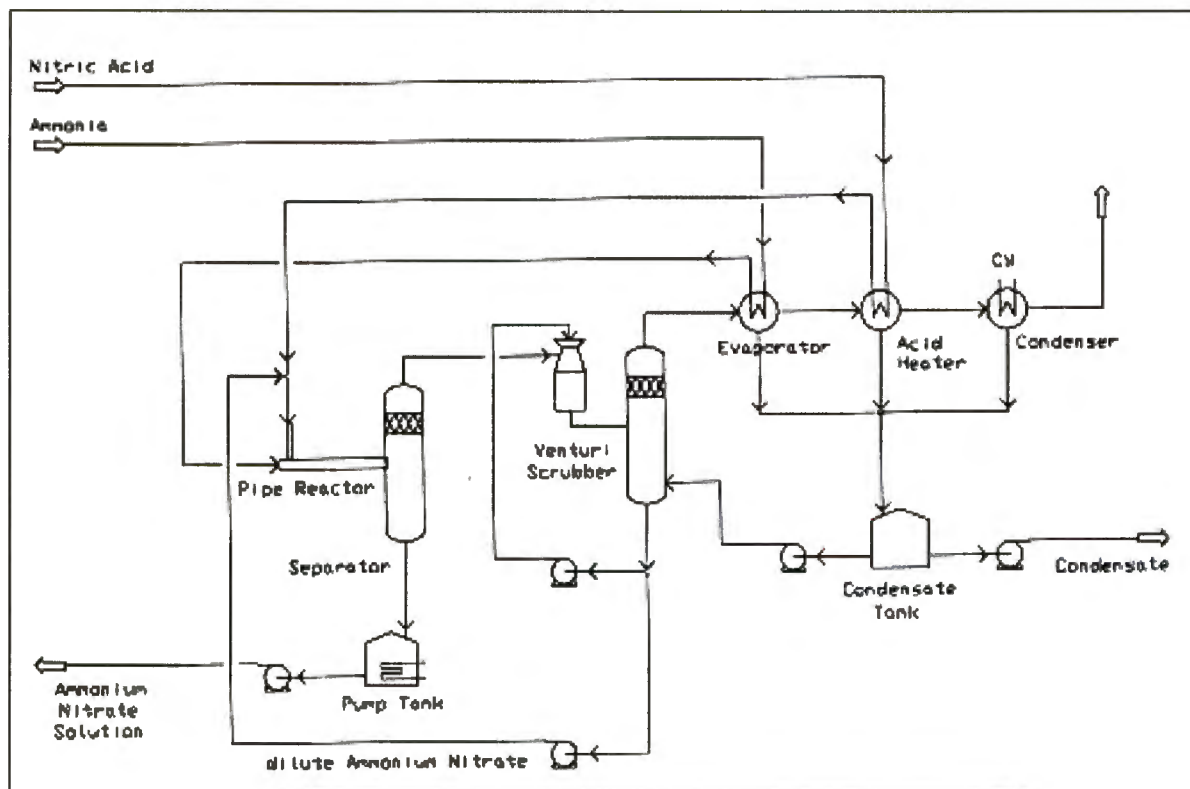


Figure 3.3: Krupp Uhde Engineering (Pty) Ltd. process for nitric acid production (Source: IFDC & UNIDO (1995)).



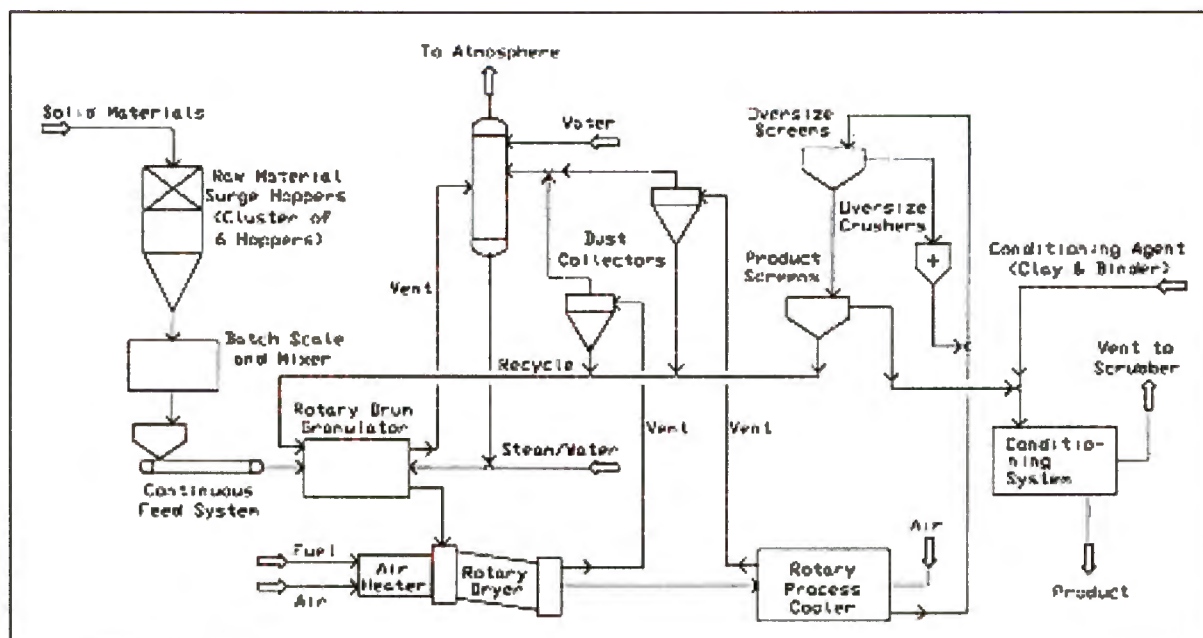


Figure 3.5: Typical NPK Fertiliser granulation plants using steam or water (*Source: IFDC & UNIDO (1995).*).

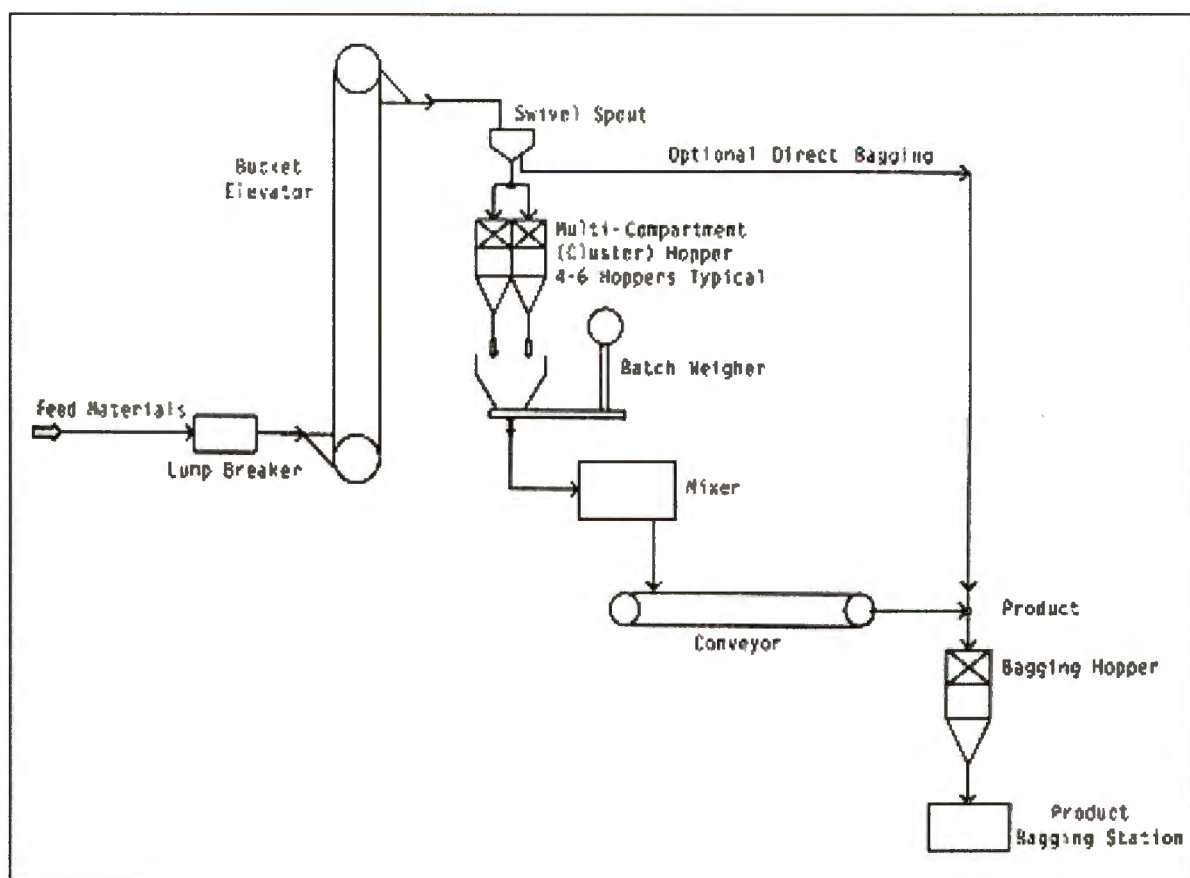


Figure 3.6: Typical batch-type NPK fertiliser bulk blending plant (*Source: IFDC & UNIDO (1995).*).

3.2.1 Nitric acid plant

The Fertiliser Manual (IFDC & UNIDO, 1995) describes a typical Krupp Uhde Engineering (Pty) Ltd. plant as installed in the Sasol Fertiliser factory. In Figure 3.3, a non-cooled air compressor supplies air required to oxidise the ammonia. It is possible to realise 1000 tpd HNO_3 by employing a combustion element and adsorption towers in typical plants. The air compressor is normally driven by a steam turbine and by a tail gas expansion turbine since the steam is generated within the plant. Alternatively, the compressor may be driven electrically; in which case all the steam generated is available for export.

The oxidation reaction of ammonia results in NO and water, which when oxidises again, produces NO_2 . The combination of NO_2 and water produces HNO_3 as well as typical tail gas from the gas/liquid contact towers, steam and condensate, boiler feed and cooling water effluents. No environmentally related complaints were ever received in terms of the NO_x emissions or bad odours (Maritz, 2000). This is most probably due to the considerable distance that the plant is removed from the surrounding residential areas. All liquid effluents drain to the liquid effluent dams on site.

3.2.2 Neutralisation plant

The neutralisation process used by Sasol is showed in Figure 3.4. In this pipe reactor process, the neutralisation (IFDC & UNIDO, 1995) is carried out using gaseous ammonia and preheated nitric acid to give an ammonium nitrate (AN) melt of up to 97% concentration directly. Again steam is produced and is used to evaporate and superheat the feed ammonia and preheat the acid.

The ammonia and acid (at pressure) are mixed at high velocity in the pipe reactor and are neutralised at a generated temperature of up to 200°C . The solution flashes into the separator operating near atmospheric pressure and the resulting steam passes overhead directly to the ammonia evaporator or alternatively to be scrubbed with dilute AN solution to reduce ammonia and AN in the downstream condensate. If the ammonium nitrate concentration is below 96%, a falling film evaporator is normally used to concentrate this stream.

3.2.3 Granulation plant

The granulation facility (IFDC & UNIDO, 1995) used by Sasol Fertiliser is similar to the process shown in Figure 3.5. In this steam/water granulation process, granules are formed by agglomeration. The solid raw materials are weighed and usually premixed before being fed to the granulator where agglomeration is initiated. In some plants, the raw materials are crushed before or after weighing to obtain a more uniform particle size distribution. In the granulator, steam / water or scrubber liquor is added to provide sufficient liquid phase and plasticity to cause the dry materials to agglomerate into product size granules. In some cases a small amount of ammonia may also be added during granulation to react with super phosphate. This promotes granulation and improves product quality due to increased acidity.

Moist and plastic granules are dried, usually in a rotary drum type connected to a fuel-fired drier and screened to remove the product size fraction. The oversized materials are crushed and recycled to the granulator along with the undersized fraction. To ensure a uniform particle size distribution of the material returned to the granulator, it is best to return the crushed oversize material to the screening unit so that only material passing the product screen is recycled to the granulator. In some cases it is necessary to cool the material before screening, depending on the fertiliser grade and local conditions. When cooling is required it is performed in a rotary drum type unit that is very similar to the rotary dryer.

Wastage in this section can result from blockage of equipment, dust formation at product transfer points and during start up and shutdown of the plant. Scrubbing systems is used in this plant to reduce emissions to atmosphere.

3.2.4 Bulk blending, bagging and loading facilities

Typical bulk blending equipment is shown in Figure 3.6. Bucket conveyers and conveyer belts are normally used to transport the fertiliser to the blending plant, as well as to a storage area from where the different blends of fertiliser is made up to suite the customers needs. The final product is bagged and sent off to the loading facility or storage area. A certain percentage of the bags tend to break at the bagging and loading facilities where spillage of product occurs. This spilled product is swept together and returned to the granulation plant as so called sweepings.

3.3 Process mass balance information

Most companies are sensitive about their process information. Obtaining explicit mass balance information is therefore difficult due to political reasons and sometimes plainly due to a lack of quality data.

Although the mass balance information of Sasol Fertiliser information is available, only information on some of the typical output streams of the relevant plant sections will be listed in this section. The reasoning behind this decision can be related to the system boundaries that need to be selected, as considered in terms of environmental cost accounting.

3.3.1 System boundaries

According to Tukker (2000:439) there are various possible approaches to the choice of system boundaries. First, the focus could be on a regionally delimited system namely a single plant, or a set of industrial activities in a certain region. Alternatively, another option is what can be termed as a functional perspective. Every individual industrial process needs an input of raw materials or other products, as well as produces wastes that have to be processed. The interventions relating to these inputs and waste treatment processes, which usually takes place at a totally different location, form the so-called “Ecological rucksack” of the central process.

Obviously, important choices have to be made with respect to the goal of the evaluation. If the interest is solely in the environmental impacts of an industrial plant on the immediate surroundings, the regional/local approach is appropriate. If indirect effects in other parts of the process chain are to be included, the relevant approach is the functional approach, which encompasses the whole production system (Tukker, 2000:440).

In terms of environmental cost accounting, the regional/local approach is selected, excluding the environmental cost of the raw materials and energy requirements of Sasol Fertiliser. This cost will have to be obtained from total independent additional studies. Raw material input cost and services are therefore not viewed as part of the “Ecological rucksack” of Sasol Fertiliser.

3.3.2 Typical emissions and effluents streams of Sasol Fertiliser

Sasol Fertiliser does not have phosphoric or sulphuric acid plants on site, reducing additional potential sources of pollution. The nitric acid plant (see Figure 3.3) has one main point of emission namely the tail gas stack of the adsorption column. Current permit requirements from the Department of Environmental Affairs are set at 150 ppm NO (measured at actual temperature and pressure), vented 61 m above ground level. Stack emissions from diesel start-up boilers should not exceed 20% opacity. The nitric acid plant does not have any liquid effluents.

The air permit requirements for the ammonium nitrate plant (see Figure 3.4 (pipe reactor)) stipulates that excess vapour from the neutraliser plant (containing nitrogen) should be vented to atmosphere at a height of 45.3 m above ground level. All off gases have to be sent through the scrubber on site and effluents are to be recycled back to the process. No stipulation was given in terms of flow rates or concentrations.

The granulation plant is a source of air emissions and effluents to the dams. The typical effluent discharge rate to the dams during the production of compound fertilisers (KAN, NPK etc.) is approximately 3 tph, while approximately 400 tph scrubber and cyclone tail gas is vented to atmosphere. The production of these compound fertilisers require various raw materials such as lime stone, ammonium nitrate, make up water, coating agents, sand, potassium chloride, phosphoric acid and ammonia.

The effluent dams on site receive approximately 5.5 tph of utility related effluent from the nitric acid plant and 3 tph scrubber effluent from the granulation plant. Storm water from so-called “clean and dirty” areas is also directed to these dams. According to Bredenkamp (2000), approximately 2 tpd of fertiliser dust ends up in the effluent dams. This dust originates from the granulation and bulk handling facilities where fertiliser spillage is gathered by sweeping. Most of the sweepings are fed back into the process.

A large area between the buildings on site is covered with cement, but a similarly large area is not covered. Fertiliser and raw material dust from the storage and production buildings is therefore a source of chemicals resulting in soil pollution. Soil pollution is a typical environmental impact found on many sites. The next section reviews literature on typical impacts, as well as the impacts found on site.

3.4 Environmental and social impacts

The impacts of Sasol Fertiliser can be deduced from the typical processes used to produce fertiliser, the type of plants on site, the layout of the facility and through visual inspection as well as interviews with plant personnel. The social impacts are normally derived from the environmental impacts and normally mainly constitute human health and nuisance issues.

The typical environmental aspects published in literature are presented, after which the environmental aspects of the Sasol Fertiliser site are discussed. General social impacts derived from these environmental impacts will also be considered in order to list and categorise the possible environmental cost in section 3.5.

3.4.1 Typical environmental impacts cited in literature

Autti (1999) summarised typical environmental issues determining and influencing a production facilities balance sheet as being: 1) contaminated soil, 2) sensitive site location, 3) unclear water collection systems and 4) old processes and weak pollution prevention systems. Other typical environmental aspects of fertiliser production are also generally well described in the Fertiliser Manual (IFDC, 1967) as published by the International Fertiliser Development Centre of the United Nations Industrial Development Organisation (UNIDO).

Information from the Fertiliser Manual was combined with impacts published by the United Nations Environment Program (UNEP, 1998) in Technical report No 26. These combined aspects are briefly described in the next sections.

3.4.1.1 Gaseous emissions.

Most of the processes used for the manufacture of fertiliser discharge gaseous effluents. By far the largest source of these is the combustion of fossil fuels used in the manufacture of ammonia. However, combustion gases do not pose an environmental problem unless they contain excessive amounts of impurities or particulates. Other effluents are process streams including oxides of sulphur, oxides of nitrogen and compounds of fluorine for which there is sufficient economic and political incentive for recovery.

When gaseous ammonia is discharged from an operating plant, it is more likely due to some spills from faulty equipment or an operating problem. Gaseous ammonia normally affects the nose, throat, eyes and skin and has a threshold concentration between 18 mg/m³ to 35 mg/m³. Exhaust gases containing ammonia are normally scrubbed and the resulting scrubber liquors are recycled to the process or discharged to the plant sewer. If vented to atmosphere, gaseous effluents containing ammonia can form smog if allowed to combine with acidic gaseous effluents. Ammonia is likely to occur in effluents from downstream plants that produce urea, ammonium nitrate, ammonium phosphate and compound fertilisers.

Oxides of nitrogen are discharged from ammonia oxidation processes, such as nitric acid plants or ammonium nitrate and NPK plants using the nitro phosphate route. These oxides are mostly NO, NO₂ or N₂O₄. Both NO and NO₂ can be harmful to people, plants and animals and can produce smog by photochemical reaction in the atmosphere.

The main source of sulphur dioxide or trioxide as a gaseous effluent from fertiliser plants originates in the captive sulphuric acid plants associated with the manufacture of phosphoric acid. Normally most phosphates fertiliser complexes have one or more captive sulphuric acid plants where a contact acid process is used. Gaseous fluorides are also derived from the manufacture of phosphate fertiliser. Various fluorides are released in processing the phosphate rock. Gaseous fluorides are considered among the most hazardous pollutants.

3.4.1.2 Mist, fumes and dust

Fertiliser plants producing mixed granular NPK, MAP or DAP fertilisers from feedstock of phosphate rock, phosphoric acid, and/or ammonia, nitric acid and sulphuric acid. These production processes produce gaseous effluents containing particulate matter mixed with vent gasses from their reactors. Most of the materials handling equipment (including screens) are exhausted using induced air. If it is dry, fine dust can be collected by a duct system and passed through bag filters with a 99% elimination of particulate matter.

More difficult is the control of particulate matter or dust from granulators, dryers and coolers in which the moisture and the temperature of the gas and contained particulates vary. To reduce the discharge from these sources, high efficient cyclones are normally installed which remove most of the larger particles. Most of these materials are recovered and returned to the various process

systems of the plant. The use of wet scrubbers is increasing in granulation plants. The scrubber liquor is recycled to build up its concentration and then returned to the granulator plant.

Ammonium nitrate emissions result from three sources namely neutralisation, evaporation and prilling. Fumes from the neutralisation and evaporation processes are normally scrubbed in wet scrubbers of relative small volumes. A further concern at urea plants is the urea dust in the exhaust of prilling towers. Recently, several new ammonium nitrate and urea plants have used granulation rather than prilling. The main purpose was to improve the size and strength of the product, as well as to decrease the difficulty in controlling fume and dust since wet scrubbers or bag filters can provide adequate dust control after granulation.

3.4.1.3 Liquid effluents

Aqueous or liquid effluents from fertiliser plants are usually of smaller volume compared to those that are vented to the atmosphere. Naturally, if pollution abatement systems adopt wet scrubbing systems to reduce air pollution, the contaminants that are eliminated from the gases remain and are concentrated in solutions or scrubbing liquor. Unless these contaminants are concentrated or transformed into a recovery for the process or a saleable product, they present a disposal problem as liquid waste.

A number of effluent components exist, depending on the type of plant and the process. These components are ammonia, ammonium nitrate, ammonium sulphate, phosphate fertiliser, phosphoric and sulphuric acid, single or triple super phosphate, compound and NPK fertiliser, boiler and cooling tower effluents (including cleaning agents) and potash.

Evans (1995) presented an excellent discussion surrounding effluent drains and systems in a typical fertiliser production facility. Control of pH is an important step in effluent management, but unfortunately also adds additional chemicals to the effluent stream.

3.4.1.4 Solid wastes

The safe disposal of solid wastes or by-products from fertiliser plants has been a problem particularly in developed industrial areas. Phospho-gypsum is by far the largest by-product in the manufacture of “wet-phosphoric” acid. Other solid wastes include gypsum, calcium nitrate and calcium carbonate, arsenic trioxide and spent vanadium catalyst.

3.4.2 On-site environmental impacts identified from literature and a site visit

A list of the typical expected environmental impacts of the Sasol Fertiliser factory can be summarised using the information already presented in this chapter. The list shown in Table 3.1 was validated and complimented by impacts observed during a site investigation.

Table 3.1: Environmental impacts of Sasol Fertiliser (Source: Primary research & Loata (2000)).

Impact origin or location	Impacts
<i>Plant areas, cooling towers and compressor houses.</i>	Emissions to air, NO _x , NH ₃ , liquid effluents, soil pollution, dust, mist fumes.
<i>Mechanical workshops, garages, restrooms, administrative buildings, parking, dispatch office, clock station and contract cabin.</i>	Used oil, sewerage and domestic waste.
<i>Storage areas, raw materials store, final product store, raw material store, sand store, diesel store tanks.</i>	Contaminated soil, contaminated runoff and groundwater as well as dust. Typical soil contamination includes limestone, ammonium nitrate, coating agents (wax), potassium chloride and phosphoric acid and diesel.
<i>Phosphoric off-loading station, raw material off loading.</i>	Contaminated soil, contaminated runoff / groundwater and dust.
<i>Materials handling, bagging and transport loading, as well as conveyer system areas</i>	Contaminated soil, contaminated runoff / groundwater and dust. Loss of product, sweepings. Plastic bag wastes.
<i>“Clean” and “Dirty” runoff areas of which some areas are covered with cement slabs.</i>	Contaminated soil and groundwater.
<i>Effluent dams and rivers.</i>	Contaminated soil and groundwater, as well as loss of vegetation.

Loata (2000) also completed an identification study on the main or important environmental impacts of Sasol Fertiliser. Questionnaires were completed with a sample of 50 production personnel up to foreman level at Sasol Fertiliser. Sasol Fertiliser in Secunda has a total number of 227 employees ranging from the factory manager (top management) and administrative personnel down to the skilled and unskilled work force. Not everybody working in the factory is directly involved with the physical production process where problems could lead to environmental damage. The production personnel of the factory total approximately 186 people.

The survey resulted in a sequence indicating the most significant perceived environmental impact at Sasol Fertiliser. Responses in terms of personnel perception were ranked as follows: *contamination at the dams (34%)> emissions to air (20%)> contaminated soil (16%) and loss of vegetation (16%)> dust (10%)> domestic waste (6%).*

Employees were not concerned with liquid effluents, mist and fumes, used oil, sewerage, and contaminated runoff, loss of product and sweepings as listed in Table 3.1. This ranking order provides a cryptic description of the status of environmental damage protection at the Sasol Fertiliser site. Observational analysis (site visit) furthermore proved that the current environmental damage prevention measures are not adequate.

A number of the identified impacts such as contaminated soil and loss of vegetation is interrelated. Contaminated runoff is not seen to be a problem, due to the fact that the contamination of the runoff cannot physically be observed easily. Since air emissions are highly visible, it also featured on the list of significant aspects, but was considered less significant due to the highly elevated level of discharge. During the site visit, the most significant environmental damage could be observed at the runoff dams (also known as dams 5, 6 and 7). Seepage of contaminated water occurred at the walls at several places with resulting loss of vegetation. Toe drain sumps were not maintained and were full of water.

The plant area is normally associated with dust and this aspect was thus not seen as such a significant problem. Unfortunately, all the mentioned aspects except emissions to air and domestic waste are interrelated since the dust in the area falls on the soil. The open soil surface areas in the factory that is not covered in cement runs off to effluent dams, taking along some of the dusty fertiliser as well as some soil. Contaminated runoff also occurs from cement-covered areas in the so-called “clean and dirty” areas. Normally clean runoff is decanted directly to the river, but since the dust falls over the total factory, all runoffs are directed to the effluent dams. A solution to solve soil pollution as suggested by some employees was to cover the remaining open surface soil areas in the factory with a cement cover. This would however not solve the contaminated runoff problem. The facility is kept very tidy and general housekeeping as at a fairly high standard. It is speculated that this is the only reason why “domestic waste” made the list of significant aspects. All domestic wastes are sent to a suitable domestic waste site at only the cost of transportation, which is considered to be insignificant.

3.4.3 Social impacts

The related social impacts of the main environmental impacts of Sasol Fertiliser are seen to be those issues resulting in increased or decreased financial expenditure, as well as increased or decreased quality of life experienced by the impacted community.

Tukker (2000:438) presented an intervention-effect chain for global warming that can be applied as a starting point to model or estimate environmental / social cost. The chain starts with the environmental intervention of transport and degradation resulting in CO₂ emissions and the consequent enhancement of atmospheric CO₂ concentration. The mid points of the chain consists of primary, secondary en tertiary impacts, while the end point of the chain includes the final impact ultimately resulting in the death of humans and the loss of biodiversity. Tukker argued that the protection areas in this example are therefore the areas of human health and ecosystem health.

The approach followed in this study is very similar to the typical impact assessment and classification approach of Life Cycle Assessment (LCA). According to Tukker (2000:447), social impact categories (included in Table 3.2) normally included in the LCA are that of human toxicity, odour and noise (nuisance). Society also shows positive or negative affection towards aspects such as ecosystems (biodiversity) and landscape, as well as death. Related social aspects are that of decreased property market value and increased household cost. Ottinger, Wooley, Robinson, Hodas and Babb (1991) discussed increased household cost in detail in their book on the environmental cost of electricity. Ottinger *et al.* (1991:219) mentioned morbidity as another component of social cost where it can be defined as the health benefits of the community due to the decrease of pollution levels.

Table 3.2: Social impacts and impact categories of Sasol Fertiliser (Source: Secondary research).

Social impact	Category	Cost
Quality of life	Human health	Morbidity, mortality.
	Nuisance	Odour, noise, visibility.
	Affection	Landscape, biodiversity, death (mortality).
	Increased household cost	Maintenance, corrosion, cleaning etc.

As already mentioned in Chapter 2, biodiversity was identified as a relevant component of environmental costing to be omitted from this study due to a lack of data. Landscape assessment is another field of environmental assessment (directly linked to biodiversity) that can influence affection and emotion. Since emotion and affection can result in actions leading to a range of insignificant to tremendous benefits or environmental and social disaster, it is categorised as an intangible cost in this study. However, since it is not perceived as a main environmental/social cost of Sasol Fertiliser, it will not be pursued any further.

3.5 Suggested impact cost categories

The typical categories mentioned in section 1.2 on cost-benefit analysis provide a guideline to be considered during the categorisation of impact cost. Shtub *et al.* (1994:117) mentioned four categories: (1) primary, (2) secondary, (3) external and (4) intangible. Ottinger *et al.* (1991:40) considers primary cost as control cost to industry, being required to control or reduce pollution.

Damage cost is related to external cost or also known as externalities. The main advantage of using damage cost is that it is the most relevant. It is the damage to society that is to be addressed and alleviated by incorporating environmental externalities. Most economists believe that if adequate studies for valuing damages exist, it could be used to determine how much industry could spend on additional pollution prevention equipment (Ottinger *et al.*, 1991:41).

Damage cost can also be categorised as a secondary cost to industry in terms of remediation cost. Cleaning up and restoring the environment to its original condition, considering chemical background values that exist in similar non-impacted areas constitute a secondary cost to the company. This cost was largely unforeseen until the proclamation of relevant environmental legislation in South Africa.

Intangible benefits and cost are those that are difficult, if not impossible to measure on a monetary scale. In this study, the focus will be on the cost that seems to be difficult to measure or estimate from a normal engineering perspective. Although a different perception (e.g. on human health) might be held by practitioners of the Actuarial Sciences, the perceptions of this researcher as well as Sasol Fertiliser personnel was used to categorise the impacts identified in this chapter (see Table 3.3).

Table 3.3: Cost categories for the environmental and social cost of Sasol Fertiliser (Source: Primary and Secondary research).

Category type	Category	Cost
Control cost	Primary	<i>NO_x emissions, NH₃ emissions, liquid effluents, chemical dust and particulates.</i> <i>Hazardous wastes (used oil and wastes from workshops), domestic waste (including plastic bag wastes), sewerage.</i>
	Secondary	<i>Contaminated soil.</i> <i>Contaminated groundwater.</i> <i>Loss of vegetation.</i>
Damage cost	External	Increased household cost: <i>Maintenance, corrosion, cleaning etc.</i>
	Intangible	Human Health: <i>Morbidity, mortality.</i> Nuisance: <i>Odour, noise, visibility.</i>

When considering Table 3.3, the disposal of hazardous wastes, domestic wastes and sewerage treatment should actually be removed from the list since Sasol Fertiliser buys in these services. The environmentally sound management of these waste sites and sewerage works lies outside the scope of this study, similar to the possible environmental impacts caused by external companies in the provision of raw materials to Sasol Fertiliser.

A further suggestion is to introduce the third cost category type namely transport cost. Any possible fumes, mist or chemical smog, as well as odours generated by Sasol Fertilisers may fall in this category. The reasoning behind this is that transport impacts do not present damage to the environment during transport, only after some time at the point of chemical impact.

3.6 Conclusion

The environmental and social cost / impacts of Sasol Fertiliser can broadly be categorised by type as control cost, transport cost or damage cost. This cost has been identified from literature, site visits and interviews, and was discussed and categorised in this chapter.

Finally, the information presented in this chapter forms the framework to be used in obtaining values where possible for the cost identified, as well as the framework for researching possible estimating procedures by considering possible mitigation for these identified impacts (as presented in the next chapter).

CHAPTER 4: ESTIMATING PROCEDURES, METHODS AND COST

4.1 Introduction

The focus of this chapter is to report on the ways or methods that can be used to assign values to the main environmental cost of Sasol Fertiliser. In doing so, the main hypothesis of this study stating that the main, seemingly non-quantifiable environmental cost of Sasol Fertiliser can be expressed in terms of monetary value, will be proven true or false.

Previously, the main environmental impacts were reported in literature (Loata, 2000) and confirmed to be the impacts related to *contamination at the dams, emissions to air, contaminated soil, loss of vegetation, dust and domestic waste*. These impacts are similar to the impacts identified in this study, but excluded the relevant social impacts (external and intangible cost), as well as implied that the impacts caused by liquid effluents to the dams are related to contaminated groundwater. The quest is therefore to obtain values for the main cost and at least acceptable procedures to estimate the cost of mitigation for the identified social impacts in order to prove the hypothesis of this study.

The valuation of the impacts identified in this study will definitely require both quantitative and possibly qualitative research. It is therefore suggested that a model for cost estimation should be proposed, based on the knowledge gained thus far.

4.2 A suggested procedural model for cost estimation

The suggested model to be followed for obtaining values for environmental and social cost is summarised in Table 4.1. This model assumes that all secondary, external and intangible cost is caused by primary impacts and therefore that mitigation of primary impacts would lead to a decrease in the dependent cost. Furthermore, an evaluation of the typical primary cost / impacts leads to the deduction that engineering solutions exist for the prevention of ongoing pollution of the environment. Typical changes to process equipment are normally facilitated by process engineering projects and are assumed to be very relevant. The quotations or capital investments required to prevent further pollution will therefore be used to assign values to the primary cost.

Table 4.1: Suggested cost estimating procedural model for Sasol Fertiliser (Source: Primary research).

Suggested Procedures	Quotation from consultant such as Process Engineers.	Quotation from consultants and cost estimation from specialist studies.	Quotation from consultants and cost estimation from specialist studies.
Chemical release, transport and impact			
Cost category	Primary cost	Intangible cost	Secondary, external and intangible cost
Category type	Control cost	Transport cost	Damage cost
Consultants / Disciplines involved	<i>Process Engineering</i> xxx xxx xxx <i>Life Cycle Assessment</i> xxx	xxx xxx <i>Environmental Risk Assessment</i> <i>Social Impact Assessment</i> <i>Life Cycle Assessment</i> xxx	xxx <i>Actuarial Sciences</i> <i>Environmental Risk Assessment</i> <i>Social Impact Assessment</i> <i>Life Cycle Assessment</i> <i>Hydrogeology / Soil Science</i>
Cost	<i>NO_x emissions</i> <i>NH₃ emissions</i> <i>Liquid effluents</i> <i>Chemical dust and particulates</i>	<u><i>Nuisance:</i></u> <i>Odour, visibility.</i>	<i>Contaminated soil.</i> <i>Contaminated groundwater.</i> <i>Loss of vegetation.</i> <u><i>Increased household cost:</i></u> <i>Maintenance, corrosion, cleaning etc.</i> <u><i>Human Health:</i></u> <i>Morbidity, mortality.</i> <u><i>Nuisance:</i></u> <i>Noise.</i>

Ottinger *et al.* (1991:3) mentioned various other methods of measuring damages such as revealed preference studies, hedonic pricing and contingent valuation. Included in these methods is the utilisation of market pricing and published values, direct, indirect and transfer cost, discount rates, real value escalation and generic versus site-specific analysis.

These methods and the associated procedures are rich in the variety of disciplines involved. In order to keep the suggested model for this study as simple as possible, it is suggested that the secondary, external and intangible cost of Sasol Fertiliser should be obtained from specialist studies, including some of the methods / studies mentioned by Ottinger *et al.* (1991).

4.3 Estimating procedures and cost

Mitigating primary impacts are perceived to result in the decrease of secondary, external and intangible cost or impacts. When the cost identified in this study is known, the secondary cost can be used as an indication of the amount of money that can be spent on primary mitigation. Sasol Fertiliser might for instance in the future, find it to be in a situation where it could be viable to implement pollution prevention technologies in order to avoid for example any damaging liabilities in a public court. On the other hand, the secondary cost could turn out to be insignificant and Sasol Fertiliser could decide to do nothing about the current pollution prevention of the factory. Sasol Fertiliser is an environmentally responsible company and it would be surprising if the company did not already obtained some quotations at the time of this study for the implementation of pollution prevention technologies.

According to Loata (2000), typical environmental damage prevention technology options available for South African players are as follows:

- NO_x emissions abatement equipment for typical nitric acid plants.
- Bag filters and cyclones for dust removal in granulation and bulk blending plants.
- Scrubbing systems for dust prevention as well as air emissions on neutralisation and granulation plants, as well as on some storage facilities.
- Demineralisation or Reverse Osmosis plants for effluent treatment.
- Routing of contaminated storm water to treatment facilities and clean storm water to rivers or channels through drains and storm water systems.
- Lining systems in ponds and below tanks in environmental sensitive areas.

The ideal damage prevention system to install on a plant would be a system that does not use water as a transport medium for the removal of particulate and dust from any emissions stream in that plant. Bag filters are therefore normally seen as the best technology option available for particulates and dust removal since no water is involved in these systems. Once water has been brought into contact with the particles, off gas or dust, the concentration of the contact medium increases and can only be released into a river or surface water system if the effluent condition complies with a Department of Water Affairs and Forestry permit requirement. Normally a concentration threshold is stipulated on the permit and samples of effluents are required to ensure compliance to the permit.

The information and discussion mentioned above serves as an example of possible mitigation measures available to Sasol Fertiliser. These measures were kept in mind while researching the costing procedures, as reported in the next section. The primary cost components of Sasol Fertiliser are used as the headings of the following sections and all relevant secondary cost for which estimating procedures and / or cost values could be obtained, are included below each heading.

Estimating secondary cost unfortunately is not so easy as obtaining cost values for primary cost, since the possible mitigation options are not so simple as engineering solutions to a specific pollution prevention problem. These methods seem more complex and are also briefly discussed in the following section as part of the primary cost discussions.

4.3.1 Primary cost

4.3.1.1 NO_x emissions

Loata (2000) interviewed consulting engineers familiar with the primary cost of typical emissions abatement equipment, required for the effective reduction of NO_x emissions. The exact technology required by Sasol Fertiliser could be installed by Krupp Uhde Engineering (Pty) Ltd. at the Sasol Fertiliser plant, for 6 million Deutsch Marks or approximately R8.7 million (year: 2000).

The contribution of NO_x emissions to increased secondary cost such as contaminated soil and groundwater is probably best observed in the possible loss of vegetation. NO_x emissions also contribute to acid rain formation and global warming, aspects that could be related back in the short term to the loss of vegetation and in the longer term to external, as well as intangible cost categories identified in this study. Various methods or procedures exist for the estimation of loss of vegetation such as *1) reduction in plant yield, 2) reductions in plant growth and 3) increased susceptibility to biotic and abiotic stresses* (Ottinger *et al.*, 1991:220).

No study exists for the estimation of the damage to vegetation of economic importance in the study area. If such a study is completed in future, it is proposed that the reduction in plant yield should be converted into cost values by multiplying the reduction with the appropriate market price for the specific crop or vegetation at that time.

Damage cost to materials and properties (*external cost* related to increased household cost) can be estimated using a combination of several different measures: 1) *material replacement cost*, 2) *the cost of periodic painting and cleaning*, 3) *the loss of consumer perceived value of material*, or 4) *the cost of developing NO_x resistant materials such as fade-resistant dyes*. Calculation of losses to materials caused by NO_x pollution should exclude effects that would otherwise have occurred such as natural weathering of materials from environmental factors such as temperature, sunlight, humidity, salt, mildew and wear. On the other hand, the acceleration of natural degradation of materials due to the presence of NO_x must be accounted for in an assessment of direct cost of damage due to NO_x (Ottinger *et al.*, 1991:223).

The intangible cost of human health (morbidity and mortality) cannot be studied under controlled experimental conditions, but must normally be inferred from animal and epidemiological studies, as well as from anecdotal evidence from polluted regions in the country (Ottinger *et al.*, 1991:216). No epidemiological study exists for the Secunda area. Cost indicators that could be used in a human health study include 1) *medical cost of treatment*, 2) *hospitalisation cost*, 3) *chronic medication* and 4) *other medical bills*.

Further intangible cost of interest is the category of nuisance cost. The nuisances of odour and noise were found to be insignificant to the plant workers during the site visits. These aspects were also found to be not relevant to the population (far removed from the factory) of the study area, since no complaints were ever received regarding noise and odour. Cost estimates can however be obtained through standard Willingness To Pay (WTP) and Willingness To Be Compensated (WTC) studies (Ottinger *et al.*, 1991:65).

As mentioned, the degrading of visibility due to chemical smog formation could also be determined using a WTP or WTC type study, *but hedonic property value studies and preference-polling studies* were also previously used in estimating a value for visibility (Ottinger *et al.*, 1991:205). A typical average value of \$10 per lost km-year per person (year: 1987) was reported. The visibility effect for a generic plant (in lost kilometres of visibility) in the study area reported on ranged from 0.1 km for the first 50 km from the plant and 0.01 km loss thereafter (up to 187 km). In the specific study mentioned by Ottinger *et al.* (1991), the total visibility losses were estimated at \$1.38 million (year: 1987). Unfortunately, the percentage of the specific pollutant in relation to the total visible air pollution was not known and therefore the

information above can only be used as an indication of the possible magnitude of such a cost (dependant on the amount of people staying in the study area).

Ottinger *et al.* (1991:228) published average environmental and social cost values for NO_x and ozone emissions. These values are to be viewed as starting points or guideline values, requiring independent studies in a South African context to validate their magnitude and appropriateness. The values listed in Table 4.2 are based on environmental cost values averaged for seven studies ranging from small to very large factories. The cost listed below obviously will be dependent on the vicinity of any fertiliser plant or factory emitting NO_x to the receiving community. The \$ values were recalculated to R-values using the R/\$ exchange rate and South African inflation values obtained from PricewaterhouseCoopers Inc.

Table 4.2: Starting point values for environmental cost due to NO_x and ozone emissions measured as cost per lb NO_x (Source: Ottinger *et al.* (1991)).

Effect	Value (average \$, year: 1987)	Value (R, year: 2000)
HEALTH		
Mortality	0.34	2.40
Morbidity	0.29	2.05
MATERIALS		
Paint and Rubber	0.01	0.07
VEGETATION		
Crops	0.01	0.07
VISIBILITY	0.17	1.20

4.3.1.2 NH₃ emissions

According to the consulting engineer interviewed by Loata (2000), the NH₃ emissions at the Sasol Fertiliser plant is localised fugitive emissions caused by a lack of maintenance of plant equipment. Although no total quotation could be provided at the time, the consulting engineer estimated the total cost to eliminate dust and NH₃ emissions to be in the order of approximately R20 million (year: 2000).

No evidence of soil or groundwater contamination or loss of vegetation could be observed in the vicinity of the plant where NH₃ could be smelled. Since the contamination in the immediate surroundings of the plant will be very difficult to determine (even impossible to determine due

to the already high nitrogen concentrations in the surroundings) no cost estimates or procedures will be suggested.

No local studies exist for external cost of increased household such as maintenance and cleaning cost, while no information is available regarding the intangible cost of human health (morbidity and mortality), odour and visibility.

Again the WTP and WTC studies mentioned can provide a good indication of some components of the intangible cost, but since the employees who are in contact with intermittent NH_3 emissions are not concerned, no such studies are proposed for the further removed communities in the receiving study area. It would however be interesting to obtain WTP and WTC values from Sasol Fertiliser employees.

4.3.1.3 Liquid effluents

As mentioned in Chapter 3, the effluent dams on site receive approximately 5.5 tph of utility related effluent from the nitric acid plant and 3 tph scrubber effluent from the granulation plant. Storm water from so-called “clean and dirty” areas is also directed to these dams and approximately 2 tpd of fertiliser dust also ends up in the effluent dams. A primary cost to Sasol Fertiliser could be the construction and operation of a reverse osmosis plant for effluent treatment.

The physical location of such a water treatment facility is important in that different settings will determine the amount of water to be treated. A less viable position would be at the river, treating all surface water runoff at the position of the RESM point nearest to the factory. Since any possible pollution is so diluted at the RESM and the fact that such a treatment facility therefore could be utilised more effectively at the effluent dams or the factory, this option is eliminated due to the very high design and operating cost involved.

The evaporation (effluent) dams at Sasol Fertiliser functions as a water sink for the Sasol Fertiliser factory and the ideal setting for a water treatment plant would be near the required (existing) infrastructure. It also needs to be near the effluent dams where only the required amount of effluent can be treated before release to the river. Such an option would definitely solve any possible water balance problems at a cost.

Implementing such an advanced technology for environmental pollution prevention would not justify leaving any of the identified impacts at the effluent dams unresolved. Mitigation of the impacts already identified constitutes the secondary cost in this case. According to Loata (2000:56), two steps should be followed regarding the effluent dams. Sasol Fertiliser has to totally rehabilitate these dams and maintain the walls and liners, as well as all related infrastructures (cut-off trenches etc.) as suggested by Lategan Bouwer Consulting Civil Engineers (Pty) Ltd. Their quotation to perform the required maintenance of the dams did not include emptying the dams and totalled approximately R2.9 million.

Dams 5, 6 and 7 still contained approximately 170 Megaliters of effluent at that time and maintenance of the dams did not include the mitigation of the loss of vegetation in the area. Additional quotations were obtained from Envirogreen Consulting (Africa) (Pty) Ltd. who quoted R4.9 million to rehabilitate the area and a staggering amount of R9.5 million to empty the dams. The rehabilitation of the area included an option for the *in situ* washing of the soil in the area, as well as installing boreholes for a pump and treat system. Furthermore, a portion of the contaminated soil and groundwater would be replaced by unpolluted soil and the polluted soil and water treated elsewhere. An actual soil washing procedure is mentioned in the next section.

No studies are available on the external cost such as the increased household cost of maintenance, corrosion and cleaning in the study area. Surface water contamination from groundwater seeping through the bottoms of the effluent dams could contribute to the members of the population of Embalenhle using more household cleaning chemicals such as washing powder etc. The most significant cost in this case is seen to be that of human health impacts and nuisance cost. This cost is currently viewed as insignificant to Embalenhle inhabitants.

Groundwater remediation is a very expensive process and a pump and treat system could be used. Groundwater could be extracted from boreholes drilled all along the perimeter of the effluent dams, upstream of the river. The cost of installation and the operation of such equipment should also form part of the secondary cost of Sasol Fertiliser. Once the operation of the effluent dams is environmentally acceptable and all risks related to polluted soil and groundwater has been eliminated, it is assumed that no further external and intangible cost would occur.

4.3.1.4 Chemical dust and particulates

Dust and particle emissions are related to the maintenance status of the Sasol Fertiliser plant (Loata, 2000:55). As already indicated in section 4.3.1.2, the estimated primary cost to effectively inhibit NH_3 emissions and continuing dust and particulate emissions is in the order of R20 million (year: 2000).

The link between dust and particulates on the one hand and contaminated soil and groundwater and the loss of vegetation on the other, has already been established in Chapter 3. Since most of the dust that falls on the soil and cemented areas is either recovered as sweepings, or transported by water to the effluent dams, the main secondary cost of interest is the contamination in the plant area only.

A large area between the buildings on site is covered by cement, but a similarly large area is also not covered by cement. Fertiliser and raw material dust from the storage and production buildings is therefore a source of chemicals resulting in soil pollution. Typical other chemicals causing possible soil and groundwater pollution include *limestone, ammonium nitrate, coating agents (wax), potassium chloride, phosphoric acid and diesel*.

As mentioned, a considerable surface area in the plant has already been covered by concrete to prevent soil pollution due to dust and spillage of product, but an approximate 16500 m² has to be covered to complete the project. Quotations for 1 m² of 100 mm thick concrete installed, are in the order of R195 per square meter, totalling R3.2 million (Loata, 2000:55).

In covering of areas with cement it is assumed that the continuing pollution of soil and groundwater will effectively be stopped and that polluted soil and groundwater poses no further risk to the environment, also resulting in more chemical dust and particles being washed to the effluent dams. This practice however ignores the cost of remediation of the already polluted soil and groundwater. Soil washing is a well-established remediation technique described by various authors such as Rajput, Higgins and Singley (1994). The cost of the equipment hire and labour, as well as the volumes of water involved can provide a cost value. Additional cost to be added is cost regarding the recovery of salts and pollutants from the wash water (using technology such as reverse osmosis or demineralisation) and either disposing of these contaminants, or packaging and selling it to a possible market.

No existing studies addressing dust and particulate impacts in terms of external and intangible cost could be found for the study area. Again the studies mentioned in section 4.3.1.1 are applicable and WTP and WTC studies are suggested to obtain cost values for decreased visibility. The cost will depend on the proximity of receiving communities and the values listed in Table 4.3 are therefore provided as a possible starting point for further studies (Ottinger *et al.*, 1991:276).

Table 4.3: Starting point values for environmental cost due to dust and particulates measured as cost per lb particulates (Source: Ottinger *et al.* (1991)).

Effect	Value (average \$, year: 1989)	Value (R, year: 2000)
HEALTH		
Mortality	0.33	2.09
Morbidity	0.03	0.19
MATERIALS	0.00	0.00
VEGETATION		
Crops	0.00	0.00
VISIBILITY	0.83	5.28
OTHER		
Ecosystems	0.00	0.00
Livestock	0.00	0.00

4.4 Breakdown of the procedural steps included in quotations

The primary cost obtained from consultants as mentioned in this chapter, was derived by the summation of the cost of the procedural steps required to achieve acceptable result in terms of pollution prevention. These totals resulted in the cost reflected in the quotations. Applicable procedural steps will be briefly listed in order to clarify primary cost estimation in this chapter.

The quotation for the NO_x emissions abatement equipment (see section 4.3.1.1) will be discussed first, followed by the estimation of maintenance cost to solve NH₃ and dust emissions as mentioned in sections 4.3.1.2 and 4.3.1.4. Finally, the procedural steps included in the quotations for the required remediation at the effluent dams (see section 4.3.1.3) will be listed.

The turnkey quotation of R8.7 million for the Krupp Uhde Engineering (Pty) Ltd. NO_x emissions abatement plant was based on four procedural steps or actions, namely:

- Compile basic and detail engineering design packages
- Deliver the required abatement equipment
- Construction of the abatement plant
- Project management and overseeing

The procedural steps listed are normal or standard deliverables in most quotations for turnkey engineering solutions (Otto, 2001). A cost breakdown of the procedural steps was not available due to the fact that the information received from Krupp Uhde Engineering (Pty) Ltd. was in the form of a lump sum quotation.

The required maintenance cost estimate to reduce NH_3 and dust emissions was based on previous maintenance records, including cost for typical maintenance items as well as cost estimates for a number of additional maintenance items (Loata, 2001). The main items include the following:

- Replacement of gaskets and seals
- Standard replacement of metal panels and pipe sections
- Corrosion treatment and painting
- Conveyer belt system maintenance
- Sealing of conveyer belt and other mass transfer point enclosures

Excluded from the maintenance cost estimate is the quotation for the prevention of further soil pollution caused by dust emitted from the factory. In this case the cost of R3.2 million was derived by:

- Measuring the area to be paved
- Calculating the cost for covering 1 m^2 of this area in 100 mm of cement
- Multiplying the total uncovered area with the calculated cost.

As already mentioned, an approximate 16500 m^2 of uncovered soil will have to be covered to prevent further soil pollution. Quotations for 1 m^2 of 100 mm (acceptable thickness standard)

concrete installed are currently in the order of R195 per square meter, totalling R3.2 million (Loata, 2000:55). According to Lategan (2001), the cost of R195 per square meter includes the construction and project management and overseeing. This quotation was based on the assumption that no existing polluted soil deeper than 100 mm would have to be removed or replaced before covering the area with cement. Implied in this assumption is the fact that the cement would stop the spreading of soil pollution due to any further water movement through the soil covering.

The quotation for the rehabilitation and maintenance of the effluent dams included a cost of approximately R2.9 million as quoted for by Lategan Bouwer Consulting Civil Engineers (Pty) Ltd. to perform the required maintenance of the dam liners. According to Lategan (2001) the procedural steps required are:

- Determine the surface areas of the effluent dams
- Hiring of civil construction equipment
- Calculate the volume and supplying the required additional liner material
- Compacting dam liners to the required density
- Maintain toe drains

This quotation did not include the cost to empty the dams. Envirogreen Consulting (Africa) (Pty) Ltd. quoted an amount of R9.5 million to empty the dams. According to Loata (2001) this quotation implied the emptying of the dams through pumping the dam content into containers and either treating the effluent (diluted liquid fertiliser) elsewhere or remove the effluent and donating it to the farming community surrounding the Sasol Fertiliser factory. The R9.5 million would therefore also include transport cost.

Finally, an additional quotation from Envirogreen Consulting (Africa) (Pty) Ltd. addressed the rehabilitation of soil and vegetation in the area surrounding the dams. The quotation for approximately R4.9 million included the following actions:

- Determining the area and volume of soil to be remediated, based on a maximum level of 450 mS/m conductivity in soil samples taken from the site.

- Dilution of inorganic salts in areas with conductivity higher than 450 mS/m, using organic material (approximately 7200 tons) ploughed into the soil to a depth of 600 mm resulting in a soil with bulk density of 1200 kg/m³ and capable of supporting plant growth.
- Deliver and apply a layer of approximately 300 mm of top soil (totalling 252 000 m³)
- Supplying and seeding the topsoil with a local plant species.
- Extend the cut-off trenches on the western and southern side of the effluent dams to intercept any possible contaminated ground water flow from below the dam liners after liner maintenance.

Envirogreen Consulting (Africa) (Pty) Ltd. also considered *in situ* soil washing or leaching. This remediation technique was finally not suggested due to the high clay content of the soils found in the area (Viljoen, 1999:16).

4.5 Relevance of published international secondary cost to the South African geographical context

One last aspect of the secondary cost values obtained from literature in this study, is the question of the relevance of this data in the Secunda and South African context. The values reported in Tables 4.2 and 4.3 were presented by Ottinger *et al.* (1991) and were published as starting points to be used in specific studies relevant to the geography and biodiversity of that specific study area. The averages calculated by Ottinger *et al.* (1991) were based on research completed for seven locations including a large city, big city and a small city. The starting point figures were reported for a typical location, which were defined as being similar to Western Washington.

Population densities and other parameters will vary with location. Ottinger *et al.* (1991) also stated that these estimates should be used with great caution, as they indicate only a possible magnitude of the secondary cost. Secunda recently received (small) city status and it is therefore expected that the secondary cost for the TEKS area will be lower than listed in Tables 4.2 and 4.3. Within South Africa as a whole, the population densities near towns and cities are also subject to large variations and specific specialist studies (as proposed in Chapter 6) should be completed as relevant to the specific environment, biodiversity and population of the study area.

The geographical relevance of the secondary cost listed in Tables 4.2 and 4.3 will therefore definitely influence these values, but not the methodology and procedures listed in this chapter.

It is therefore stated that the geographical differences will influence the extent of such specialist studies, but not the procedures and methodologies followed to relate environmental and social cost to cost values, allowing the hypothesis of this study to be proven as true.

4.6 Cost summary and conclusion

Various methods and procedures were mentioned in this chapter that allows the allocation of cost values to the environmental and social impacts of Sasol Fertiliser. Consideration of these methods allows the hypothesis of this study to be proven as true. Unfortunately, monetary values are not available for all the environmental and social impacts of Sasol Fertiliser. It is therefore proposed that the studies, as discussed in this chapter (and as proposed in Chapter 6), be completed within a South African context.

A summary of the cost values obtained during this study shows that Sasol Fertiliser will have to spend a minimum of approximately R50 million on various environmental impacts. This total excluded the cost of for example a proposed reverse osmosis water treatment plant, a pump and treat system, a soil washing facility, epidemiological study cost and WTP and WTC study cost, as well as the actual compensation of the inhabitants of the study area if considered. The available cost values can be summarised as follows:

- Contamination of dams - R12.4 million
- Emissions to air - R8.7 million
- Preventing further soil contamination - R3.2 million
- Loss of vegetation - R4.9 million
- Dust and NH₃ - Approximately R20 million

The ranking of the cost obtained in the study is shown in Table 4.4. This table also indicates those impacts for which studies can be completed, but no monetary values are available as yet.

Future studies are required to obtain the missing values in Table 4.4. An estimation method should also be included to express these values as such to allow comparison based on the time value of money for one specific financial year (outside the scope of this study).

Table 4.4: A summary and ranking of the environmental and social cost values of Sasol Fertiliser (Source: Secondary research).

Category	Cost	Type	Rank	Value (financial year)
Primary	<i>NO_x emissions</i>	<i>Quotation</i>	3	R8.7 million (2000)
	Liquid effluents	Quotation to be obtained	-----	-----
	<i>Chemical dust, particulate and NH₃ emissions</i>	<i>Quotation</i>	1	R20 million (2000)
Transport	Odour <i>Visibility</i>	Specialist studies and WTP / WTC studies	----- -----	----- R5.28 / lb particulate (2000) and R1.20 / lb NO _x (2000)
Secondary	Contaminated soil and groundwater	Specialist studies, WTP / WTC studies	5 2	R3.2 million (2000) R12.4 million (2000)
	Loss of vegetation		4	R4.9 million (2000) R0.07 / lb NO _x (2000) and R 0.00 / lb particulate (2000)
	<i>Maintenance Corrosion Cleaning</i>		-----	R0.07/ lb NO _x (2000) for maintenance, corrosion and cleaning.
	Morbidity		-----	R2.05 / lb NO _x (2000) and R0.19 / lb particulate (2000)
	Mortality		-----	R2.40 / lb NO _x (2000) and R2.09 / lb particulate (2000)
	Noise		-----	-----

CHAPTER 5: CONCLUSIONS

The principles of cost / benefit analysis provide a very good guideline or framework to study the environmental and social cost of any company. In this study these principles were used to develop a list of cost values. Since only the cost section of this methodology was investigated for Sasol Fertiliser, the question still remains whether the benefits of inorganic fertiliser really outweigh the cost. This is obviously a question that requires further study to be answered in full.

However, investigating the cost in terms of environmental and social aspects rendered interesting results. Firstly it was realised that the components of the receiving environment had to be identified, which was done in Chapter 2. Sasol previously set up various environmental monitoring stations in the study area and in most cases the volumes and concentrations of pollutants can actually be measured at the point of impact. Various other available methods and procedures that can be used (discussed in Chapter 4) to estimate the cost of the impacts of Sasol Fertiliser were mentioned, that is procedures that can be used independently from data obtained from these monitoring stations.

The primary component in any pollution chain was found to be the source of pollution. The possible sources of pollutants were identified through reviewing published information and actually conducting site visits and interviews. The findings or results were discussed in Chapter 3 and from the information presented in this report, a pattern emerged that was transformed into a cost-estimating model in Chapter 4. The cost-estimating model includes primary cost, transport cost and damage cost.

The total primary cost of Sasol Fertiliser was estimated to be in the order of R28.7 million based on quotations received in the year 2000. This amount excludes the cost for design, construction and operation of a water treatment facility required to solve possible water balance problems. No cost estimates could be obtained for the transport cost of Sasol Fertiliser (within the South African context) as well as for the study area. Specialist studies were discussed, including scientific acceptable “Willingness to Pay” and “Willingness to be Compensated” studies (as previously used internationally to obtain cost estimates). These studies combined quantitative and qualitative research as generally required for studies of this type.

The damage cost of Sasol Fertiliser was found to include various components. This cost can be categorised as secondary cost and include typical cost for environmental remediation of contaminated soil, groundwater and loss of vegetation. It was also found to include cost towards materials damage, maintenance, corrosion and cleaning. The human health aspects of mortality and morbidity were also included, as well as nuisance cost (e.g. noise). Quotations obtained for secondary (remediation) cost added up to R20.5 million (year: 2000). Various average values for the components of secondary cost, expressed in \$ values, were obtained from international literature.

An interesting aspect of this study is that the categorisation of environmental and social cost in this fashion allows the management of any business to make informed decisions. It was found that it was possible to make a decision on whether it would be preferable to continue the operation of a factory as is, or to invest in the health and well being of the environment by spending the required primary and even the remediation cost.

The cost presented in this study did not fully allow the comparison of the totals of the different cost categories as proposed above, but ranking of the components of the main cost of Sasol Fertiliser was possible. The primary environmental cost of Sasol Fertiliser outweighs the secondary cost. This conclusion is only based on the current information that is at hand. Further study is required (using the values presented in Chapter 4 as a starting point), including the development of a financial calculation method to present cost estimates in the different currencies obtained in different financial years, on a common basis.

Finally, the hypothesis of this study was proven to be true in that methods and procedures already exists, that allow the estimation of the environmental and social cost identified in this study to be estimated in monetary value.

CHAPTER 6: RECOMMENDATION FOR FURTHER STUDY

The recommendations briefly presented in this section, focus on the studies that are perceived as being the most important to the field of environmental cost accounting, not only for Sasol Fertiliser, but also for all industries in South Africa. If Sasol Fertiliser can be used as a starting point for the studies that could be performed to obtain cost values (for the impacts for which no cost values could be obtained within the scope of this study), the following required studies are recommended:

- The investigation of alternatives to water treatment (including reverse osmosis, demineralisation etc.) in terms of their environmental cost, as well as total cost in terms of design, construction and operation.
- An investigation into the environmental cost of the soil washing remediation technique.
- The evaluation and performing of WTP and WTC studies to obtain cost values for social issues such as quality of life, including increased maintenance or household cost and nuisance issues within a local context.
- An epidemiological study in order to investigate the cost values of human health within the Sasol Fertiliser study area.

It is recommended that the publication of Rajput *et al.* (1994) be used as a starting point for the soil washing remediation study. A modelling exercise can be used to estimate the volumes of water required and a database compiled allowing easy estimation of the cost of water to be used when combined with the cost per kiloliter.

The proposed WTP and WTC studies should possibly be performed at a fertiliser factory where the social impacts identified in this study, as well as possible other identified issues are burning concerns. It is proposed that the methodology to be followed be explained extensively and that the study be completed at a fertiliser factory where the receiving population is in close proximity of that factory. In so doing, the results of such a study will allow comparison of WTP values vs. WTC values within a South African context. It will also allow a more accurate indication of the possible magnitude of these values than that of the Sasol Fertiliser case where the factory is far removed from the receiving population. Both the soil washing remediation study as well as the WTP/WTC studies mentioned above should be performed at Ph.D. level.

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