POLLUTION CAUSED BY MINE DUMPS AND ITS CONTROL

By

Chimwemwe M. Chikusa

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"The decade of environment is nearing its halfway mark with little sign that it is any better off than the destructive 1980s - and this despite events such as last year's Earth's Summit where billions were pledged to cure the world's ills. Some scientists and environmentalists - or prophets of doom - are now warning the world is unequal to the challenges of the next century." (Goussard, 1993). This follows the 1980s, which was the international decade for natural hazard reduction. (NRC, 1987).

"...RESPONSIBLE ENVIRONMENTAL MANAGEMENT IS NOT A COSTLY FIRST WORLD EVIL, WHICH MUST BE AVOIDED WHEREVER POSSIBLE, BUT A NECESSARY BENEFICIAL PART OF SOUND PROJECT PLANNING, EVEN IN DEVELOPING COUNTRIES" (Walmsley, 1993).

"IT IS IN THE NAME OF NET PROFIT, BUDGET SURPLUS AND GROSS NATIONAL PRODUCT THAT THE NATURAL ENVIRONMENT IN WHICH WE ALL CO-EXIST IS BEING DESTROYED. THOSE WHO SPEAK THIS LANGUAGE HAVE MORE SOCIAL POWER TO INFLUENCE THINKING AND ACTIONS THAN THEY PERHAPS REALISE, OR UTILISE" (Hines, 1991).

"MANY (SA COMPANIES) ARE STILL AT THE STAGE OF MENTIONING ENVIRONMENTAL ISSUES IN ONE LINE OF THEIR REPORT OR PUTTING A BUTTERFLY ON THE COVER AND THINKING THE PUBLIC WILL BELIEVE THEY ARE RESPONSIBLE. HOW, THE PUBLIC IS NOT EASILY FOOLED" (Betty, 1993).

"IT IS A KNOWN FACT THAT SLIME DAMS ARE THE BIGGEST CAUSE OF ANNOYANCE IN THE MINING INDUSTRY WHEN IT COMES TO AIR POLLUTION".

"Although we must think global, we must act local" (Sittert, 1993).

"WE LOOK AFTER THE BUGS, AND THEY WILL HELP US LOOK AFTER THE PLANET EARTH" (Canby *et al.*, 1993).

ABSTRACT

All mine dumps are a point source of either physical, chemical or both forms of pollution. Physical pollution includes the physical site coverage of the dump, slumping of parts of the dams and dust that may originate from it (air pollution). Chemical pollution from, or related to the mine dumps include the dominant acid drainage (which contains heavy metals), radioactivity, electromagnetic radiation, noise and chemicals released from the mineral processing stage.

In one way or the other, exposure to these pollution forms is detrimental to the human health and his environment. It is this fact that urges the public, government and the responsible mining companies to find ways of monitoring the pollution and stopping it, preferably at the source. Where it can not be stopped, techniques of reducing it, or containing it have been, and are still being developed. Personal protection is the priority. Pollution exposure to the general public is minimised as much as possible.

Pollution control techniques that employ less expensive, natural, self-sustaining elements suitable for the environment such as wetlands and vegetation are recommended. The artificial short term and often expensive alternatives are of secondary priority. However, choice of which technique to use is based on the merit of each problem, knowing that chemicals act faster but are effective for a short period as compared to the natural systems.

Pollution management is the critical part of the whole process. This involves decision making on courses of action and financial allocation on the part of both the polluter and the monitoring department/agent. The ability to effectively manage pollution programmes is achieved these days with the aid of computers. It is emphasised that pollution control should be handled in an integrated, multi-disciplinary approach manner. This is because pollution is a question of life and death, hence every individual remains accountable to it.

Keeping the public and the concerned parties educated, informed and welcoming their concerns on the environmental issues related to the mine dumps generated in a mining venture is essential in the modern days of environmental public awareness, or otherwise face the public lath.

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1.0 INTRODUCTION

The mining industry is of key importance to the economies of many countries of the world and its products are used in every facet of life throughout the world. However, with its legacy of poor environmental management, capitalist heritage and the strategic importance of many of its minerals, it has become (rightly or wrongly) an easy target for environmental pressure groups, political activists and politicians (Walmsley, 1993).

One of the areas in which this industry can help itself is the environmental management. In most of the so called developed countries, the industry has been helped on its way by greater environmental control legislation which has forced existing mines to clean up their operations. At the same time, new ventures have been subjected to public scrutiny through the environmental impact assessment process. In Southern Africa, environmental control legislation is still in its infancy or even non-existent and therefore it is largely up to the individual mining groups to introduce environmental management into their operations (Walmsley, 1993).

In this report, the most sensitive mine pollution component will be examined through literature search. This component is "the pollution caused by mine dumps" (Sittert, 1993a). It is a sensitive issue because it is the easily visible undesirable result of mining to the public. The techniques of controlling this pollution have also been examined both technically and administratively. It is hoped that this dissertation will lay a simplified base and/or reference for those concerned in the pollution caused by mine dumps. The principles recommended here-in are also applicable in handling any form of both artificial and natural pollution.

Examples on worldwide experiences on the various relevant issues are presented wherever necessary. These examples may not necessarily be the best. For Southern Africa, most of the lessons will be taken from the experiences in the Witwatersrand Gold Mines and the Rossing Uranium Mine. This is because there has been a substantial amount of publicised work on their environmental activities.

1.1 Mine Dump

1.1.1 Definition of mine dumps

Disposal of the large volumes of waste rocks, ore tailings and slags from smelting generated by mining processes is achieved in most cases by forming dams and dumps within the mine area (Fig 1)(Loos *et al.*, 1990 and McGarry *et al.*, 1975). **Tailings** is a mill term for output from a mill for discard, while the input (ore) is called **head** (Dennen, 1989). A **mine dump** is therefore a mine residue deposit (Dawson, 1993 and Funke, 1990). The mine residues are known as **slimes dams**, if the composition is of extremely fine clayey pulp material derived from ore, associated rock, or altered rock by process of natural weathering, infiltration or non-selective severance (Dennen, 1989). Dowling, (1993) and McGarry, (1975) have discussed tailing dumps comprising **slags** from smelting of various metal ores such as platinum, chromium and lead. This type of mine tailings will only be dealt with in the section considering the proper utilisation of mine dump materials. The dumps which are still being constructed are termed **active**, as opposed to the old **inactive** ones, with no relation as to whether they are generating pollution or not.

In a study of the Witwatersrand mine dumps, the above classifications of mine dumps have been applied by Funke, (1990) and Sittert, (1993a) as follows:

i) The dumps consisting of barren overburden material or low-grade material which is not economical to process for the recovery of the commodity such as gold. These are called **rock waste dumps**.

ii) The mine dumps which were deposited mechanically in a moist state in the old days are called **sand dumps**. These reach heights in some instances of over 100 m above ground.

iii) The mine dumps formed by hydraulic deposition of fine tailings are called **slimes dams** (dam is a mining term for hydraulically placed deposits).

In this discussion, the term **mine dumps** will be used to represent any or all the dumps mentioned above according to the context.

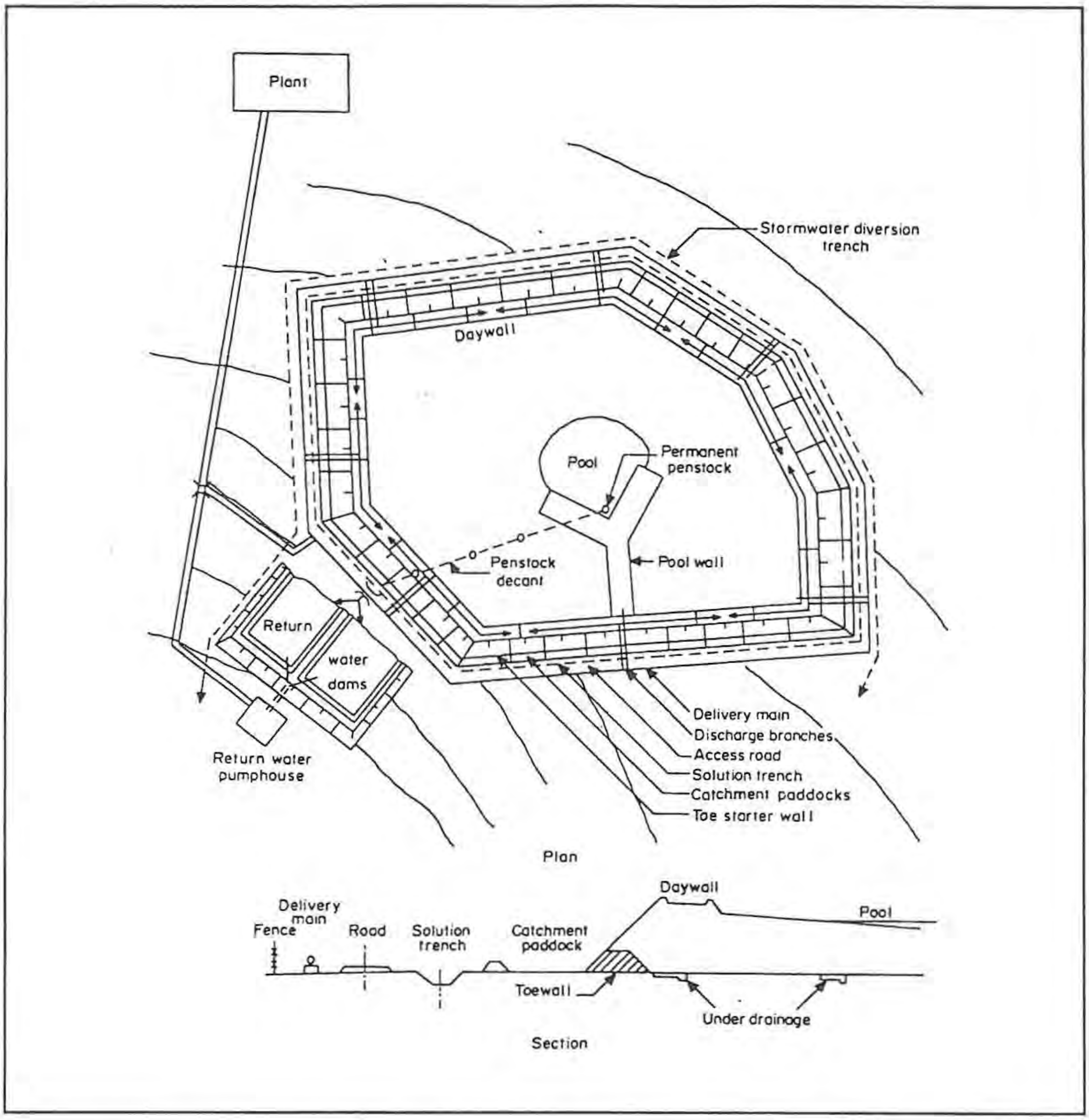


Figure 1. Typical layout of a mine dump (From Funke, 1990).

1.1.2 Structure of mine dumps

Some mine dumps, like most in the Witwatersrand gold mines, form big piles of varying sizes (seldom exceeding 30 m height) with steep slopes (Fig 1). This is due to particles lying at their angle of repose resulting from end tipping (often dumped by cocopans which run up and down special ramps, stabilised with boiler ash). These slopes, which vary from 10^0 to 44^0 are deliberately made in order to maximise waste volume disposal per unit area.

Some of the properties of the mine dump steep slopes are;

i) Lack of stability.

ii) Very draughty.

iii) If fine textured, they are susceptible to erosion by both wind and water.

These make rehabilitation efforts (such as revegetation) difficult and expensive, or worse still, impossible to achieve. The issue of ideal or maximum permitted slope angle for closure compliance is currently a matter of debate (Dawson, 1993). Flatter slopes for cheaper rehabilitation are preferred, although a relatively large area is occupied by the dump. A slope angle of about 18^0 is favoured for easy use of mechanised vegetation and reduced chances of slumping. Terracing of the slopes from the start is recommended (Thatcher, 1979). Horizontal furrows/trenches are recommended for water catchment in order to reduce erosion by rain water (Down, 1975).

1.1.3 Design and construction of mine dumps

The Government Mining Engineer in South Africa has lain safety regulations and recommendations (Thatcher, 1979) regarding:

i) The maximum height to which the slimes can be built.

ii) The margin to be left between railways, major and minor roads, buildings, water courses and other important objects.

iii) The nature and area of site on which the dam is to be built.

iv) The construction of the dam.

v) The provision of safety trenches and catchment areas.

Construction techniques are influenced by the following four factors (Thatcher, 1979):

i) The control of pollution as run-off from the outer surface and by seepage from the dam.

ii) In-situ leaching.

iii) Requirements from the subsequent vegetation of slopes and top surface of the dams.

iv) The dam may ultimately be used as a site for building.

In the conventional hydraulic-fill construction (Fig 1), tailings slurry is deposited along the length of the impounded wall into the so-called day-paddocks. Coarser particles settle faster than finer ones hence they are adjacent to the point of deposition. The finer particles remain in suspension longer, eventually settling towards the centre of the dump. The slurry is pumped during the day into one of the day-paddocks along the perimeter, with a freeboard of about 0.7 m to 1 m in height. Tractors and ground-shaping devices are used on free-boards whenever necessary, as well as decanting of water (Funke,1990).

It is recommended that in the construction of the top of the dam, the following be considered (Thatcher, 1979):

i) The top of the surrounding wall of the dam level around the periphery should be at least 6 m wide, to form a road way which should be graded towards the centre of the dam so that rain water run-off does not flow over the outer edge.

ii) The free-board night wall to day wall should be a minimum of one metre.

iii) The floor the top of the dam should be as level as possible, sloping slightly towards the penstock (Figs 1 and 5).

iv The penstocks should be serviceable and functionary efficient.

Fine details of a dump design depend on the minerals in the tailings, local environment (including weather) and the type of rehabilitation to be done, among other things. For example, in the Witwatersrand gold and uranium tailings, the maximum rise is usually 7 to 14 days. This is the rate of deposition that allows enough cycle time on the dam's day-paddocks to facilitate drying out of the tailings. Desiccation of the slime is essential for compaction and gain in strength thereby reducing the ratio of horizontal to vertical permeability. Failure to adhere to some of these damming details resulted in some of the following experiences;

i) The failure of a platinum tailings dam at Bafokeng on 11th November, 1979 apparently initiated by horizontal piping erosion (Funke, 1990).

ii) The overflow of tailings from a dam at Khitti floatation plant belonging to a 200-350 years old Bo Ngam Mine in Thailand, due to lack of maintenance (McGarry *et al.*, 1975).

1.1.4 Mineral and chemical composition of mine dumps

Composition of the dumps depends on the type of lithologies forming the ore, footwall and hangingwall. For example, in the Witwatersrand gold mines, the major constituent is silica in the form of quartz (75-85%), while pyrite (Appendix I) is between 1.5 and 2.5%.

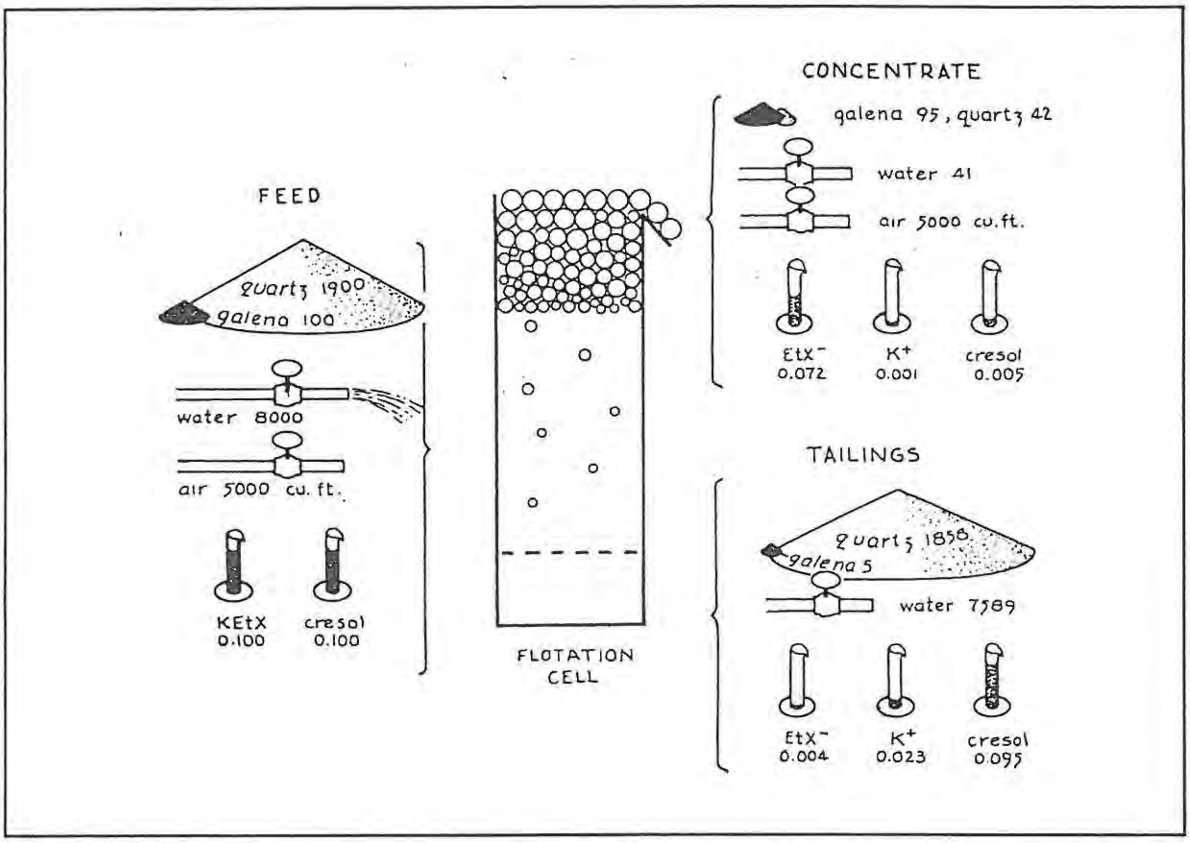


Figure 2. Idealized mineral separation in a floatation cell (From Dennen, 1989).

Most of the ores of copper, lead, zinc, coal, gold and uranium, whether of sedimentary, chemical, hydrothermal or igneous origin contain a substantial amount of hazardous and/or toxic mineral elements. Sulphides are the most common hazardous minerals (of which pyrite is the most abundant). Among the toxic elements are arsenic, uranium, lead, zinc, cadmium, mercury and some other trace elements. Their relative proportion is higher in the dumps than in the ore. This is because the mineral bonification (processing) removes most of the desired commodity, leaving behind almost all the original amounts of the undesired minerals (Down, 1975) (Fig 2). The effort to achieve a high grade product by the use of successive separator stages results in the loss of more of the commodity onto the tailings (Fig 2 and 3). This is particularly a problem when the commodity is a potential pollutant such as uranium, pyrite, mercury, arsenic and galena (Pb).

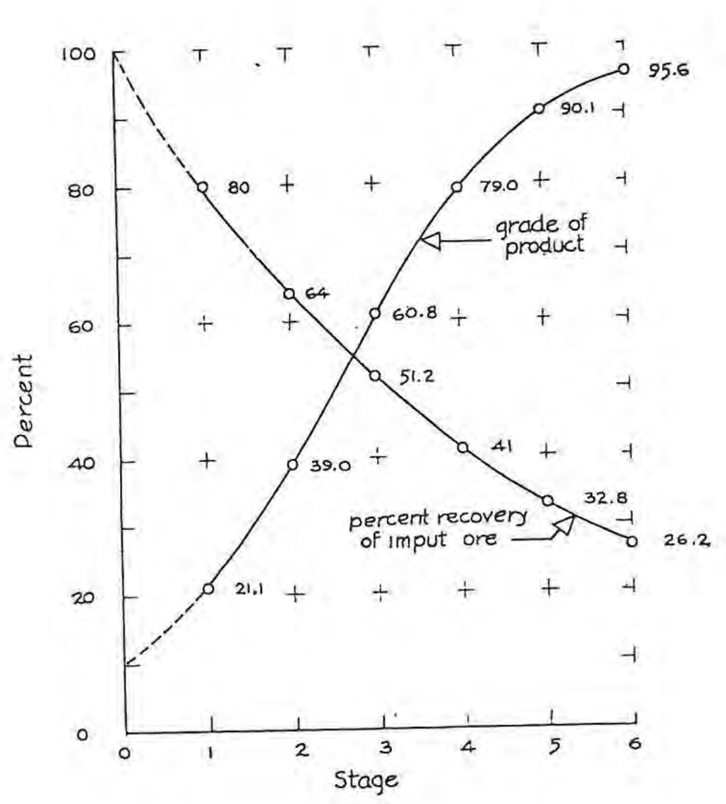


Figure 3. Change in product grade and tonnage in successive separatory stages. Note that the higher the grade, the smaller the commodity amount recovered and the more the commodity lost in waste (From Dennen, 1989).

Some of the chemical(s) used in the ore dressing and reclamation activities often constitute a notable proportion of the mine dumps (Fig 2). These include cyanide, mercury, acid, KEtX (potassium ethyl xanthate), cresol ($CH_3.C_6H_4.OH$) and biological inhibitors (Dennen, 1989).

1.1.5 Particle size composition of mine dumps

With the exception of coal, most of the ore forming minerals are disseminated and fine

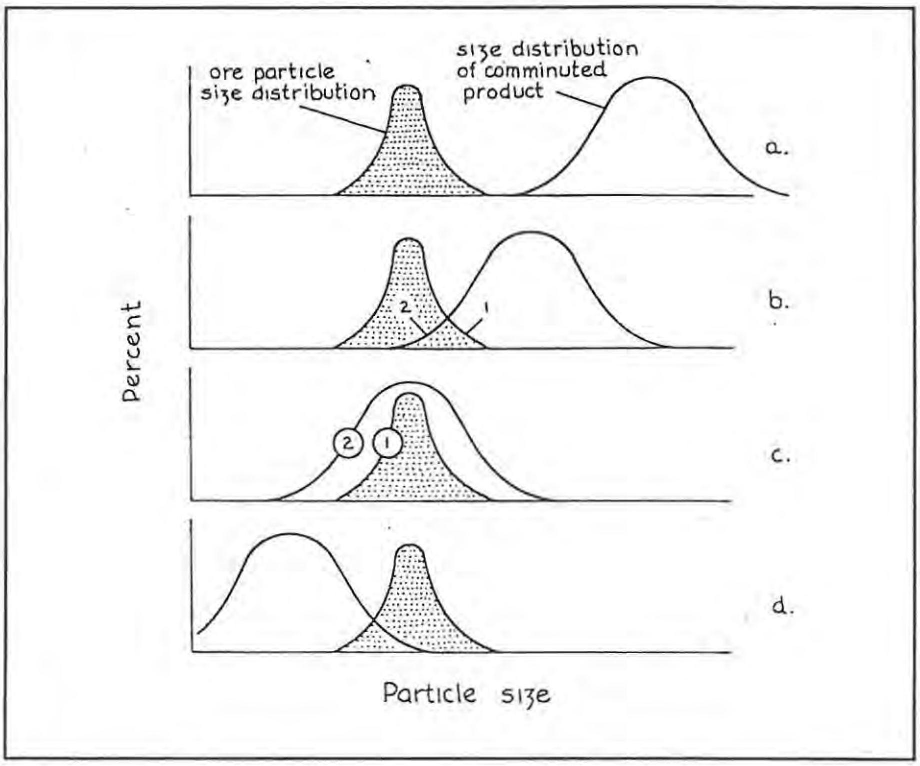


Figure 4. Unlocking mineral grains from ore: a) Comminution starts. b) Unlocking begins. c) Unlocking continues. d) Unlocking nearly complete (From Dennen, 1989).

grained. In order to liberate the desired mineral for winning purpose, the ore is crushed to fine particle size, ideally smaller than the smallest mineral grain (Fig 4) (Dennen, 1989).

For example, gold mineralisation in the Witwatersrand is generally fine and disseminated. Consequently, a typical two-stage size-reduction process as described by Funke, (1990) is employed;

i) Crushing (about 450 mm reduced to 10 mm) and

ii) Milling (10 mm to 0.1 mm).

As a result, most of the Witwatersrand mine dumps comprise barren pulp with about 4% greater than 0.5 mm, 11% less than 0.1 mm and 85% between the two (Thatcher, 1979 and Sitter, 1993a). This milling process produces a burk factor (volume expansion) of about 1.67 times.

Apart from liberating the individual commodity mineral grains, the reduction in grain size (comminution) has the advantage of increasing the surface perimeter of the grains. This is necessary for maximising chemical reaction (Appendix II) in the subsequent mineral winning stages if required.

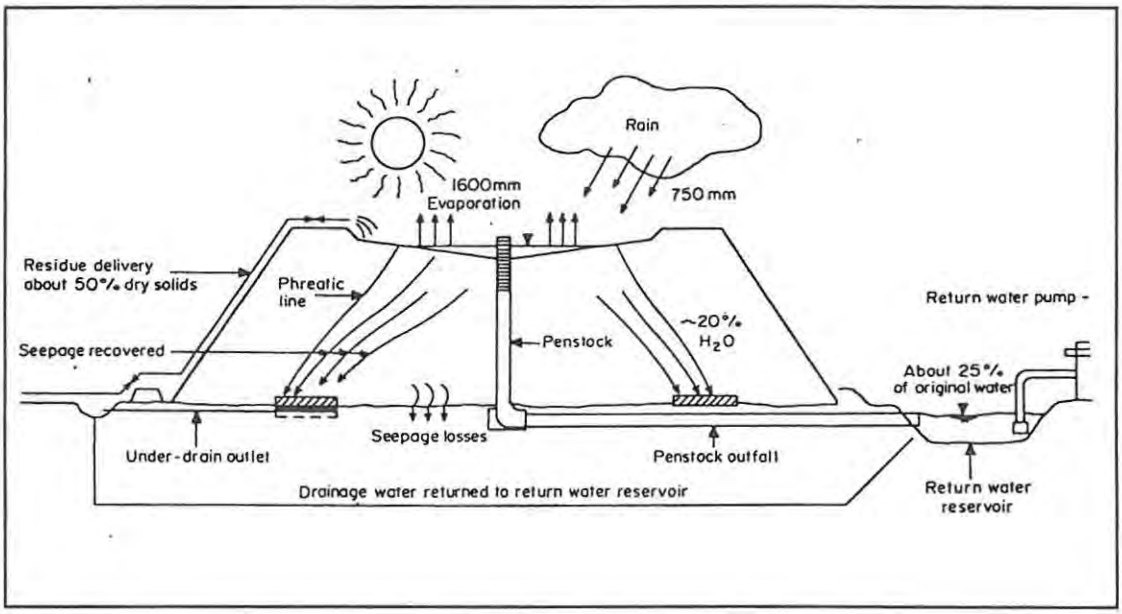


Figure 5. Water balance for a mine dump (After Funke, 1990).

1.1.6 Mine dump reserves

Rock waste dumps (non-reef rocks mined adjacent the ore) are kept separately from slimes dams or sand dumps. This has been found useful because with the development of new processing methods, the currently so called barren slimes dams may prove economical in future. Also the methods of handling the different types of mine dumps are not quite the same.

Considering gold mining alone, the Witwatersrand, by the early 1970s had well over 6800 hectares of slimes dams, and 1200 hectares of sand dams. The other South African goldfields occupied over 3642 hectares (Thatcher, 1979). To date, with the rapid mining due to improvements in mining technologies, together with the opening of new mines, the mine dumps occupy far greater areas.

1.2 Pollution

Pollution is the presence of undesired matter or energy radiation in a place. The undesired matter (pollutants) can be in the form of solid, liquid, gas and forms of energy such as sound (noise), radioactivity and electromagnetism. The causes of pollution may be human or natural, and deliberate or accidental placement. Domenico *et al.*, (1990) calls the pollutants contaminants and defines them as any dissolved solute or non-aqueous liquid that enters the water as a consequence of human activities. Sittert, (1993a) defined pollution simply as unwanted material. He classified pollution in two;

i) That carried by the atmosphere (air, noise and radioactivity) and

ii) That carried in liquid or solid form.

Platt, (1975) classified pollution in a mining environment in terms of earth, water and air.

Domenico *et al.*, (1990) have discussed pollution of ground water in three general terms which are also applicable to surface water and other form of pollution;

i) **Degree of localisation**; Point or non-point sources of contaminants. Point sources are characterised by the presence of identifiable small scale source such as leaking storage tank or mine dumps, producing a well-defined plume (Fig 6)., Non-point source refers to a large scale source with a poorly defined plume such as chemicals used in agriculture (fertilisers and pesticides).

ii) **Loading History**; This is how the concentration of a contaminant or its rate of production varies as a function of time at the source (Fig. 7). The structure of active mine dumps is shown in Figure 7c. The release of pollution much depends on frequency of waste addition, type of waste, rain-fall, temperature, wind and other widely varying factors. Inactive dumps will tend towards Figure 7d.

iii) **Kinds of contaminants emanating**; There are thousands of water contaminants and activities generating them. The USA Environmental Protection Agency has listed 129 priority pollutants (15 of which are inorganic species, mainly trace metals) which are a common cause of adverse health effects, or persisting within food chain (Table 1), and their most common sources (Table 2). These tables unfortunately do not quantify, nor rank the pollutant and their sources according to the severity.

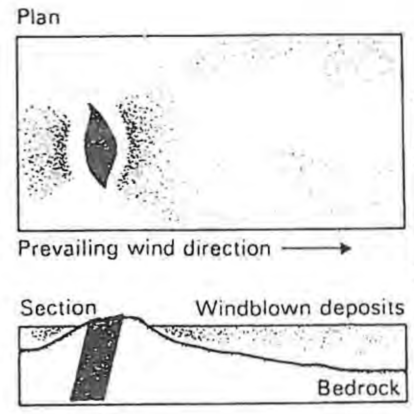


Figure 6. A well defined plume of wind blown pollution (After Open University, 1974).

It has been found convenient in this discussion to classify pollution into two categories, namely physical and chemical.

Physical pollution includes the non-usable space occupied by the dumps, tailings/dust and waterborne fine solids (suspension load). The **chemical pollution** includes toxic metals (in solution), acids, gases, chemicals released from mineral processing and emissions (energies transmitted in air or space such as noise, radioactive and electromagnetism).

2.0 MINERAL POLLUTION

As already mentioned above, pollution is the presence of pollutants in space, air, liquids and solids. It is worth noting that under normal natural conditions, these mineral pollutants may exist in the same media. The main difference is that they are present in such low concentrations that they either have no effect or are actually desirable for the survival of the human being and/or his environment. On the other extreme, their deficiencies may result in adverse effects. Although this is a concern too in some areas, this will not be tackled since the subject of this discussion is the excesses which constitute mineral pollution. Domenico *et al.*, (1990) state that "as a broad generalisation,

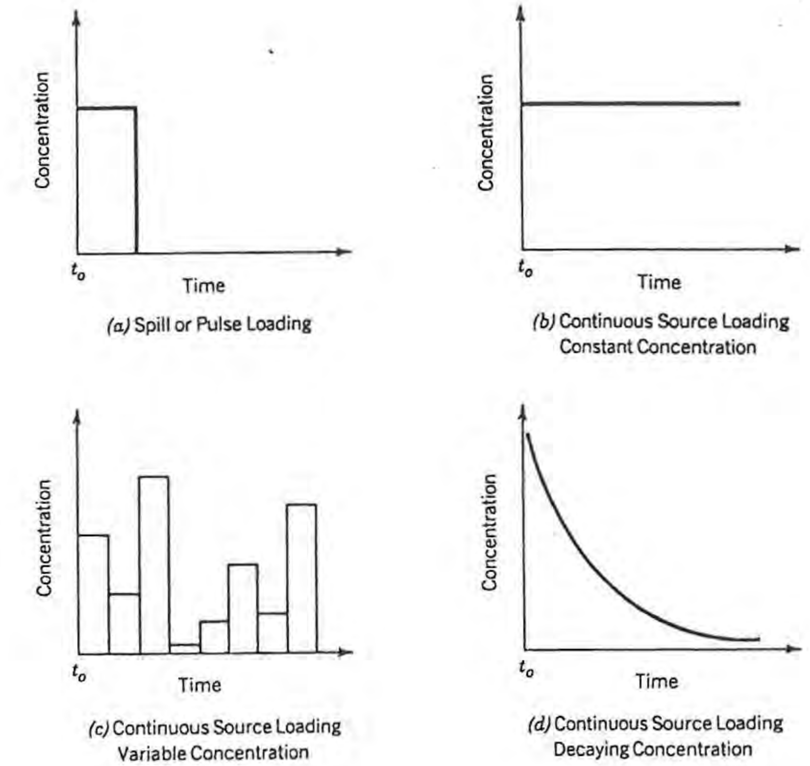


Figure 7. Examples of functions used to characterise contamination loading from a spill (a) or long-term leakage (b, c and d) (From Domenico, 1990).

too much of anything in water can produce health problems in humans". This is equally the same in space, air, and solids.

Mine dumps are produced by human activities. Therefore the pollution emanated from them, facilitated by agents such as water and wind (Dennen, 1989 and Loos *et al.*, 1990), is of human cause. The following are some of the common types of pollution related to mine dumps:

Table I. List of priority pollutants, subdivided according to the method of analysis by the Environmental Protection Agency-USA (Domenico et al, 1990).

BASE-NEUTRAL EXTRACTABLES

Acenaphthene	Diethyl phthalate
Acenaphthylene	Dimethyl phthalate
Anthracene	2,4-Dinitrotoluene
Benzidine	2,6-Dinitrotoluene
Benzo[*a*]anthracene	Di-n-octyl phthalate
Benzo[*b*]fluoranthene	1,2-Diphenylhydrazine
Benzo[*k*]fluoranthene	Fluoranthene
Benzo[*ghi*]perylene	Fluorene
Benzo[*a*]pyrene	Hexachlorobenzene
Bis(2-chloroethoxy)methane	Hexachlorobutadiene
Bis(2-chloroethyl) ether	Hexachlorocyclopentadiene
Bis(2-chloroisopropyl) ether	Hexachloroethane
Bis(2-ethylhexyl) phthalate	Indeno[1,2,3-*cd*] pyrene
4-Bromophenyl phenyl ether	Isophorone
Butyl benzyl phthalate	Naphthalene
2-Chloronaphthalene	Nitrobenzene
4-Chlorophenyl phenyl ether	*N*-Nitrosodimethylamine
Chrysene	*N*-Nitrosodiphenylamine
Dibenzo[*a,h*]anthracene	*N*-Nitrosodi-n-propylamine
Di-n-butyl phthalate	Phenanthrene
1,2-Dichlorobenzene	Pyrene
1,3-Dichlorobenzene	2,3,7,8-Tetrachlorodibenzo-*p*-dioxin
1,4-Dichlorobenzene	1,2,4-Trichlorobenzene
3,3'-Dichlorobenzidine	

ACID EXTRACTABLES

p-Chloro-*m*-cresol	2-Nitrophenol
2-Chlorophenol	4-Nitrophenol
2,4-Dichlorophenol	Pentachlorophenol
2,4-Dimethylphenol	Phenol
4,6-Dinitro-*o*-cresol	2,4,6-Trichlorophenol
2-4-Dinitrophenol	Total phenols

VOLATILES

Acrolein	1,2-Dichloroethane
Acrylonitrile	1,1-Dichloroethylene
Benzene	*trans*-1,2-Dichloroethylene
Bis(chloromethyl) ether	1,2-Dichloropropane
Bromodichloromethane	*cis*-1,3-Dichloropropene
Bromoform	*trans*-1,3-Dichloropropene
Bromomethane	Ethylbenzene
Carbon tetrachloride	Methylene chloride
Chlorobenzene	1,1,2,2-Tetrachloroethane
Chloroethane	1,1,2,2-Tetrachloroethene
2-Chloroethyl vinyl ether	Toluene
Chloroform	1,1,1-Trichloroethane
Chloromethane	1,1,2-Trichloroethane
Dibromochloromethane	Trichloroethylene
Dichlorodifluoromethane	Trichlorofluoromethane
1,1-Dichloroethane	Vinyl chloride

PESTICIDES

Aldrin	Dieldrin	PCB-1016[a]
α-BHC	α-Endosulfan	PCB-1221[a]
β-BHC	β-Endosulfan	PCB-1232[a]
γ-BHC	Endosulfan sulfate	PCB-1242[a]
δ-BHC	Endrin	PCB-1248[a]
Chlordane	Endrin aldehyde	PCB-1254[a]
4,4'-DDD	Heptachlor	PCB-1260[a]
4,4'-DDE	Heptachlor epoxide	Toxaphene
4,4'-DDT		

[a]*not pesticides*

INORGANICS

Antimony	Chromium	Nickel
Arsenic	Copper	Selenium
Asbestos	Cyanide	Silver
Beryllium	Lead	Thallium
Cadmium	Mercury	Zinc

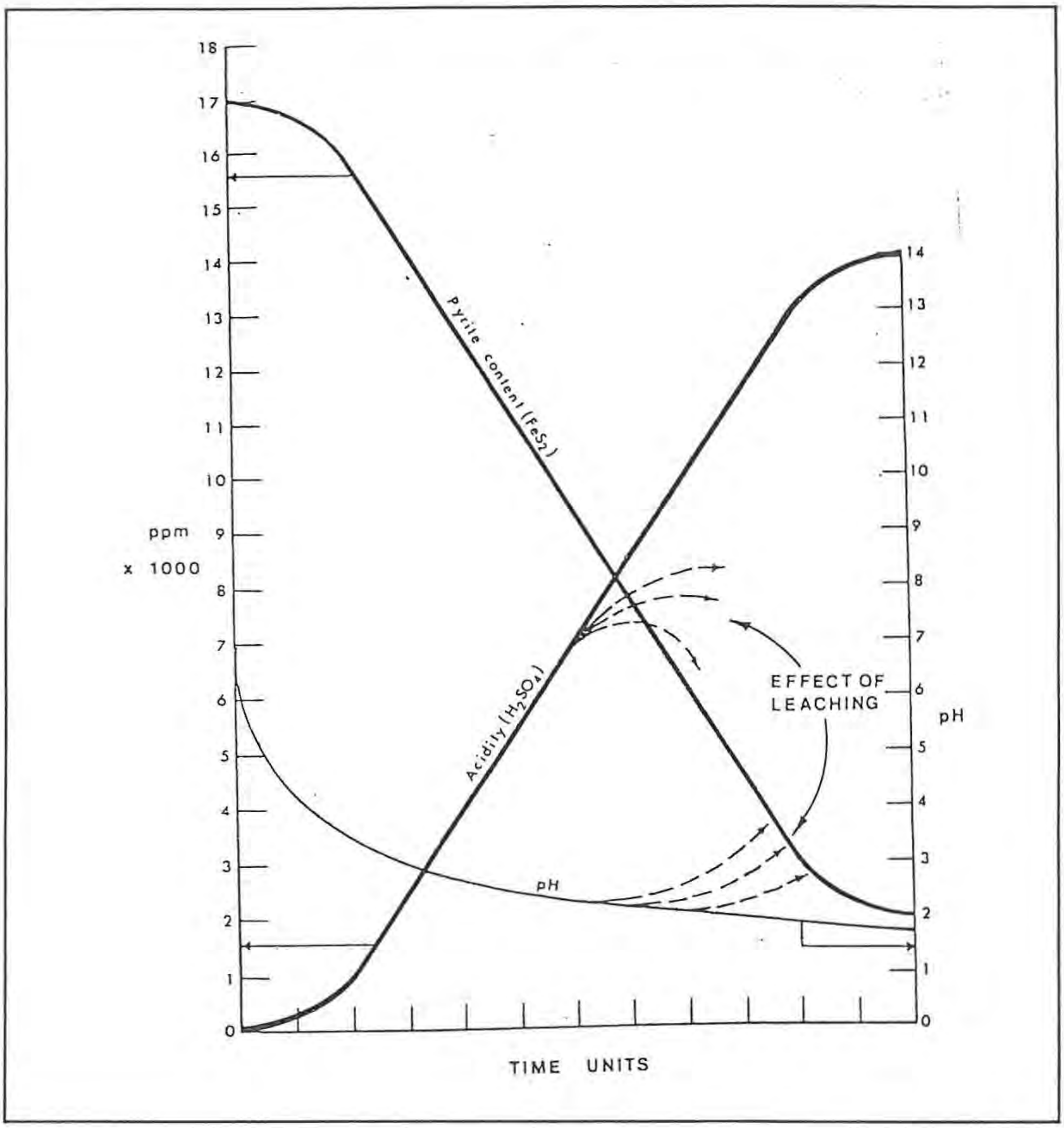


Figure 8. Relationship between pyrite, acidity and pH. Leaching reduces these acidity values raising the pH (From Thatcher, 1979).

2.1 Physical Pollution

Thatcher, (1979) calls land **derelict** when:

i) It has been damaged by extractive or other industrial processes which in its existing state:

   a) It is unsightly and incapable of reasonable beneficial use.

   b) It is likely to remain so unless subjected to special reclamation treatment.

He recorded the following five causes of dereliction:

i) Wasteland resulting from strip and surface mining, where the overburden has been removed.

ii) **Wasteland resulting from the accumulation of tailings, from micro-sized to coarse-sized materials, originating from mining.**

iii) Wasteland originating from the accumulation of industrial waste, such as domestic refuse dumps.

iv) Wasteland resulting from land clearance of slums or industrial sites.

v) Natural wastelands, such as portions of Iceland.

2.1.1 Ground surface area occupied

The following are some of the elements of physical pollution caused by mine dumps:

i) The mine dumps cover a piece of ground which would have been used for other traditional purposes. The would-have-been uses include access (such as roads), farming and house construction. The 1.67 bulk factor resulting from milling means that the volume occupied is 67% more than the original in-situ ore.

ii) The other forms of pollution emanating from the dumps do increase the unusable area far beyond that physically occupied by the mine dump itself. Such emanations include dust, smell and hazardous chemicals.

iii) The vertical height also blocks the original vision across the area and

iv) Mine dumps are often unsightly.

2.1.2 Dust pollution;

The two stages that release dust on the mine dumps are during the deposition of dry fine material on the dumps and during heavy winds if the dump surfaces are dry.

,2,i) Definition of dust

The fine particles constituting the sand and slimes dams lack binding or water retention properties. Consequently, they have a high potential for wind erosion, generating **dust** or **air pollution** (Thatcher, 1979). It is estimated that a sand dump is liable to lose 181 metric tonnes of dust per annum. Actually, prior to 1963, on windy days, visibility was so drastically reduced (to as low as 10 m) that there were frequent traffic and machinery disruptions, as well as dust in houses causing a high rate of ear, nose and throat infections. The best example was the Johannesburg area during the months of August and September. Evidence of the pollution was also manifested in the slow residential development in the most affected southern leeside of Johannesburg (Thatcher, 1979). Sittert, (1993a) has a comprehensive coverage of dust pollution. He defines dust as pulverised material in a settled or airborne state. In air pollution, dust is the particulate component in the atmosphere, undesired for man and the environment.

There are several classifications of particulate dust. Two of them are as follows:

a) Size classification:

- Lumps; These are particles with an aerodynamic diameter of more than 50 micrometers.
- Dust; These are particles with an aerodynamic diameter of between 50 and 2 micrometers.
- Fumes; These are particles with an aerodynamic diameter of less than 2 micrometers.

b) Medical classification;

- **Inspirable particulate matter** is the dust with an aerodynamic diameter of larger than 50 micrometers. This dust is harmless to the human body because it is larger than 25 micrometers.
- **Thoracic particulate matter** is the dust with an aerodynamic diameter of between 7 and 25 micrometers. A portion of this dust will remain in the nasal region and in the upper respiratory tract where it can cause medical problems such as **sinusitis** and respirable malfunctioning.
- **Respirable particulate matter** is the finest form of particulate mater between 0 and 7 micrometers. This can penetrate past the terminal bronchioles and into the alveoli, where it can cause severe damage such as **pneumoconioses** and obstructive airway diseases (this is the same range of particulate matter which forms the largest portions of tobacco smoke).

ii) <u>Diseases and other problems caused by dust</u>

The impact on health of the inhaled particulate matter depends on the physical, chemical, and toxicological properties (Hamilton, 1975, Sittert, 1993b and Klein, 1993). Goddard *et al.*, (1975) and Guthrie *et al.*, 1993 summarised the following as some of the diseases which can be caused by prolonged and/or excessive inhalation:

a) **Pneumoconiosis**, due to the inhalation of harmful dust, such as silica; **asbestosis**, caused by asbestos fibres; **talcosis**, caused by talc and **pneumoconiosis**, caused by coal dust.
b) **Pneumonitis**, caused by metallic dust and fumes.
c) **Silicosis**, is pulmonary fibrosis, caused by dust containing free crystalline silica.
d) It is also an acceptable fact that the inhalation of high concentrations of silica will increase susceptibility to **tuberculosis**.
e) The inhalation of total dust will also affect the nasal and respiratory system causing **sinusitis** and **obstructive** airway diseases.

Surveys on some of the mines in South Africa, such as the Witwatersrand, indicate that only a very small proportion of the airborne dust from mine dumps can be classified as respirable (Thatcher, 1979). This, however, means prolonged exposure can be dangerous. Miners in clay mines on the island of Milos in Greece have a shortened life expectancy, where the oldest are in the early fifties. This is because of the prolonged exposure to airborne dust from dry waste dumps as well as the clay product itself which generates some of the diseases above (Harben *et al.*, 1984, Guthrie *et al*, 1993 and Tsikos, 1993).

Mine dumps containing fibrous minerals require special care to reduce chances of airborne respirable dust as the resultant cancer disease is generally incurable and fatal.

It is worthy noting that although dust greater than 25 micrometer diameter is of little harm to human beings, it is disastrous to equipment. For example:

a) When mixed with grease, quartzitic dust creates a very effective grinding paste.
b) The very fine dust ruins electronic equipment, such as computer

keyboards, by either forming an insulating layer or producing static electricity (Sittert, 1993a).

Vandalism and the use of old dams as motorcycle racetracks and for horse riding have resulted in extended erosion of some of the dams (Funke, 1990), as well as dust generation affecting both the participants, spectators and their equipment.

2.2 Chemical Pollution

The unwanted chemical elements and/or compounds in fluid form are here called chemical pollution. Of these, acid pollution from mine dumps and ore processing (acid leaching/ bioleaching) are the most common. Other chemical pollution forms include toxic and radioactive minerals.

Loos *et al.*, (1990), reported that in the United States of America, in 1972, the US Department of the Interior estimated that 16,000 km of streams and 11,700 ha of impoundment and reservoirs were seriously affected by surface mining operations. It is estimated that $3.6 * 10^9$ kg of acidity per year ($1 * 10^7$ kg/day) were released from these operations. Abandoned mines alone produced about $2.3 * 10^6$ kg/day.

Funke, (1990) has established that leaching and pollution from inactive sand dumps in the form of contaminated seepage still continues until the pollutants are finished or the transport media is absent. Examples include the old gold mine dumps in the Witwatersrand area.

Vandalism and the use of old dams as motorcycle racetracks and for horse riding have resulted in slimes agitation and cutting into the dams. The consequence is aeration of deeper levels of the dams, with the result of more acid generation. The acid and radioactivity, if present will affect the people, horses and motorcycles. The serious nature of these effects requires proper public education and action.

The following is a summary of some of the common chemical pollution forms:

2.2.1 Acid mine dump drainage

The mine dumps that contain sulphide minerals mainly pyrite (FeS_2), will produce sulphuric acid when exposed to natural weathering lowering the water pH (Fig 8). The recommended sulphate concentration in water, by the South Africa Bureau of Standards, is 250 ppm and a maximum allowable limit of 400 ppm (Thatcher, 1979). Accepted amounts of the various elements and compounds in effluent or waste water is set in the General and Special Effluent Standards by the Department of Water Affairs and Forestry (Appendix III).

Examples of the acid effluent problem areas are the Witwatersrand, Klerksdorp, Orange Free State gold mines and others in Appendices V to VIII. The gold ores here have pyrite content varying between 0.6 and 1.6%. While the slimes released from the gold reduction works are alkaline, the drain water from freshly deposited tailings is highly acidic. Within the first one month, pyrite in the top 0.1m is virtually completely oxidised, producing iron compounds and sulphuric acid. This oxidation deepens to 1 m in 2 to 3 years. On average, the oxidation goes as deep as 2 m in old inactive tailings. As low as 1.5 pH has been encountered at 0.3 m depth (Fig 9). In extreme cases, mainly in the old sand dumps (1930-1950) with very high permeability, oxidation of pyrite has been observed to reach depths of about 10 m and more, resulting in leaching of between 22% and 24% sulphur in the form of acid and ferric sulphate (Sittert, 1993a and Funke, 1990).

The slow depth penetration of oxidation is probably due to the lack of oxygen in the dump because of high water content (20%). This water flows mainly horizontally and along the phreatic line, where it is collected at the toe channel as return (Fig. 5). Downward movement of seepage water, with the potential of polluting ground water, is therefore supposed to be low. However, with the complication of evaporation, rain water and resident water, there is a still a component of vertical seepage observable in the dumps (Fig. 5). This makes ground water pollution still eminent. Work done on some inactive 1950 to 1968 dumps by the Rand Mines and ERGO to assess the values of gold, uranium oxides and sulphur (acid) revealed notable sulphide leaching in the outer 4.3 m of the slimes dams (Funke, 1990).

Acid water dissolves toxic heavy minerals hence both get released, thus constituting

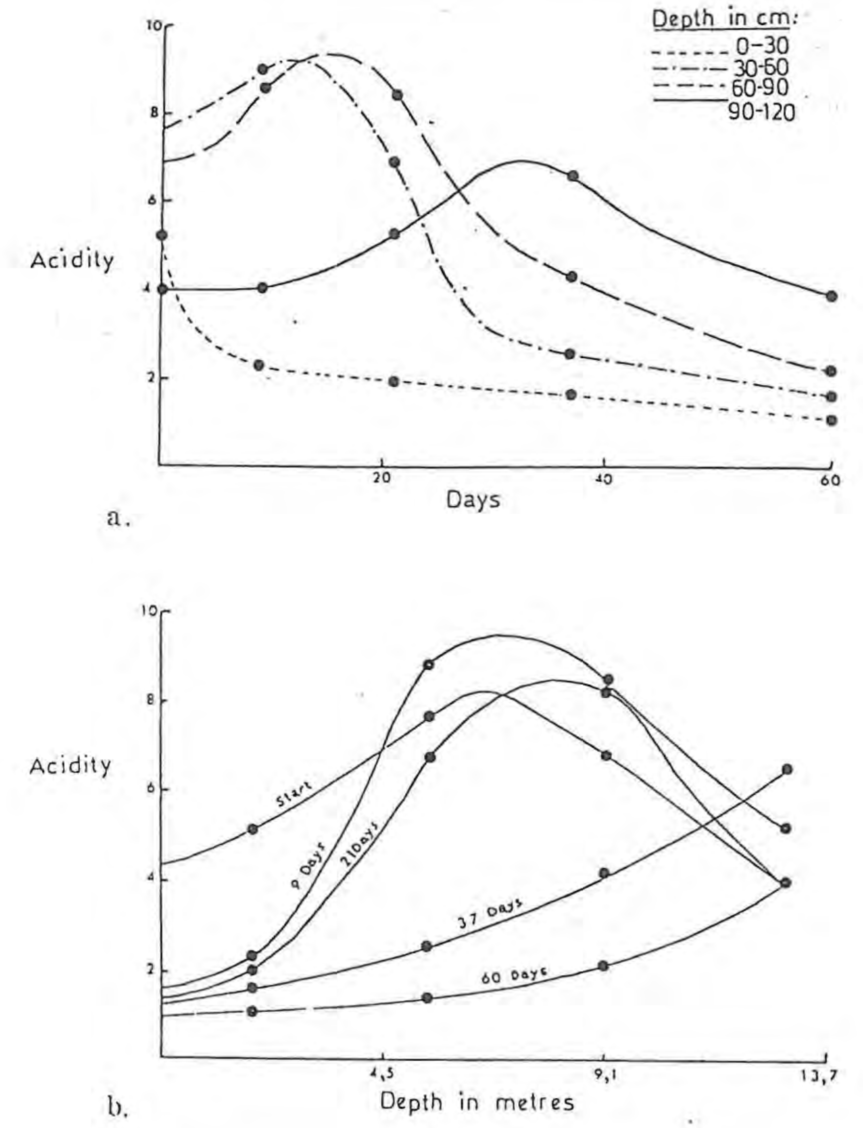


Figure 9. Slimes dam leaching: a) Changing in acidity at various depths (cm) with time. b) Change in acidity profile with time (From Thatcher, 1979).

mine dump acid drainage (Fig. 5). If well contained, this drainage can be treated in ponds. Unfortunately, in practice, a lot of the mines release their mine dump acid drainage into local streams. These contaminants therefore gradually build up in the local drainage system, causing serious environmental pollution. A composite pollution of the acid, heavy metals, base metals and remnants of the chemicals used in the ore bonification stage (Fig. 2) is accountable for the death of a lot of plants in the neighbourhood of slimes dams. This is reported to be common in the Zairian copper mining areas (Master, 1993). Seepage losses under the dumps result in ground water pollution. Below is a summary of how acid pollution is produced:

i) Acid generation: Chemical and biological:

Bacteria (Appendix IV) **sulphide mineral oxidation** is the principal cause of **sulphuric acid** generation in base metal tailings, coal spoils and quarry effluents. Requirements for **sulphide mineral oxidation** are the same as for any other type of oxidation; **oxidizable substrate** (mineral), **oxidant** (oxygen) and **promoter** (enzyme system of micro-organism) (Silver, 1989 and Loos *et al.*, 1990).

The following is a summary of the processes involved in the acid production:

Autotrophs such as *Thiobacillus ferrooxidans, Leptospirillum ferrooxidans, Sulfolobus brierleyii*, and the *thermophilic thiobacilli* are commonly associated with biologically oxidised iron from pyrite during acid generation. Other autotrophs such as *Thiobacillus thiooxidans* and certain heterotrophic bacteria may also be implicated (Silver, 1989 and Loos *et al.*, 1990). Non-bacteria associated acid production in the mine dumps is thought to be slow and therefore constitutes a small fraction. This involves the break-down of sulphide (pyrite) by hydration and other direct chemical reactions. The following discussion will concentrate on the dominant bacteria-associated acid production:

The **bacteria oxidises sulphur** minerals either **directly** or **indirectly**. In the direct mechanism, either or both of the Fe and S moieties are oxidised, forming metal sulphates:

$$MS + O_2 \text{ ----> } MSO_4$$

In such reactions, some of the minerals go into solution while some precipitate depending on their solubility constants. In the equation below, ferric iron acts as the oxidant, forming metal sulphate, ferrous sulphate, and elemental sulphur:

$$MS + Fe_2(SO_4)_3 \text{ ----> } MSO_4 + 2FeSO_4 + S^0$$

Bacteria can then reoxidise the ferrous iron to ferric iron:

$$4FeSO_4 + O_2 + 2H_2SO_4 \text{ ----> } 2Fe_2(SO_4)_3 + 2H_2O$$

and the elemental sulphur to sulphuric acid:

$$2S^0 + 3O_2 + 2H_2O \text{ ----> } 2H_2SO_4$$

The **indirect mechanism** is not limited to metal sulphides. Arsenides, carbonates, oxides and silicates may also be leached. Thus, metals that do not occur as sulphides including Al, Cr, Mn, U, and alkaline earths may also be solubilised (Silver, 1988 and Loos *et al.*, 1990).

Pyrite, and its polymorph; marcasite have been extensively studied. They are oxidised as follows:

$$4FeS_2 + 4H_2O + 14O_2 \text{ ----> } 4FeSO_4 + 4H_2SO_4$$

$$4FeSO_4 + O_2 + 2H_2SO_4 \text{ ----> } 2Fe_2(SO_4)_3 + 2H_2O$$

$$4FeS_2 + 15O_2 + 2H_2O \text{ ----> } 2Fe_2(SO_4)_3 + 2H_2SO_4$$

Note that the pyrite is first oxidised directly with the formation of ferrous sulphate. The ferric iron formed can then oxidise the mineral: $2FeS_2 + 2Fe_2(SO_4)_3 \text{ ----> } 6FeSO_4 + 4S^0$

The ferric iron can then be oxidised biologically to ferric iron, and the elemental sulphur to sulphuric acid (Silver, 1988 and Loos *et al.*, 1990).

ii) <u>Other reactions associated with acid production</u>

Oxidation of **non-sulphide** minerals is mainly by **indirect oxidation**. For example, uranium minerals such as uraninite (pitchblende) and brannerite, with indirect oxidation by ferric iron: $UO_2 + Fe_2(SO_4)_3 \text{ ----> } UO_2SO_4 + 2FeSO_4$

$$UTiO_2 + Fe_2(SO_4)_3 \text{ ----> } UO_2SO_4 + TiO + 2FeSO_4$$

For carbonate minerals such as siderite, oxidising by iron oxidising bacteria is:

$$4FeCO_3 + O_2 + 6H_2O \text{ ----> } 4Fe(OH)_3 + 4CO_2$$

For smithsonite, by sulphur-oxidising bacteria:

$$2ZnCO_3 + 3O_2 + 2H_2O + 2S^0 \text{ ----> } 2ZnSO_4 + 2H_2CO_3$$

In the weathering process in which aluminium is released, both autotrophic and heterotrophic bacteria have been implicated. For break-down of silicate minerals such as glauconite, illite, and microcline, *T. ferrooxidans* is involved. Silicates and other minerals are transformed by fungi, probably by acting as a sink for K. Al from silicate and oxide minerals can be solubilised by chelating compounds (excretion products of microbial metabolism; organic acids) and humic and fluvic acids (products of plant tissue degradation).

Mn, which forms 0.1% of the earth's mass can reach concentrations of 10%. It occurs as a divalent (highly soluble) and tetravalent (highly insoluble) species in oxide minerals. Its reduction is stimulated by acidity and reducing conditions (in the presence of heterotrophic bacteria metabolism, plant root exudates, autotrophic S, thiosulphate, and sulphide mineral oxidation) (Silver, 1989).

iii) Anaerobic acid generation

The above reactions are **aerobic**. But there is also evidence that under appropriate conditions, sulphuric acid can be formed **anaerobically**. Sulphur oxides are reduced to sulphide with intermediate formation of sulphite by sulphate-reduction, with or without other bacteria. The sulphite and thiosulphate formed by the condensation of sulphite and elemental sulphur, may migrate to regions in which free oxygen is available. This oxygen causes *thiobacilli* to oxidise these compounds to sulphuric acid. The facultative anaerobic *Thiobacillus denitrificans* can also oxidise sulphur compounds and, perhaps, elemental sulphur to sulphuric acid.

The formation of sulphuric acid by the anaerobic oxidation of elemental sulphur in which ferric iron acts as the oxidant in two steps is as follows:

$$S^0 + 4FeCl_3 + 3H_2O \text{ ---> } H_2SO_3 + 4FeCl_2 + 4HCl$$

$$H_2SO_3 + 2FeCl_3 + H_2O \text{ ---> } H_2SO_4 + 2FeCl_2 + 2HCl$$

$$S^0 + 6FeCl_3 + 4H_2O \text{ ---> } H_2SO_4 + 2FeCl_2 + 6HCl$$

This mechanism occurs in the *thiobacilli*, including the iron- oxidising bacteria, and the lobate thermophile *Sulfolobus acidocaldorius* (Appendix III). Laboratory leaching tests suggest that this mechanism occurs in oxidised sulphide tailings (Silver, 1989 and Canby *et al.*, 1993).

Most of these reactions produce brownish weathering colour on the mine dumps due to abiological hydrolysis of ferric sulphate which produces jarosites. It is associated with biological iron oxidation, and forms part of the ochre deposits (yellow boy), coatings, crusts and infillings. The reaction is:

$3Fe_2(SO_4)_3 + 2AOH + 10H_2O \dashrightarrow 2A[Fe(SO_4)_2.2Fe(OH)_3] + 5H_2SO_4$

Where "A" is (in the order of decreasing stability) K^+, Na^+, NH_4^+ and H^+. Jarosites exist between pH 1.8 and 2. Their formation removes ferric and monovalent cations from the solution and increases free sulphate concentrations. This causes pH values to decrease.

2.2.2 Toxic and harmful heavy metals and minerals

Most of the heavy metals that often constitute mineral pollution belong to the trace metals group in the periodic table. They can be toxic to humans even at relatively low concentrations because of their tendency to accumulate in the body. Their bioaccumulation in organisms lower in the food chain results in severe health problems in the human being at the top of the food chain (Domenico *et al.*, 1990).

Insidious seepage of acid mine dump drainage carries a lot of dissolved heavy metals which, if not contained and treated, eventually reach toxic levels (Funke, 1990, Thatcher, 1979 and Open University, 1974). Heavy metals are classified as being those with density greater than 5 (Down, 1975). These metals include arsenic, lead, mercury, cadmium, chromium, manganese, iron, cobalt, nickel, copper and zinc (Morea *et al.*, 1990 and Machemer *et al.*, 1992). Fluoride and other nonmetals are pollutants mainly in the areas where they are mined. Such local highs do manifest that these are of point source origin, be it by human or natural activity.

Different heavy metals have different levels that qualify them as toxic in different living beings. Although toxicity is not very well understood, metals are known to affect metabolic sites such as in plant cells, where they disrupt respiration and synthetic processes. Sterility may result, and a particularly unfortunate effect (from the point of view of revegetation) is that root growth may be inhibited, resulting in death or stunted plant growth. The presence of several toxic metals in a dump, which is quite common, has an even greater effect (Down, 1975).

The following are some of the common heavy metals whose pollution from mine dumps can be toxic:

i) Lead Pollution

It is known that mining activities are often the cause of fresh water lead pollution. At not much higher than the natural unpolluted levels, fish and other aquatic fauna begin to suffer. Lead pollution is worsened by the fact that geologically, lead occurs together with other heavy metals such as zinc, copper and cadmium (McGarry *et al.*, 1975).

The modern man is daily exposed to large quantities of lead from both natural and artificial origins such as food, tobacco smoke and urban air (from car fuel's anti-knock tetraethyl lead). This lead can be ingested by human beings. Not all of it is absorbed into the human system (most is excreted). 40% of the lead reaching the body is absorbed via the lungs. Very little lead is known to enter the body by direct consumption in water or food. The effects of lead poisoning are abdominal cramps, headaches, constipation, lose of appetite, fatigue, anaemia, motor nerve paralysis and encephalopathy.

The World Heath Organisation Standard for drinking water is 100 micrograms/litre of lead McGarry *et al.*, 1975).

ii) Zinc Pollution

At high concentrations, zinc is toxic to aquatic life but less so to human beings. Zinc from lead mines is known to have been the cause of fish kills in rivers of west Wales in the past (McGarry *et al.*, 1975).

iii) Cadmium Pollution

Less is known about cadmium poisoning with respect to the other heavy metals. However, it is established that its attack is more striking on humans than plants. Pollution concentrations are limited to the areas affected by water- and air-borne pollutants, such as around lead and zinc mine dumps (McGarry *et al.*, 1975).

The rare heavy consumption of cadmium causes a disease called "Itai-Itai" in Japan. In this disease, the cadmium replaces calcium in the bones. This leads to deterioration and eventual fracturing of the bones accompanied by intense pain, largely in post-menopause women (McGarry *et al.*, 1975).

The disease was first discovered in Japan in 1935. In 1967, more than 100 human deaths occurred upon food ingestion containing an average of 600 micrograms/head/day in the area of Kamioka Zinc Mine. Some scientists think this concentration is not high enough to be toxic (McGarry *et al.*, 1975).

In a typical Japanese diet, the daily average cadmium content is 60 micrograms, of which 23 micrograms is rice-derived. Rice plant has the ability of taking up cadmium from the soil. These cadmium anomalies are traceable from the 1945 and 1956 washing away of sludges from the mine dumps, which were deposited in the low lying stream areas where the rice is grown (Japan's national average value cadmium content in rice plants is 0,07 micrograms/l, while in the polluted area, it is 1.0 micrograms/l (McGarry *et al.*, 1975).

This concentration of cadmium by plants is also observable for other metals such as mercury (see below). This poses a problem in setting up **safe consumption levels** of such elements. Bell, (1975) discussed toxic levels of the common heavy metals; Cu, Pb, Cd, Zn and Ni (Fig 10).

iv) Mercury Pollution

Mercury is one of the longest used metal in man's history. It is a transition metal like zinc and cadmium. It often occurs in association with silver bearing ores and sulphides as it replaces other large diameter molecules in crystal lattice. It melts at -39^{0}C, boils at 357^{0}C and a specific gravity of 13,500 kg m^{-3} (Open University, 1974). This means mercury exists in liquid form at room temperatures and vaporizes easily by latent heat even at room temperature, mostly in hot countries. Its crustal abundance is 0.08 ppm, which is very low compared to most metals. It requires a concentration of about 2.5 * 10^4 (0.2%) to become minable (Open University, 1974).

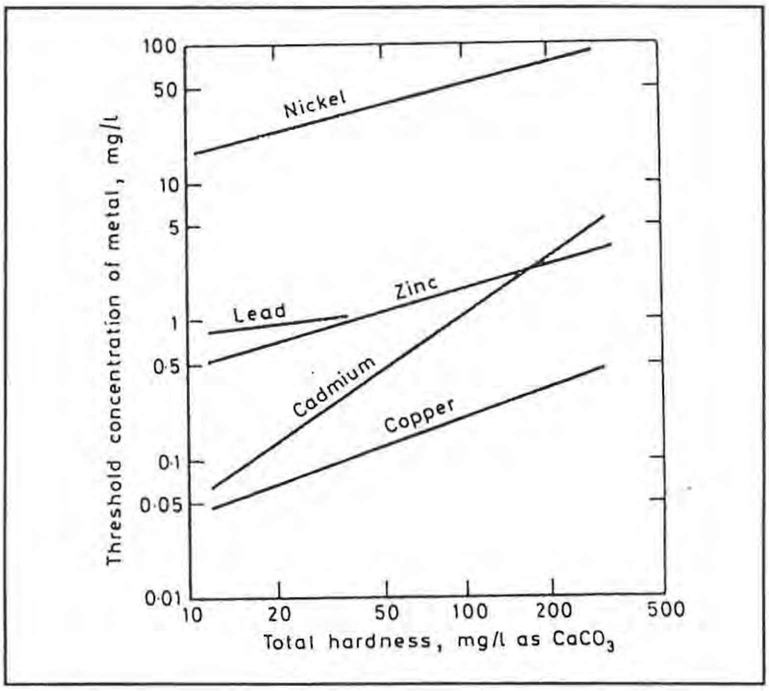


Figure 10. Relationship between total water hardness and threshold concentrations for rainbow trout of nickel, lead, cadmium and copper (Bell, 1975).

It has been observed that swallowing of mercury has a far less toxic effect than inhaling its vapour. Air in equilibrium with liquid mercury at room temperature will contain 14 mg m^{-3} of mercury. This means within a few minutes of spilling mercury in a hot room temperature, every human being within the vicinity will be inhaling a very toxic vapour.

The toxicity of mercury has been known for a long time. In the early sea sailing days, leakage of mercury vapour from its leather containers killed rats and some members of the crew, leaving the rest mentally and physically debilitated (Open University, 1974).

Even the temporary derangement of Sir Isaac Newton at about 50 years old, is thought to be due to the inhalation of the vapour of the mercury which he was working with (Open University, 1974).

The mercury pollution associated with mine dumps is much worse than the above as it takes a different route which affects a lot of living beings. The remnant mercury in the mine dumps (from the mercury mines) together with inorganic mercury compounds (effluents from some chemical processes) and organo-mercury compounds used as fungicides (if present), form part of the leachate from dumps. The inorganic mercury compounds can be biologically converted into soluble organic compounds such as dimethyl mercury $[Hg(CH_3)_2]$, which can enter into food chain together with the organo-mercury and remnant mercury. In this food chain, the mercury forms strong covalent bonds with proteins resulting into slow release of the mercury if ingested. This is harmful, since it decreases cell membrane permeability, causing its desiccation (Open University, 1974).

The first recognition of this type of pollution occurred in Japan in the period 1953-60, when 111 people were poisoned after eating fish and shell-fish from Minimata Bay in Japan. This was due to the build up of mercury in the fish as they continuously ingested mercury bearing planktons and effluent discharged from a chemical plant. The persons developed symptoms of numbness of fingers and toes, blurring of vision , deafness, loss of coordination and at worst, emotional instability and progressive loss of muscular control (Open University, 1974).

v) <u>Arsenic Pollution</u>

Arsenic is a common pollutant in gold and base metal mine dumps where it is contained in the mineral arsenopyrite (Bell, 1975 and Funke, 1990).

It is interesting that modern research has demonstrated that gold mineralisation is electrochemically controlled, explaining the common association of arsenic with gold (Wit, 1992b). This is a well known fact which has been used for tracing gold mineralisation (Crocket *et al.*, 1986 and Boyle, 1986). The following summary of electrochemical gold mineralisation in the presence of arsenic is necessary. When pyrite is syngenetic and/or in contact with arsenopyrite, it acts as a p-type semiconductor (cathode; electron donor), while the arsenopyrite is an n-type semiconductor (anode; electron acceptor). This forms a self driving electrochemical cell in which gold is preferentially deposited on the p-type semiconductor (Fig 11). Similarly, in zoned pyrite containing As, Co and Ni, the As-rich zones form p-type semiconductor, while the Co and Ni rich zones form the n-type semiconductor. This zoning and intergrowths result into formation of p-n-p and n-p-n combinations, which are efficient in gold extraction even from the very weak hydrothermal gold solutions (Wits, 1992b).

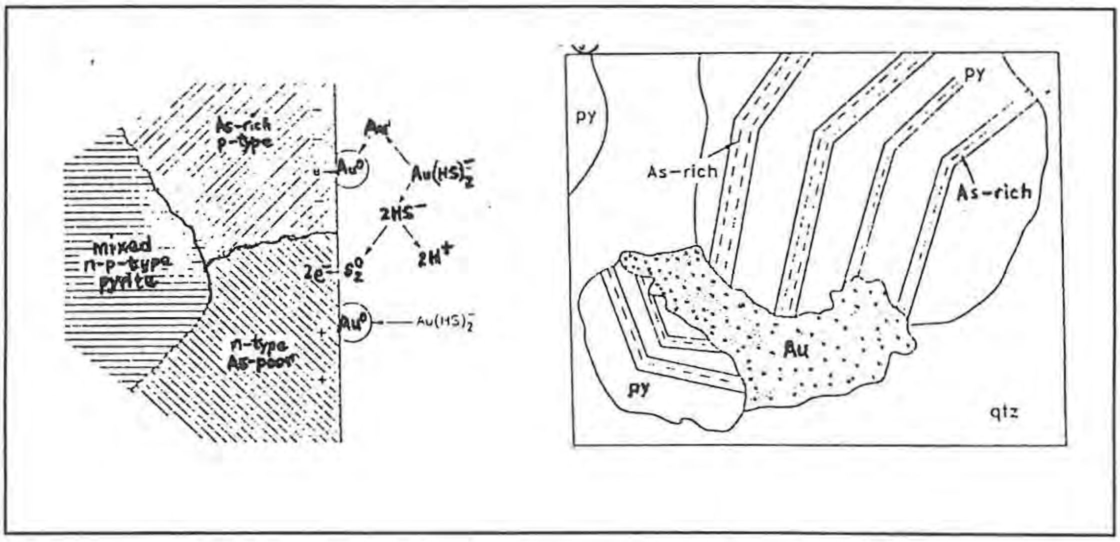


Figure 11. Association of pyrite and arsenopyrite in gold electrochemical mineralisation (Wits, 1992b).

Unfortunately, this intimate pyrite/arsenopyrite co-existence can be seen to bring four problems:

a) The fineness of the gold mineralisation requires that the ore be ground very fine, which increases the surface perimeter of the pyrite and arsenopyrite. This results into rapid chemical reaction on the mine dump, producing acid and heavy metal pollution.

b) The pyrite has so high the As values that it falls short of the requirement for sulphuric acid production as a raw material.

c) It is virtually impossible to separate the As- rich zones from the rest of the pyrite.

d) The above two problems result in dumping of all the zoned pyrite and pyrite-arsenopyrite intergrowths into mine dumps. The consequence is a complex pollution problem since as the sulphides decompose to sulphuric acid, the As, as well as most of the heavy metals present go into in the acid, worsening the acid pollution.

vi) Other inorganic Species;

In high concentrations, some of the non-trace metals such as Ca and Mg make water unfit for human consumption and industrial use. Most of these belong to the alkali group of metals which are the major contributors to overall salinity of water. Their resultant health-related problems are not as serious as those of the heavy metals. It is known that intake of high concentrations or excessively low concentrations of these metals results in adversities. An example is Na, which results in disruption of cell or blood chemistry, with serious consequences. Leachate from mine tailings is considered one of the biggest source of this pollution (Domenico *et al.*, 1990).

2.2.3 Chemicals released from ore processing

In the processing of minerals, various techniques are used, some of which involve the use of chemicals to separate the commodity from waste. Ideally, all the chemicals used are supposed to be recycled, and re-used. In practice, a good amount of the chemicals are not removed from the waste, hence they get released into the mine-dumps (Fig. 2). These are leached by water into the local drainage system, both surface and underground. Gradual accumulation occurs, generating chemical pollution (Bell, 1975 and Dennen, 1989). The following are some of the chemicals which cause pollution:

i) Cyanide and Mercury;

The purpose of cyanidation is to dissolve gold in the crushed ore (Fig. 12). This process succeeds amalgamation, where mercury performed the function of cyanide (Thatcher, 1979). Silver and minor amounts of other metals such as, copper, are also extracted by the cyanide. This technique was introduced after 1918. Gold bearing slimes are conditioned by about 0.15 kg/t of cyanide (NaCN), at 1.46 specific gravity (50% solids).

CaO (1 kg/t) may be added to ensure protective alkalinity. The contact between gold and cyanide is enhanced by air-agitation, resulting into the following reaction (Funke, 1990);

$$4AU + 8NaCN + O_2 + 2H_2O \text{ ----> } 4NaAu(CN)_2 + 4NaOH$$

Separation of the gold bearing cyanide solution from slimes is currently done by filtering (Fig. 12). At various stages, hydrochloric and sulphuric acids are added to remove magnesium and some of the nickel, silica and alkalis ($CaCO_3$) precipitates. To precipitate the gold from the cyanide, zinc dust and lead nitrate are added (before calcining at about 600°C). The precipitation reaction is:

$$Zn + 2NaAu(CN)_2 \text{ ----> } Na_2Zn(CN)_4 + 2Au$$

A cheaper and simpler modification utilises **carbon-in-pulp (CIP)** process. This process recovers gold from the cyanide leached pulp by adsorption onto a suitable granular activated carbon. One of the techniques used to separate the loaded carbon from the slimes is DSM screen. It is then eluted from NaCN under pressure.

Resin-in-pulp (RIP) is a post-cyanidation alternative technique, just like the CIP. It uses strong and weak-base anion resins to extract gold cyanide from the conditioned pulp. It is easier to handle than CIP, but more expensive.

In the three techniques mentioned above, and even when applied to heap-leaching of residual gold in mine dumps (Fig. 13), cyanide is used. The day to day escape of little amounts of cyanide with the slimes builds up with time into a massive chemical pollution in the local drainage system (Funke, 1990 and Bell, 1975). Thatcher, (1979) and Dennen, (1989) argue that cyanide is not a danger as the concentration is usually very low (0.006% KCN, never higher than o.1%). They also reason that as the supernatant solution of the dam is exposed to both sunlight and the atmosphere, the cyanide rapidly decomposes reducing the level to below 0.001% in 24-36 hours.

ii) Acid Leaching

While cyanide is used for leaching gold, acids, such as sulphuric acid (with or without ferric chloride) and hydrochloric acid, are used for leaching some metals such as base metals (copper) and uranium (Dennen, 1989).

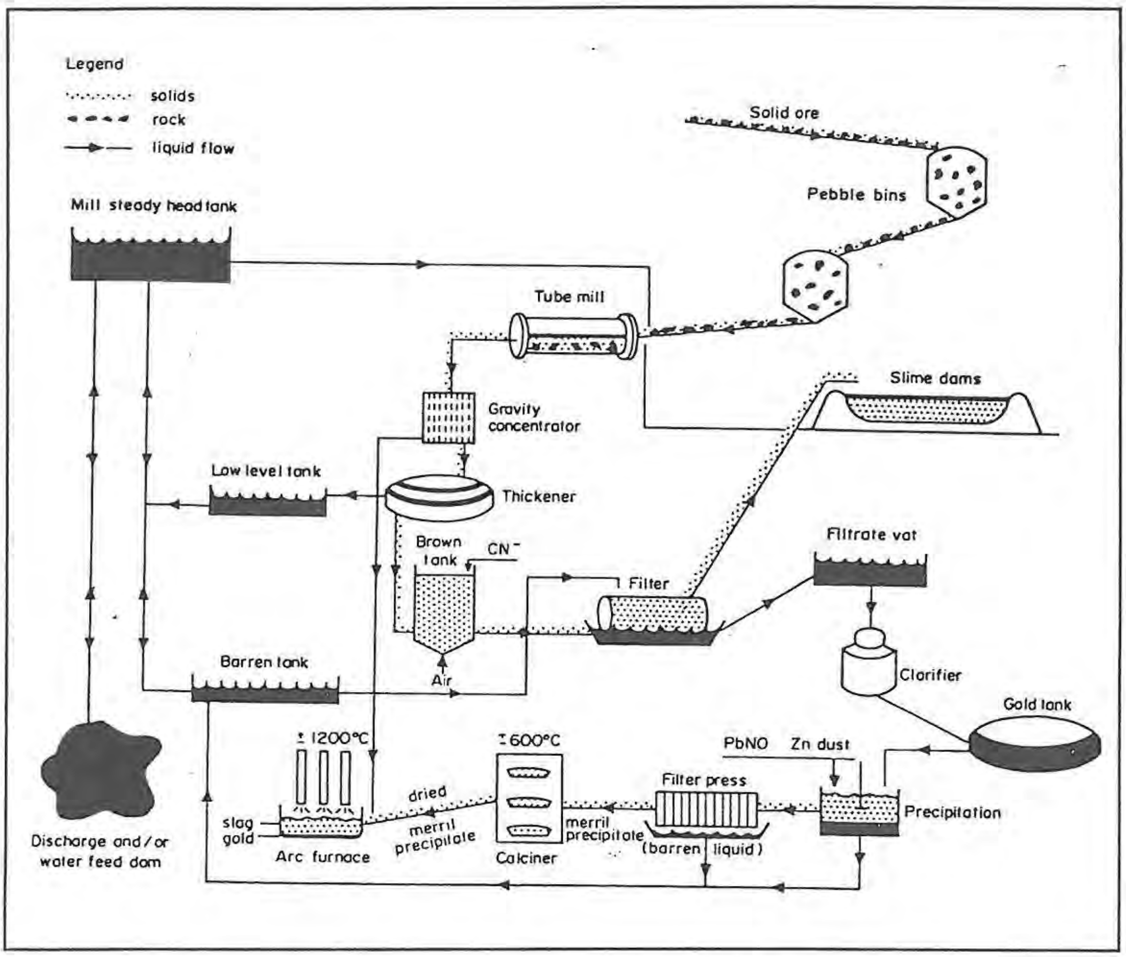


Figure 12. Flow sheet of a typical gold reduction plant (From Funke, 1990).

The chemical reaction involved for HCl is:

$CuSO_4$ + 2HCl ----> $CuCl_2$ + H_2SO_4

The copper is recovered by reacting the leachate with iron;

$CuCl_2$ + H_2SO_4 + Fe ----> Cu + $FeCl_2$ + H_2SO_4

It is not surprising to see some of the acid spilled off the dump area. Evidence of pollution in the working environment is the lack of plant life.

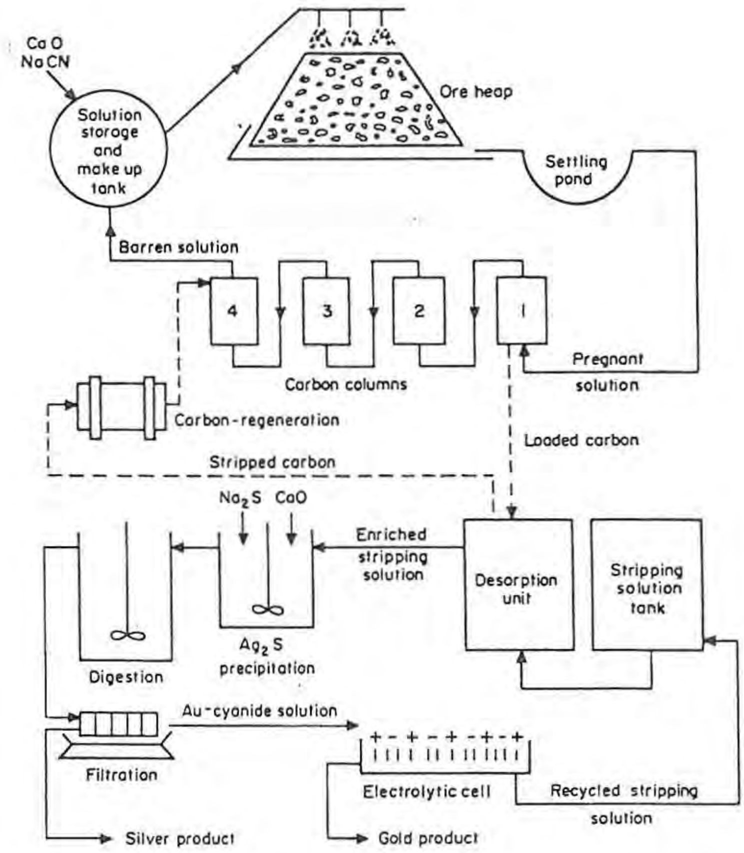


Figure 13. Heap-leaching extraction circuit of residual gold by cyanide and adsorption on to activated carbon (CIP) (From Funke, 1990).

2.2.4 Bacteria inhibitors

In an effort to reduce acid generation in mine dumps, various artificial chemicals have been tested. These include sodium lauryl sulphate (SLS) and sodium benzoate (Appendix VII). These are applied directly on the mine dumps, with the aim of discouraging the growth of the bacteria which is associated with the generation of sulphuric acid from the sulphide minerals in the dumps. Not all of the chemicals applied are reacted or decomposed. These get leached by water into local drainage system. The required repetitive application of the inhibitors adds small doses each time, resulting in cumulative chemical pollution.

2.2.5 Gaseous pollution

There are several gases which are evolved from mine dumps. These include SO_2, H_2S, CO_2 and the radio-active radon and thoron (radon-220). The SO_2 and the H_2S are produced as by-products of the break-down of pyrite in the formation of sulphuric acid. They are therefore common in the pyrite bearing gold, base metals and coal mine-dumps. The CO_2 is released from the internal combustion of some of the old coal dumps.

While the radioactive gases are hazardous for their radioactivity, the other three are active reactants. They produce sulphuric acid and carbonic acid, the later of which is the main constituent of acid rain. The acid rain and the un-reacted gases vigorously react with metals such as iron and copper (rusting). This reduces the life and efficiency of many machinery in industry, which are principally made from these two metals.

2.2.6 Odour pollution

The concept of odour pollution is similar to gaseous pollution. Some elements, compounds or a mixture of these in vapour form constitute smell when sensed by a living being's nose. An offensive smell is an **odour**. Cormack, (1975) states that apart from the concentration of molecular species in the air, odour also depends on fatigue, dilution, temperature and relative humidity. It is worthy noting that not all gases produce odour and not all odorous gases are toxic. Figure 14 contains some of the chemicals which produce odour when in gaseous state. Not all mine dumps generate odour pollution, but where it exists, it is a public nuisance.

2.2.7 Fluoride pollution

Fluoride is probably the best example of a trace nonmetal occurring as a contaminant. Like the metals, relatively low concentrations of fluoride can produce health problems. An increase in concentration to as little as 7 or 8 times the levels for combating tooth decay can cause **skeletal fluorosis** (Domenico *et al.*, 1990). Brown teeth may also result even in naturally occurring anomalies. Quality of drinking water and mine dump effluents in the fluorite mining areas must therefore be closely monitored (Appendix III).

2.2.8 Radioactive pollution

This is one of the three forms of energies associated with mine dump pollution; the others being electromagnetism and sound.

Chemical	*Odour thresholds, ppm*
Acetaldehyde	$2{\cdot}1 \times 10^{-1}$
Acetic acid	1·0
Acetone	100·0
Acrolein	$1{\cdot}0 \times 10^{-1}$
Amine, dimethyl	$2{\cdot}0 \times 10^{-2}$
Amine, trimethyl	$2{\cdot}0 \times 10^{-4}$
Ammonia	46·8
Aniline	1·0
Butyric acid	$1{\cdot}0 \times 10^{-3}$
Chlorine	$3{\cdot}0 \times 10^{-1}$
Dimethyl sulphide	$3{\cdot}0 \times 10^{-3}$
Ethyl mercaptan	$1{\cdot}0 \times 10^{-3}$
Hydrogen sulphide	$5{\cdot}0 \times 10^{-4}$
Methanol	100·0
Methyl ethyl ketone	10·0
Methyl isobutyl ketone	$4{\cdot}7 \times 10^{-1}$
Phenol	$4{\cdot}7 \times 10^{-2}$
Pyridine	$2{\cdot}1 \times 10^{-2}$
Vanillin	$3{\cdot}2 \times 10^{-8}$

Figure 14. Some of the chemicals which produce odour and their thresholds (From Cormack, 1975).

Elements that have imbalanced protons and neutrons in their atoms are unstable. They disintegrate spontaneously, changing into new daughter elements Table 3), emitting heat energy in the process. Different atoms of different elements emit different types of radiation (radioactive emission) which including alpha, beta, gamma or X-ray (Funke, 1990 and Rossing, 1993).

If controlled, these forms of energies can be used for various purposes such as heat generation to generate electricity and utilised in nuclear bombs as a catastrophic warfare weapon. On the other hand, the emitted energy is hazardous to living beings when exposed in high levels (Rossing, 1993 and Domenico *et al.*, 1990).

These radioactive mineral elements are sometimes in such high concentrations that they form the main commodity of an ore. In Australia, Canada and the USA, uranium ore is mined with grades between 2% and 4% (Funke, 1990). However, in some cases, they are an accessory ore forming mineral. In both cases, upon extraction of the commodity, there is a substantial proportion released into the dumps as waste.

Radioactivity is such a strong form of energy emission that it is harmful to the human body in prolonged exposure. This means that people staying near mine dumps with high radioactivity are gradually affected. This is more so dangerous than the other forms of energies because it can not be detected by any of the human natural senses.

Among the adverse effects on the human beings are the causing of cancer, crippled babies and sterility. Although some natural environments have notable radioactivity too, such as granites and some sediments, the mine dumps often have higher concentrations.

It is known that the effect of radiation depends on many factors (Rossing, 1993), including:

a) The type of radiation,
b) The amount received,
c) The rate at which it is received and
d) Which part of the body is exposed.

Radiation exposure can be divided into three categories (Rossing, 1993):

a) **High-level radiation**; This is fatal because it causes massive tissue damage that the body can not repair. Atomic weapon is one source. On the other hand, controlled high doses are used to destroy cancer cells as a therapy.
b) **Medium-level Radiation**; This may cause damage to reproductive cells or other body cells, but will not kill a person. Cancer, which will take a long time to appear, may develop.
c) **Low-level Radiation**; This has a very small risk of damaging reproductive cells and causing cancer. It forms the back-ground radiation similar to the radiation at low grade uranium mines. Actually, there is a certain amount of natural radiation

in the environment human beings live in.

Most of the uranium mines, such as the Rossing Mine are of low grade, hence belong to the Low-level Radiation category. After the processing of the ore, not all the uranium is extracted. This remnant goes with the slimes to form mine dump. Eventually, the uranium, which is easily soluble in acid mine dump drainage water will be leached from the dumps. This leachate will pollute both surface and underground water resources. Preliminary results of an ongoing research by Council for Nuclear Safety on discharges from the mining operations in the Witwatersrand are already showing the need for controls (Funke, 1990). Natural high radio-nuclide concentration are also present in underground water where reservoirs contain radioactive minerals.

In South Africa, there are no limits set for radioactivity levels within the general standards for the disposal of effluents into public streams nor in the SABS specification for drinking water (Funke, 1990). However, recent surveys indicate acceptable levels of radiation for the public consumption to be;

^{226}Ra: 0.19 Bq/l

Uranium: 44 ug/l

The most common source of radioactive mineral in SA is uranium. For example, the Witwatersrand ores contain varying amounts of uranium and thorium and the radioactive isotopes from their decay. The Far West reefs contain about 50g/t of U^{308}. In the East, it is about 200g/t while in the West, near Klerksdorp, it reaches 640g/t, and 600g/t at Beisa in the Orange Free State goldfield (Funke, 1990). Funke has also reported that recently acquired knowledge of radiotoxicity has shown that uranium, thorium and polonium nuclides are of higher toxicity than ^{226}radon. Tests of water-borne radioactivity (measured as ^{226}Ra), from old dry gold tailings deposits on the Central Rand apparently show that radioactivity does not pose a threat to surface waters accessible to the public (Funke, 1990). This is because ^{226}Ra is effectively retained, most probably by adsorption in the slimes. On the other hand, borehole-water in the mining areas, particularly in the vicinity of uranium tailings, is severely contaminated by sulphate (up to 1,400 mg/l), Mn (up to 300 mg/l) and Zn (up to 40 mg/l). Note that uncontaminated dolomitic aquifer water comprises a bicarbonate solution with calcium and magnesium as major cations, and is characteristically devoid of any sulphate (Funke, 1990).

While ^{226}Ra is readily adsorbed onto particulate materials, such as sand, clay or sewage sludge and is thus removed from clarified water, this is not the case with uranium which stays in solution. Uranium can, therefore, be transported with mine service water through the mine, but also with mining effluents on the surface. Even underground water has been polluted in some old uranium mines (pre-1960).

In Western Areas of the Witwatersrand, the Atomic Energy Corporation found that the dolomite water entering the mine was contaminated with radioactive uranium, and even as far as 15 km downstream in the Wesrietspruit. Increase of ^{210}Po has been observed in beef liver from cattle raised on irrigated land downstream one mine to a level double that of control samples (Funke, 1990).

Existing storage of 18.5 * 10^{14} Bq in the 65 km^2 of slimes dams and the 15 Km^2 of sand dumps on the Witwatersrand probably constitutes a health hazard. Tailings containing uranium will constantly emit gaseous radon (^{222}Rn), which decomposes into radioactive solid short-lived decay products; ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po and ^{210}Po (Table 3). It is claimed that inhalation of these radon decay products, attached to air-borne particles, is by far, the biggest contributor to total radiation exposure (90% and over).

The average annual exposure levels in various sections at Rossing Mine are shown in Table 5. A comparison of the various causes of death compared to those related to radiation exposure are shown in Table 4 (Rossing, 1993).

2.2.9 Noise pollution

Noise is a worldwide problem. Webb, (1975) has defined noise as the **unwanted sound** from which if people are not protected, they can eventually suffer hearing loss and other adversities including psychological effects (such as producing a feeling of fatigue). The International Standard noise limit for the industry is 85 decibels (a typical live rock concert produces noise levels of up to 120 dB) (Rossing, 1993).

The dumps themselves do not generate any noise. It is the trucks and machines when depositing the slimes that generate the mine dump related noise (Davies *et al.*, 1975).

Table III. Uranium decay series

Nuclide	Historical name (element)	Half life	Major radiation energies, (MeV) and intensities		
			Alpha	Beta	Gamma
^{238}U	Uranium I (Uranium)	4,51 x 10^9 years	4,15 (25%) 4,20 (75%)		
^{234}Th	Uranium X (Thorium)	24,1 days		0,103 (21%) 0,193 (79%)	0,063 (3,5%) 0,093 (4,0%)
^{234}Pa	Uranium X (Proactinium)	1,17 min		2,29 (98%)	0,765 (0,3%) 1,001 (0,6%)
^{234}U	Uranium II (Uranium)	2,47 x 10^6 years	4,72 (28%) 4,77 (72%)		0,053 (0,2%)
^{230}Th	Ionium (Thorium)	8,0 x 10^4 years	4,62 (24%) 4,68 (76%)		0,068 (0,6%) 0,142 (0,072%)
^{226}Ra	Radium	1 062 years	4,60 (6%) 4,78 (95%)		0,168 (4%)
^{222}Rn	Emanation (Radon)	3,82 days	5,49 (100%)		0,51 (0,07%)
^{218}Po	Radium A (Polonium)	3,05 min	6,00 (100%)		
^{214}Pb	Radium B (Lead)	26,8 min		0,65 (50%) 0,71 (40%)	0,295 (19%) 0,352 (36%)
^{214}Bi	Radium C (Bismuth)	19,7 min		1,0 (23%) 1,51 (40%)	0,609 (47%) 1,12 (17%)
^{214}Po	Radium C' (Polonium)	0,164 sec	7,69 (100%)		0,799 (0,014%)
^{210}Pb	Radium D (Lead)	21 years		0,016 (85%) 0,061 (15%)	0,047 (4%)
^{210}Bi	Radium E	5,01 days		1,161 (100%)	
^{210}Po	Radium F (Polonium)	138,4 days	5,305 (100%)		0,803 (0,0011%)
^{206}Pb	Radium G (Lead)	Stable			

2.2.10 Electromagnetism pollution

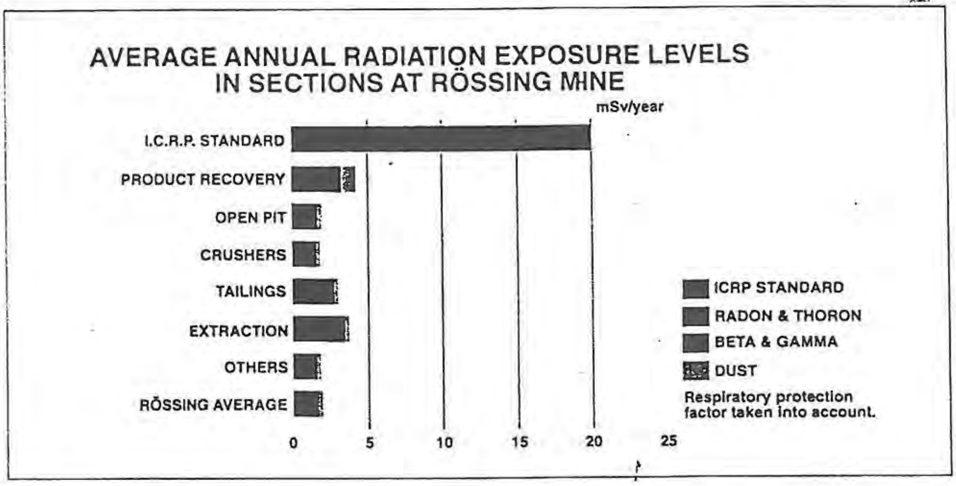
Mine dumps do not originate any pollution due to electromagnetism. However, it is the activities associated with them that produce most pollution. Of greatest annoyance to the public is the unprotected electric motors in the vehicles and machines used during the construction of the dumps known, which are known to cause interference to radio and TV signals in the neighbourhood (Davies *et al.*, 1975).

Table IV. Annual risk of death: Common causes and accidents in industry (From Rossing, 1993).

	Annual Death Risk
Smoking 20 cigarettes per day	1 in 200
Heart disease in general population	1 in 300
Deep sea fishing	1 in 400
Natural causes, 40 years old	1 in 500
Influenza	1 in 4 000
Coal mining	1 in 4 000
Road accidents	1 in 5 000
Metal manufacture	1 in 7 000
Accidents at home	1 in 10 000
Pregnancy	1 in 13 000
Rössing final product worker (4,1 mSv)	1 in 14 400
Accidents at work (all industry)	1 in 20 000
Cancer from working in nuclear industry	1 in 20 000
Anaesthesia	1 in 25 000
Rössing production worker (2,0 mSv)	1 in 30 000
Total Rössing employee (1.8 mSv)	1 in 33 400

Bright looking mine dumps such as those made from limestone, kaoline and quartz are a source of discomfort to many. This is due to the high proportion of reflected sunlight.

Table V. Average annual radiation exposure levels in sections at Rossing Mine (Rossing, 1993).



3.0 MODE OF POLLUTION TRANSPORT

Pollution would have been localised to the sources in the absence of transporting agents. Unfortunately, there are several transporting agents which spread the various forms of pollution to wider areas than the original sources. The pollution is dispersed either on the surface or underground in a typical point source pattern.

The following are some of the common pollution dispersion agents;

3.1 Water Pollution Transport

Water is the most effective media of transporting the largest amounts of the widest range of pollutants both on the surface and sub-surface. Work on mine dumps has shown that both rain water and water used for sliming, act as the main water transport of pollution in the mine dumps, despite an eventual high evaporation rate (Fig. 5). This polluted water will seep into the local surface and subsurface drainage systems, if not contained (Thatcher, 1979).

3.1.1 Surface pollution water transport

Surface water flow is relatively very fast because it is free flow, controlled basically by surface topographic features.
Water can transport pollution on the ground surface in three forms (Open University, 1974):

i) In solution, as dissolved chemical elements and compounds, constituting chemical pollution. This form of pollution can be transported over long distances, and can be precipitate from the water when favourable conditions prevail.
ii) In suspension, as fine solid particles. These particles can be transported over a shorter distance, before being deposited as hydraulically sorted sediments.
iii) **Colloids** are solutions of the fine particles in water between the above two. They remain in suspension due to, brownian motion and electrostatic charges on them, but settle by flocculation when their charge is destroyed. Colloids pollutants include $Fe(OH)_3$ and contaminated clay. These are transported by rivers for long distances until when saline environment is reached such as at the sea. The

salinity destroys the charges, causing precipitation by flocculation.

Part of the conclusion of Slingerland *et al.*, (1986) states that presently, it is known that heavy-mineral segregations in water-lain deposits occur on hierarchically different scales (from millimetres to kilometres). The many geomorphological sites where segregation occurs, act as natural dressing mills. They remain relatively fixed in space as a selective sorting circuit processing a pulp and storing the concentrate where it will not be diluted. The sorting circuits rely upon different responses of heavy and light grains to local fluid forces acting on a sediment bed. Sorting by density may occur during entrainment, transport, settling from suspension (Fig 15. & 16), or dispersion by grain-to-grain interactions. Natural heavy-mineral enrichment often involve a combination of these processes (Fig. 17). Pure settling behaviour, embodied in the classical idea of "hydraulic equivalence," probably does not play as important a role as is believed by some workers" (Slingerland *et al.*, 1986). Slingerland *et al.*, (1986) have therefore rightly stated that transport sorting results when one size or density fraction of a sediment mix is transported at a different rate from another and so may come to rest at a different location.

Mine dumps often contain almost a uniform size of particles (such as 0.5-0.1 mm diameter). This means when they are eroded by water (similarly wind), the mineral distribution will be more dependent on the mineral density than size. The more dense minerals (such as gold and pyrite) will settle faster than the lighter ones (such as quartz), resulting in:

i) Horizontal stratification with heavy mineral layers at the bottom, decreasing in density upwards, if the pulp is in a stationary fluid.

ii) Density controlled fractionated pods of minerals at different elevations above the bed, if the pulp is a suspended load of a turbulent flow.

iii) Small scale enrichments, which may cumulatively constitute a high concentration area, frequently associated with asymmetrical bed-forms; commonly, heavy-mineral segregations occur on the stoss sides, crest, and slip faces of active ripples, dunes and in foresets and trough surfaces of dune-formed cross-beds.

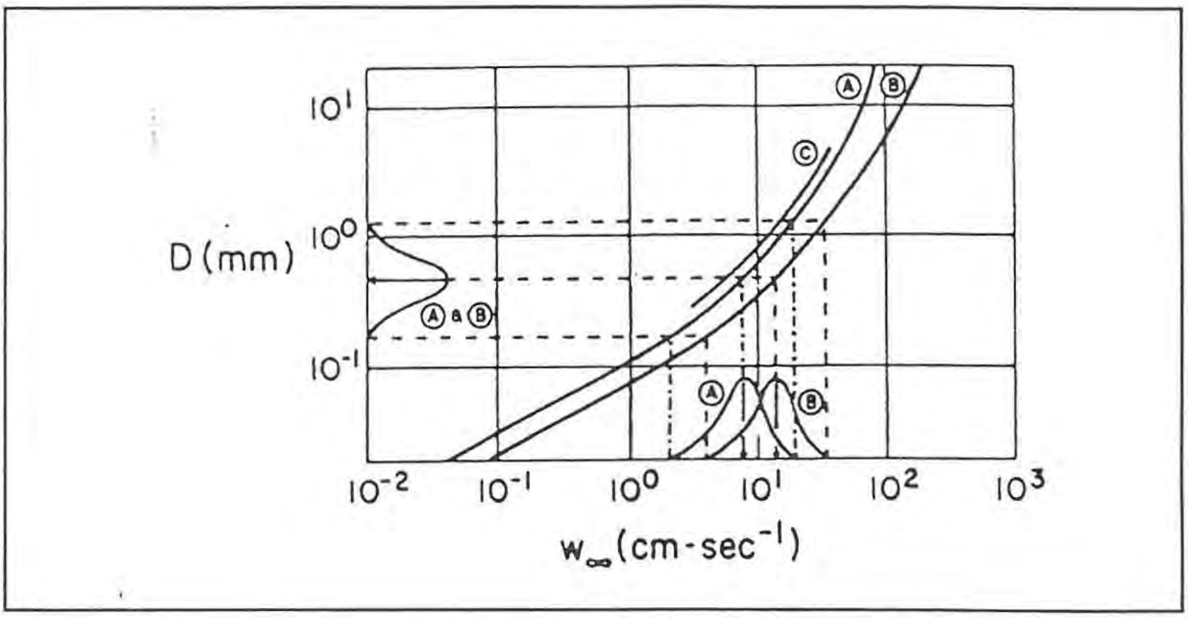


Figure 15. Unhindered terminal settling velocities of spheres in still water versus their diameter (D). Curve "A" is quartz (density; 2.65 g cm^{-3}), "B" is magnetite (5.10) and "C" is natural quartz (From Slingerland *et al.*, 1986).

iv) The lighter grains preferentially remain in suspension for relatively longer periods hence transported farther (distal) than the heavy grains which settle fast. They are affected by either entrainment transport or shear sorting (proximal).

In 1950, research carried out in South Africa by the Council for Scientific and Industrial

Research revealed that Witwatersrand streams were being significantly polluted by dissolved mineral salts from slimes dams. During the rain season, as much as 10 tons per hectare of dam per annum of matter was transported by water. ERTS-1 satellite images indicated in 1974 that the mine dump pollution from the Witwaterstand was going as far as the Northern Cape. The Vaal River's Vaal Barrage is an example of the worst water polluted area. It is said that even if the mine dumps were removed, the pollution in the rivers and soil would still go on for about 100 years (Thatcher, 1979).

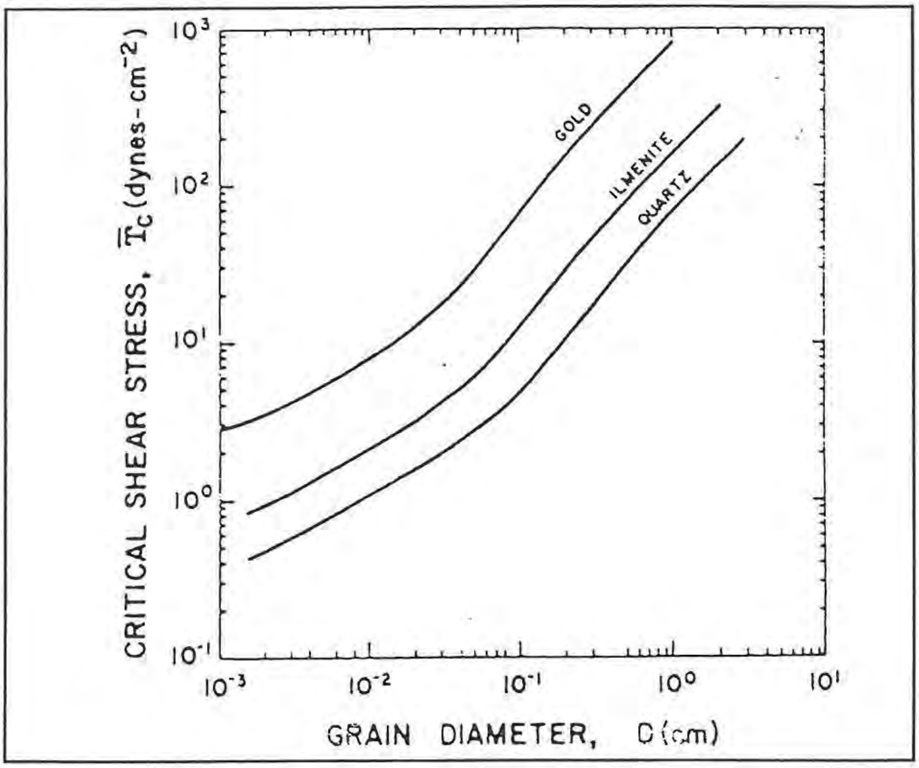


Figure 16. The effect of grain density on the critical boundary shear stress. Densities for quartz, ilmenite and gold are 2.65, 4.70 and 19.3 (g cm^{-3}) respectively (From Slingerland *et al.*, 1986).

These show that water transport results in both dispersion and concentration of the various minerals eroded from the mine dump. The heavy minerals being deposited near the dump, while the lighter ones, far away. In most of the mine dumps which generate acid and toxic mineral pollution, the dominant mineral is quartz, followed by pyrite. Therefore the pyrite (and other heavies) will be deposited proximally, while the quartz will be deposited distally. Therefore if the concentration of the pyrite and other heavies in the mine dump was, say, 1%, the new placer would even be well above 10% locally. The weathering of such concentrated layers will produce worse pollution than the parent mine dump. To date, it is apparent that all the efforts on pollution control are directed towards the reactions generating pollutants in the mine dumps, or other active sections of the mine, totally disregarding the secondary concentrations, which are potential "pollution time bombs".

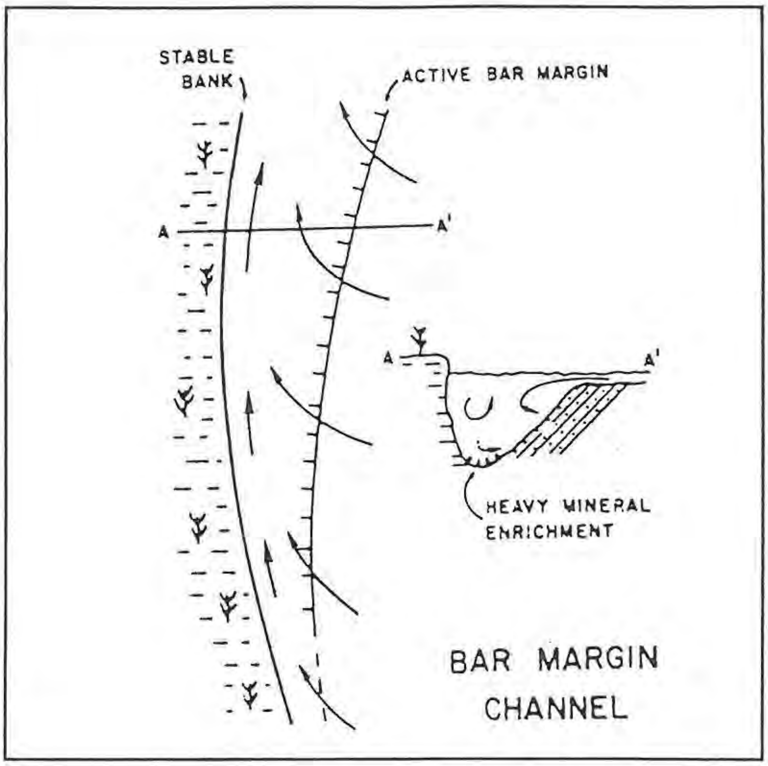


Figure 17. Generalized geometry and flow pattern formed by an active bar migrating towards a stable bank. Heavy minerals concentrate in the constricted channel ways (Slingerland *et al.*, 1986).

3.1.2 Ground water pollution transport

Ground water, on the other hand, is slow because it is controlled by several factors (Domenico *et al.*, 1990) including:

i) Hydraulic conductivity distribution within the flow field.

ii) Configuration of the water table or potentiometric surface.

iii) Presence of source or sinks such as well.

iv) Shape of the flow domain.

Domenico *et al.*, (1990) demonstrated the relationship between lateral and vertical flow components of ground waterborne pollution movement in a homogeneous strata. This is illustrated in a simplistic simulation , considering only dispersion and advection components of transport; the rest being constant (Fig 18). A more complex flow occurs in a fractured rock such as in karsted limestones (Fig 19).

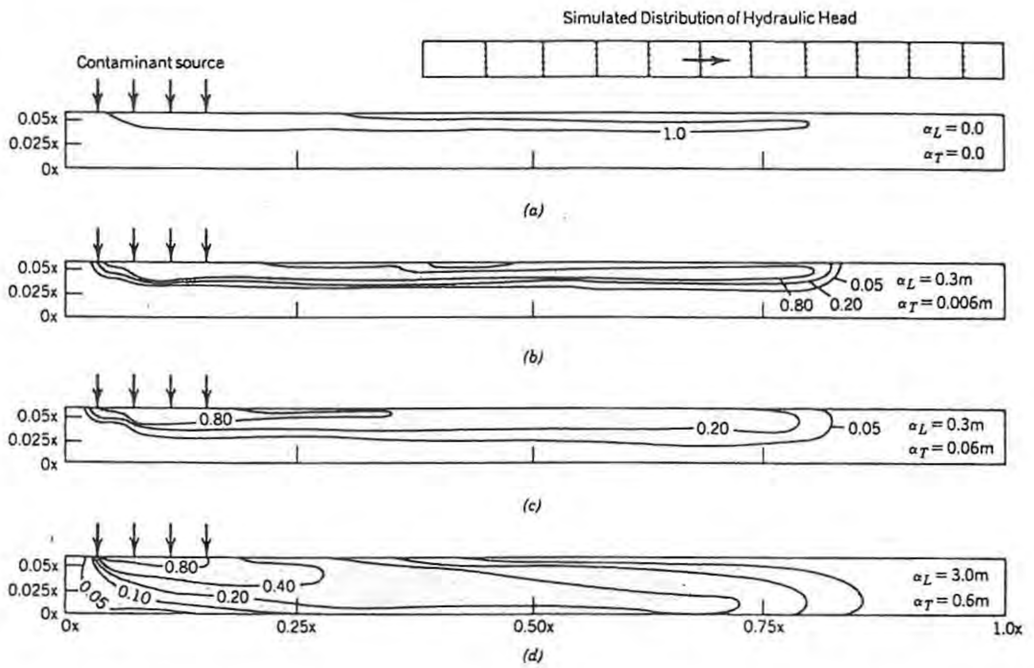


Figure 18. Changing plume shapes as a function of the longitudinal and transverse dispersivities in ground water flow (From Domenico *et al.*, 1990)

Assuming that changes to constant density fluid viscosity do not occur throughout its motion, its flow through porous formation interact with the latter in two essential ways (Domenico *et al.*, 1990). These two mechanisms of interaction are:

i) Through dispersion and

ii) Through geochemical reaction with the porous matrix.

The mechanism whereby miscible fluids (such as air-water combinations) displace one another within the pores of a porous medium is called **hydrodynamic dispersion**. In representing motion of ground water, the term signifies the transport of contaminants which are soluble in, and miscible with the flowing water through the simultaneous actions of mechanical and physico-chemical phenomena (Domenico *et al.*, 1990). Therefore dispersion:

i) Acts to reduce concentration gradients in all regions and hence to reduce the maxima in concentration values other than at locations where constant concentrations, such as the slimes dam pond.

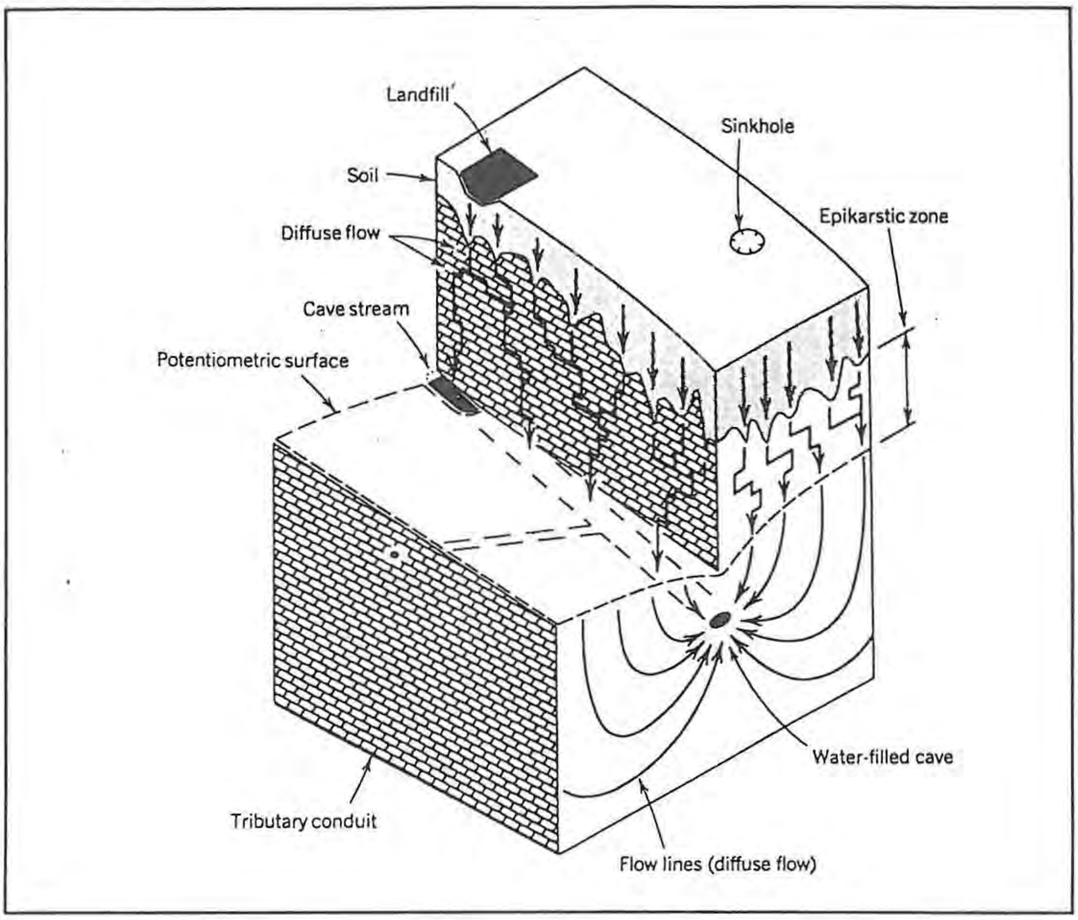


Figure 19. The complex pattern of flow and contaminant migration in a maturely karsted terrane (From Domenico *et al.*, 1990).

ii) Causes concentration plumes to spread both along and perpendicular to the direction of fluid motions. Therefore it may cause contaminants to be transported to previously uncontaminated areas, even if the motion in that direction is negligible.

iii) Has a constant which is proportional to fluid velocity.

Interactions of chemical species, in the mobile (fluid) phase, with the formation matrix are sometimes referred to as "**sorption**", meaning surface reactions. Such interactions are caused by a number of geochemical mechanisms such as precipitation and co-precipitation, buffering of acidity, radioactive decay and cation-exchange. Therefore in some of these reactions the chemical species attach themselves to, or detach themselves from, the grain of the porous medium through surface reactions which may or may not be reversible. In others, the solid matrix merely serves as a catalyst for chemical reactions or as a means of neutralising the acidity of the flowing fluid and this, in turn, causes precipitation of certain chemical species onto the solid grains. Such precipitation may, under favourable circumstances, be irreversible, cause co-precipitation of other normally mobile chemical species and/or be accompanied by re-dissolution (Domenico *et al.*, 1990).

3.2 Wind Pollution Transport

The wind speed and direction are very important in the transportation, dispersal and impact of air pollution. The amount of load which moving air (wind) can carry varies proportionally with its speed. Such wind has a vector property with maximum transport along the sense of its motion. This means if a mine dump is located in a wind corridor, there will be a lot of the dump material carried by the wind. This will be deposited along the corridor wherever the aerodynamic forces (wind strength) reduce. The pollution will therefore be over a wide area than if there was no wind. Fine particles are transported the farthest than the coarser fraction. Experiments in the Namibian wind corridors have shown that even up to 4 mm diameter sand can be transported over a long distance. The mass transport of the very fine particle (thoracic and respirable particulate matter) constitutes air pollution. Any living beings exposed to this loaded wind-flow will be negatively affected (see 2.1 above).

The dust from the dumps is excessive when the dumps are dry. Therefore during the mining operations air pollution may not be very visible as most of the active dumps are watered. Settled dust is also an environmental concern. It covers plants and any infra-structure in the vicinity, affecting their appearance and survival. Actually, because of these reasons, it is known that "slime dams are the biggest cause of annoyance in the mining industry when it comes to air pollution" (Sittert, 1993a).

Regular routine surveys are recommended to identify problem areas and propose corrective action. Results of surveys should be compared against original background pollution levels. This will be even more important during the decommissioning and closure phases of the mining.

3.3 Air/Space Pollution Transport

3.3.1 Dust, gas, fumes and odour

Fine mater, including gas, fumes odour and dust which move randomly in space constitute air. When in vectorial motion, the air becomes wind (see 3.2 above). The absence of mater (air) constituted space (emptiness or vacuum). Space does not propagate physical pollution. Wind is the most effective media of airborne pollution. Wind is often part of air flow in convective motion caused by differential temperatures, pressures and gaseous molecules or compounds.

There is often an established trend of wind currents in an area. This is the direction in which airborne pollution is propagated (Fig 6).

3.3.2 Sound transmition

Sound travels in the air by emitting or releasing purses or bundles of energies from the source into the neighbouring air particles. In turn, these air particles transmit to the next in a radially growing spherical rarefactions, with reducing strength with distance. In the absence of air, no sound can be transmitted. If undesired, this sound constitutes noise.

With respect to the mine dumps, the only time noise may be considered is when constructing dry dumps. The source would be collision of the dry particles/rocks and the machines in use (Sittert, 1993a).

3.3.3 Radioactivity transmition

Of three energies associated with mine dumps, radioactivity is probably the biggest problem. It is a form of energy released by some heavy mineral elements as they decay with time (Table 3). These bundles of energy are released or ejected radially into space, and die out with distance.

Uranium is the most abundant radioactive mineral which has been widely used. Natural uranium, mined from uranium bearing lithologies such as granites (alaskites), emits alpha energy radiation. This radiation cannot penetrate more than 6 cm of air, and it can be completely stopped by any solid object, such as a sheet of paper or even the outer layer of human skin (Rossing, 1993). However, alpha-emitting materials can become hazardous to health if ingested because they come in contact with internal tissues.

3.3.4 Electromagnetic transmition

Mine dumps do not have any source of electromagnetic energy waves, except reflecting bright light on bright days if the dumps are white. Quartz, kaoline, mica and limestone dumps do reflect a substantial amount of photons of visible light spectra from the sun. This of course damages the human vision if exposure is prolonged.

3.4 Living Beings Pollution Transport

Vandalism and the use of old dams as motorcycle racetracks and for horse riding (Funke, 1990) have resulted in slimes agitation and cutting into the dams. This results into aeration of deeper levels, with the consequence of acid generation. This acid and any other form of pollution that may be present such as toxic and radio-active elements will stick on the pedes and bodies of the living beings and their equipment (vehicles). This will be propagated to wherever they are released. The amount dispersed by an individual is very small. However, if a large group participates frequently, including spectators, the pollution dispersed will be significant. Even vehicles moving in the area will also contribute to the pollution transport (Davies *et al.*, 1975).

4.0 MINERAL POLLUTION MONITORING

This is the detection of the presence and extent of pollution. There are many monitoring methods depending on the type and environment of the pollution. Some involve visual observation and judgement, electronic detection and chemical analysis. Of these, some are manually operated, while others are automatic and often computer based.

Critical in pollution monitoring is the reference and adherence to the baseline findings and recommendations respectively (Appendix IX). Most mining companies these days have an individual or a department set aside to monitor environmental issues. Environmental issues are often a question of life and death to everyone in the community. Therefore the strategy of the responsible individual or department should be to empower everyone involved in the mining activities to become responsible and sensitive to pollution issues. All the individuals and departments should therefore be held accountable for the control and monitoring of mining related pollution as well as the consequences. This is an essential multidisciplinary approach concept (Burritt *et al.*, 1993; Markris, 1993; Jones, 1992 and Betty, 1993) . It is also recommended for private and government owned ventures to involve external authorities such as the government and specialised agencies such as the Atomic Energy Agencies, at least once a year, in order to get advice and gain both public and self confidence (Walmsley, 1993- Appendix IX and Rossing, 1993). Higher frequency of joint monitoring will improve efficiency. However, finances may be a limiting factor, which may be addressed by the multidisciplinary approach.

Some of the mines taking the right steps in pollution monitoring are the Richards Bay Sands, Klenkopje and Wonderwater Collieries (Richards Bay Company Report, 1993; AMCOAL, 1993 and Circle No 220, 1993):

4.1 Dust Pollution Monitoring

Automatic continuous dust monitoring is done from weather stations established on site in most of the mines. This is the case in most of the new mines such as at Wonderwater Coal Mine (Circle No 220, 1993) and the Namakwa Sands- Fig 20 (AAC, 1990).

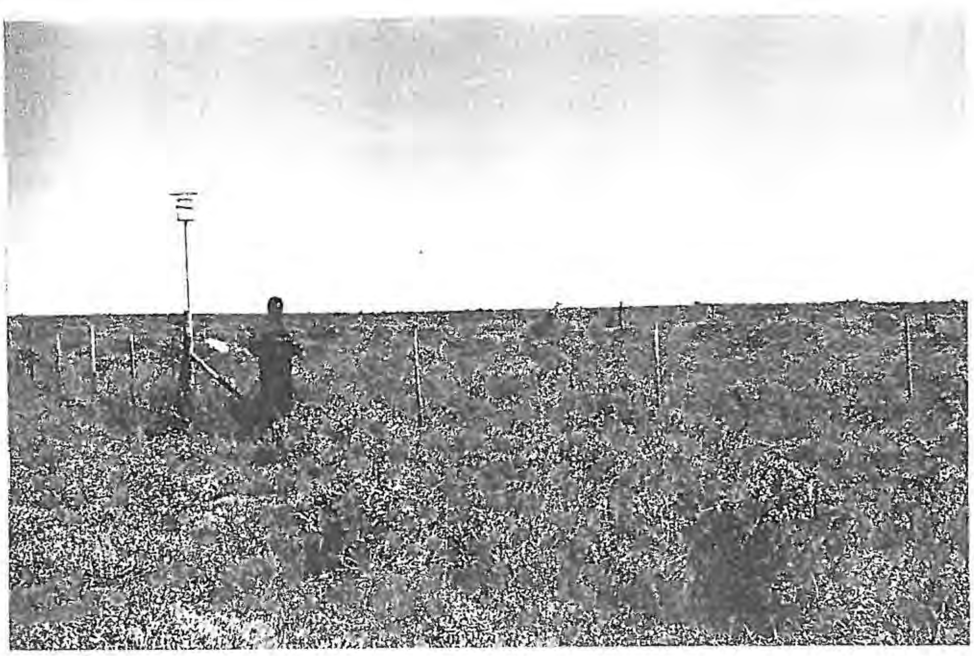


Figure 20. Part of a weather monitoring station at Namaqua Sand Rehabilitated site (Personal Communication, 1993).

Another example is the dust monitoring programme at the Rossing Uranium Mine which has been designed to assess tailings erosion. This comprises:

i) The use of stakes (Plate 21) placed in the tailings surface is to monitor;
   a) Surface movement.
   b) Directional dust samples.
   c) Airborne dust at various heights (up to 10 m)

ii) The visual tracking of the wind deposited dust plumes from the tailings (Rossing, 1993 and Rossing, 1993b).

4.2 Acid Pollution Monitoring

There are both electronic and chemical techniques of detecting the presence of acid in water. The use of electronic pH meters and litmus papers give quick estimates of acidity levels based on a 14 division scale. On this scale, pH 7 is neutral (pure water), above which is increasing alkalinity and below is increasing acidity.

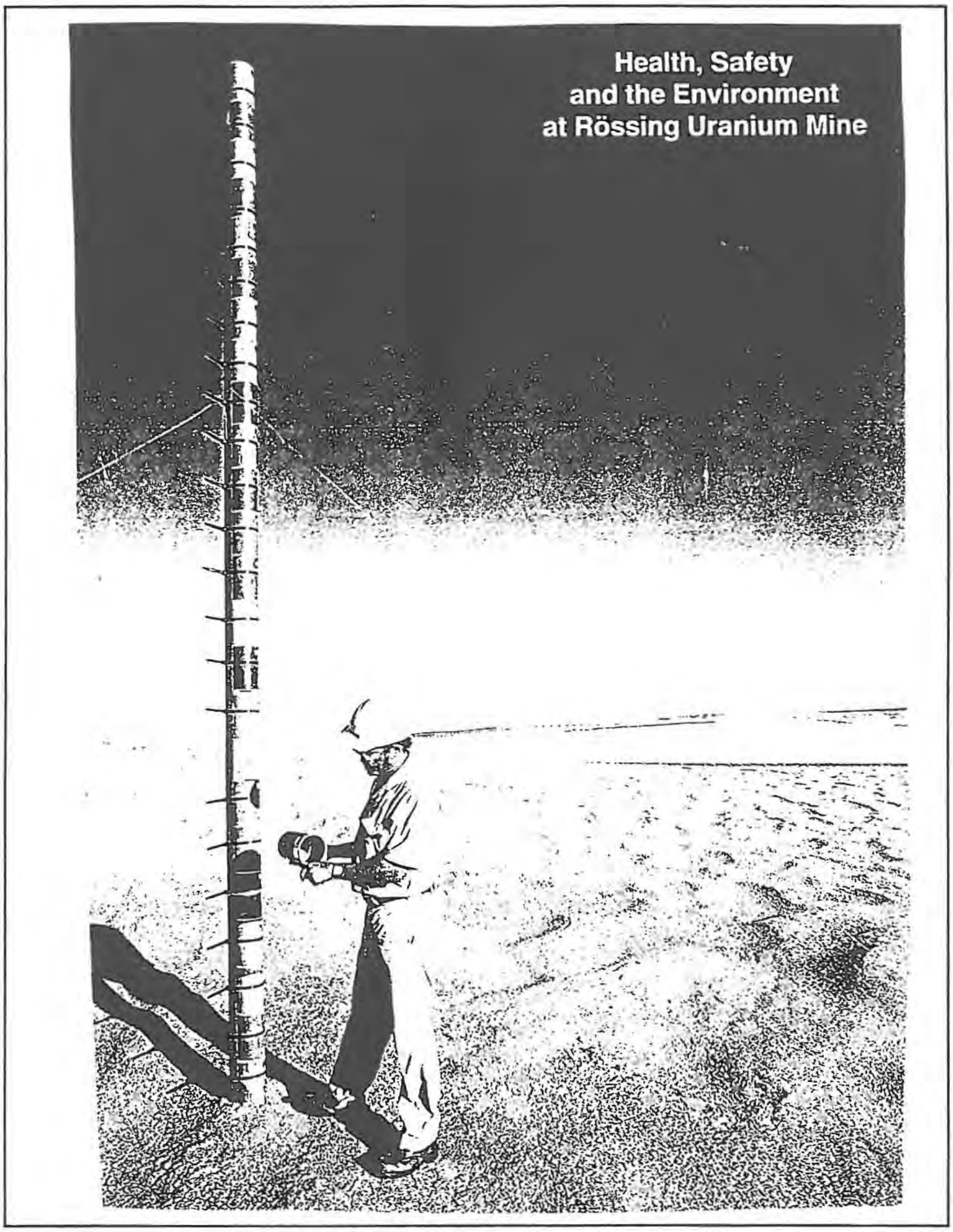


Figure 21. Stakes used to monitor dust at the Rossing Uranium Mine (Rossing, 1993).

There are many other techniques with greater or lesser precision which can be used depending on the environment, speed and precision required.

Corrosion is one of the acid pollution indicators. The acid and other chemicals constituting pollution are known to cause severe corrosion on metals within their realm. Corrosion, as defined by Funke, (1990) is an electrochemical process in which differences in electrochemical potential develop between dissimilar metals, or between different areas of a single metal (Fig 22).

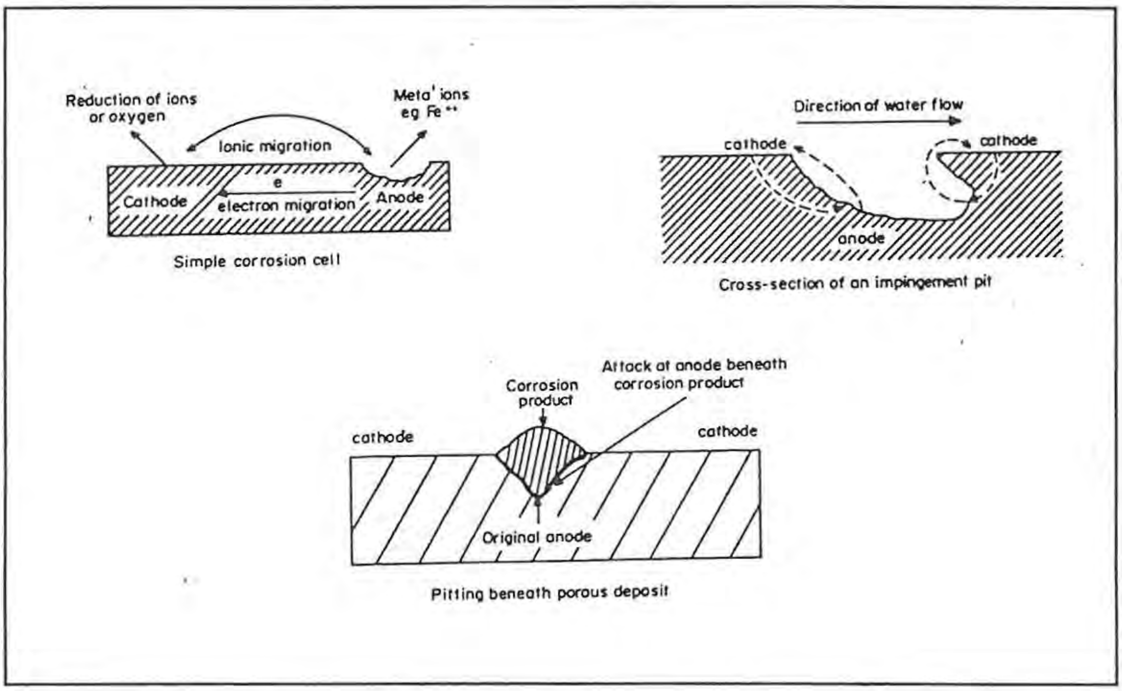


Figure 22. Various forms of corrosion cells (From Funke, 1990).

These sites constitute corrosion cells, where the anode is the region of lower potential, and the cathode is the region of higher potential. At the anode, metal ions go into solution. Various metals such as iron, steel and copper are attacked

at different rate by different chemicals (Funke, 1990). An example of anodic reaction is:

$Fe \longrightarrow Fe^{2+} + 2e^-$

Brown coloured water is indicative of iron corrosion which is not wanted in drinking water in the South African Water Standards (Appendix III).
In acidic environment, the important reactions are:

$2H^{+} + 2e^{-} \longrightarrow H_2$

$O_2 + 4H^{+} + 4e^{-} \longrightarrow 2H_2O$ (in aerated acid solutions)

This is therefore severe where two different metals join, and where fresh metal is exposed. Low pH acid water from the mine dumps and mine effluents cause most of this corrosion. As a result, there are high repair expenditures on the mines when pipes have to be replaced (pipe installations cost 75% of all the costs spent on piping) (Funke, 1990).

Another corrosive product of acid generation in the mine dumps is H_2S. This is a gas which attacks copper in electrical installations. The result, which can be used as a monitoring indicator for this gas, is a nonconductive CuS layer, which leads to power failure and burnt out motors (Funke, 1990).

Recycled mine dump acid drainage water sometimes has high content of chlorides. Experiences at the Rossing Uranium Mine (Smit, 1991) have yielded the following results which can be used as indicators to monitor the presence of high content of chlorides in the recycled water, hence the mine dumps' pollution:

i) Corrosion of expensive stainless steel pipes.
ii) Increased levels of dissolved solids leading to rapid wearing of pump glandseal components.
iii) Precipitation of jarosite and related precipitates in pipes resulting into restriction in the solution throughputs.

In many mines where untreated acid drainage is disposed off in the surrounding areas, vegetation has not survived. The Zairian copper mines are an outstanding example to date, where virtually no reclamation is being done (Master, 1993). On the other hand, vegetating fails to grow in low pH areas including mine dumps (see 2.0 above and 5.0 below). These problems can be used as visual indicators of acid pollution (with or without toxic metals and harmful chemicals such as cyanide).

4.3 Radiation Monitoring

Radiation can be detected by many instruments including radio-meters (geiger counters) and photographic film. Funke, (1990) noted that the analytical methods to determine radioactivity hazards are complicated, long-winded and costly.

In places of high radioactivity, a personal dosimeter is used to monitor how much radiation the person has been exposed to (Rossing, 1993). The one used in some mines such as Rossing is a Thermoluminescent dosimeter (TLD). It is known that if some of the human body fluids show high uranium values, the possibility of internal radiation exposure is eminent. At Rossing, this is done by testing urine every month. A radiation scanner can also be used to detect uranium contamination in the whole human being.

It is always important to base pollution monitoring on background levels. This includes comparing the current results with the original background values before mining started. An alternative is to measure the values outside the mining area (assumed they are unpolluted background values), with those inside the mine area such as the mine dumps.

The chemical analyses or electronic detection for various pollutants is done by the individual companies, and compared with other independent laboratories and specialised national and international organisations such as the Atomic Energy Corporation of South Africa (for confidence and avoiding bias).

Natural radioactivity anomalies can be so high that they would constitute a potential hazard to human health. In such areas, equal caution, just as the human caused pollution should be exercised. In South Africa, radiological surveys are recommended in areas such the Warmbaths (Transvaal), North-Western Cape and Springbok Flats coal reserve areas where natural radioactive levels are high (Funke, 1990).

The Council for Nuclear Safety, established in 1988, has, in consultancy with the Government Mining Engineer, undertaken to establish the acceptable risk levels for the mining and processing of uranium and thorium-bearing ores (including the mine dumps), and the burning of uraniferous pyrite in sulphuric acid plants (Funke, 1990).

4.4 Gaseous, Fumes and Odour Pollution Monitoring

There are electronic and chemical techniques for determining both qualitative and quantitative presence of gases, fumes and odour (Rossing, 1993 and Cormack, 1975). Turner, (1975) discussed the monitoring of airborne metal fumes including Pb, Fe, Zn, Mn, Cu, Cd, As, Be, Co, Cr, Mo, Ni, Sb, Ti and V. These detectors are strategically placed both within the mine dump area, within the other mine areas and outside the mine area for continuous monitoring (iso-kinematic sampling).

The chemical techniques employ various types of analyses, which include chemical analysis, atomic absorption and flame emission spectroscopy, spectrophotometry, polarography, X-ray fluorescence and emission spectroscopy (Steenhoudt, 1975). The initial values of pollutants outside the mine area are taken as background values. These values should be the same as or not far from, the initial values (before mining commenced). Differences between the two indicate the amount and trend of pollution and the source. This pollution approach is the same for all the gases although the detectors may differ.

South Africa has her own air quality standards which may be different from those of the other countries, because such standards depend on local factors. These factors include population density and the level of industrialisation (Appendix III)(Rossing, 1993a and Rossing, 1993b).

There are also computer programmes which enable a comprehensive characterisation of emission from the mine, as well as make predictive models when some of the operational parameters change. This is an effective pollution management tool. An example is the United States Environmental Protection Agency programme which is used at the Rossing Uranium Mine (Rossing, 1993).

4.5 Noise Pollution Monitoring

As noise is a health hazard, its levels and spread must be monitored. There are special microphone-based noise (sound) monitoring equipment which are calibrated in decibels. The results are communicated to the concerned section on the mine, with recommendations which may require them to maintain the current status (if low noise in operations) or reduce the noise (if high noise levels in operations). For the mine dumps this monitoring is essential when depositing waste rock dump.

4.6 Indirect Pollution Monitoring

While most of the above pollution monitoring involves measuring or observing the pollutant directly, there are also several indicators of pollution. This is mainly through development of diseases and, in worse cases, death of vegetation, fish, birds, micro-organisms and even human beings (see mineral pollution section above).

A good example is a 17 year old pyrite mine at Nairne in South Australia, which closed in 1972. It contained 15% of pyrite and pyrrhotite. Upon closing, untreated effluents from the mine dumps flowing into the local drainage system where fish were killed in streams. The pollution comprised a solution of 4025 ppm Fe, 2000 ppm Al, 133 ppm Mn, 186 ppm Zn and 8.6 ppm Cu in water at pH 2.5 (Blesing *et al.*, 1975).

It is therefore recommended that the most sensitive organisms of the suspected pollution in the area, be closely monitored in order to detect the pollution while it is still low. An example is the waterborne heavy metal pollution in effluents from a base metal mine, into a stream called New Brunswick in Canada. Here, the *Salmo salar* (Atlantic salmon) fish which attempted to go into the polluted area, returned at rates proportional to the amount of toxic metals (Fig 23). Extreme toxicity caused death of the fish (Bell, 1975).

Pollution of heavy metals in water is often very low but becomes concentrated in the lower plant (phytoplanktons), increasing in the higher organisms which feed on them. The result is that some pollutants which are below toxic levels to fish will increase to toxic concentrations in human beings after having eaten several fish. Mercury is a good example of such metals (Open University, 1974). Similar concentrations also occur for cadmium in rice plants (McGarry *et al.*, 1975). These are already covered under mercury and cadmium pollution in section 2.2 (ii).

4.7 Regional Pollution Monitoring

The aerial coverage of mine dumps and extent of its effects can be monitored by satellites, geochemistry and normal ground geological mapping. Whitmore, (1975) has reviewed how it was possible to monitor the build up of some mine dumps even in the early days of the launching of the Earth Resources Technology Satellite (ERTS-1).

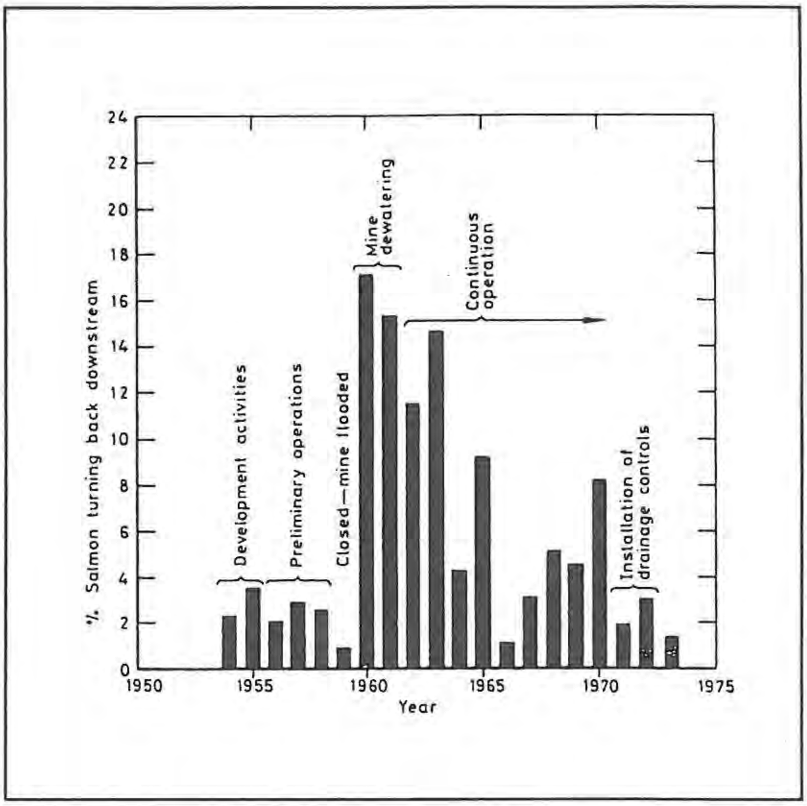


Figure 23. Salmon avoidance in a New Brunswick stream (Bell, 1975).

The problem which ERTS-1 had was a large field of view of 60 m square. The new more advanced satellite systems have solved this problem to less than 10 m square. These include the Landsat- 4, 5 and 6, Seasat, Sky Lab, Radar Imagery (SIR-A) and the EOSAT (Earth Observation Satellite). Periodic aerial photographs can be utilised for surveillance (Franey, 1991).

A special important function of satellite surveillance is its ability to detect particular properties such as vegetation colour, heat, brightness and topographic variations as well as specific metal elements or compounds such as iron (Franey, 1991). It is therefore possible to continuously monitor the vegetation around mine dumps and rehabilitated areas. Acid and heavy metal pollution would be indicated by death or mutation of plants. The sensitivity to metal elements, in particular iron, can indicate the extent of mine dump drainage effluent. Dust, both airborne and settled can be monitored, depending on its differential light reflection with respect to the surroundings. The normal geological mapping is an essential tool either on its own, or for confirming the satellite pictures.

Geochemistry is valid for establishing and quantifying the exact pollutants (Thornton, 1975).

4.8 Management of Pollution Monitoring Systems

In some mines, pollution is monitored automatically in fully equipped stations which include weather monitoring. The data is then stored and processed by computers. An example is the SASOL's Wonderwater Coal Mine in South Africa, where water quality is monitored automatically every 10 minutes by solar-panel driven data-loggers (Circle No 220, 1993). The data is then computer managed.

Although some countries such as Namibia have no legal standards for water quality, proactive companies such as the Rossing Uranium Mine are ensuring proper environmental monitoring, including water management. Standards from other countries such as Australia and America are used as references (Smith, 1991). In order to achieve this task, an advanced computer application system called TARGET (a mnemonic name which denotes: Transient Analyzer of Responses to Ground water flow with Effluent Transport) is being installed in the mine's environmental assessment unit. This follows studies which developed a comprehensive computer based mathematical model, adapted to predict the flow, mass transport and consequences of seepage from uranium mill tailings impoundment (Sharma *et al.*, 1986).

Accurate pollution data monitoring and processing is necessary within the Rossing mining area because the tailings are in a structurally and lithologically complex terrain. The Namib Desert, in the mine area has an annual rainfall of about 30 mm and temperatures range between 4^0C and 40^0C, influencing an evaporation rate of about 7.2 mm per day (Smit *et al.*, 1993). It is therefore evident that surface water is scarce, hence management of available water, and prevention of polluting ground water is critical. Currently, most of the water which has been used at the mine is recovered as acid mine drainage water and seepage water (recycled in a 10^6 m^3 pond) providing 50% of the company's water needs. If this pollution monitoring succeeds in controlling the pollution, it will help in the accomplishment of the mine's decommissioning.

5.0 MINERAL POLLUTION CONTROL

"Man has progressed beyond simple evolution in accord with his natural environment. For the first time in his history he is faced with the prospect of polluting himself out of existence in the foreseeable future. Also, however, man has recognised the possible consequences of his failure to take steps to control his natural environment and that **action is necessary to save himself from himself**" (Platt, 1975).

Mineral pollution control is the effort performed to stop or reduce pollution. It can be both preventive and curative. Most of the pollution control related to mine dumps is done through rehabilitation with two main objectives;

i) To restore land for normal use.

ii) To prevent pollution by containing waste.

The set of operation carried out in a rehabilitation programme is outlined in an "Environmental Management Programme" (Sittert, 1993a). Good pollution control anticipates possible pollution and counter-acts before it occurs. Where pollution has or is already taking place, the following is the proposed sequence of operations to stop or reduce it;

i) Cutting off the pollution transporting agents.

ii) Destroying the already produced pollution.

iii) Stopping the source from generating more.

Pollution control is an emotive and highly contentious issue. Mining has a poor record in controlling its own pollution of its environment, and is currently being faced by an increasingly hostile anti-pollution lobby (Platt, 1975).
This is a result, unfortunately, of most of the old mines (some of which are still operational) which did not take much care, if at all, of their polluted mine effluents (Blesing *et al.*, 1975).

Recent rehabilitation attempts of the old derelict land encounter various common problems, from which new mines are taking their lessons (Cogho *et al.*, 1992). Regarding mine dumps, these problems include steep slopes, high erosion potential, and often acid water. This acid water also contains toxic elements, which affect vegetation growth during rehabilitation.

It is evident therefore that the choice of materials and the techniques to be used in pollution control depends on the physical and chemical conditions of the site (Dawson, 1993 and Blesing *et al.*, 1975). It is also important to note that some of the pollution can only be controlled from the source and not at a later date. Their effects on human can only be controlled by personal protection. Such pollutions include dust, noise and radio-activity (Sittert, 1993a).

Among the attempts made, world wide, to reduce the volume of acid drainage include reducing infiltrating water to mine workings, treatment of water by liming before discharge into rivers, treatment by passing through wetlands coupled with limestone treatment, addition of waste organic matter such as sawdust (to promote growth of anaerobic sulphate-reducing bacteria), chemical inhibition of *T. ferrooxidans* and establishing vegetable cover.

There are also computer based pollution management systems. Some of which are:

i) The Environmental Engineering Division of the Chamber of Mines Research Organisation (COMRO) in South Africa has the programme AQUA-Q for use by mine water technologists, optimising water quality management on existing mines (Funke, 1990).

ii) Through funding from the United States Environmental Protection Agency (EPA) the US Computer Science Corporation has produced a "Geostatistical Environmental Assessment Software" programme. The principal functions of the package are:
   - the production of 2-dimensional grids and
   - contour maps of interpolated (kriged) estimates from sample data.

Other functions include data preparation, data maps, univariate statistics, scatter plots/linear regression, and variogram computation and model fitting (EPA, 1988). This programme is apparently distributed freely to Environmental Scientists worldwide. This is a very useful tool in revealing a pollution pattern, origin, extent and severity using existing data. By varying some parameters, it is possible to see what effect there will be on the pollution. This is therefore essential in pollution management.

Jones, (1992) made a useful proposal regarding the choice of what to do with waste. As a management decision, he proposed that the priority should be to **reduce** the waste (pollution). If this fail, then **re-use** the waste. As a final solution, **recycle** it.

5.1 Physical Pollution Control

Physical pollution control is the barring or containing of solid material pollution from moving beyond a certain limit. In most cases, these physical controls will not interfere with the pollution's chemical composition.

Personal protection and safety is highly recommended in these operations. Protective clothing is recommended such as overalls, gloves, boots, and breathing air filters.

5.1.1 Back-filling of mines.

The whole effort of rehabilitating the mine dumps is to stop the chemical and physical pollution they generate in their vicinity. Both the physical and surface chemical pollution can be eliminated if the tailings can be used to back-fill the mine. This would reduce the hazardous collapse of roof rocks above some of the old shallow mines which are hazardous because they are difficult to locate from the surface, until when they collapse due to heavy buildings or machine on them (Atkinson, 1993).

In the open cast mining, such as the Kleinkopje Colliery, Lindum Gold Mine and Richards Bay Heavy Mineral Sand mining in SA and the Consolidated Diamond Mining in Namibia, the back-filling is being practised cost-effectively (AMCOAL, 1993; Lindum, 1993; RBM, 1993 and Schulte, 1993). Some underground mines are also practising back-filling. This includes the Carletonville Mine which is using South African made wear- resistant high density polyethylene back-fill pipes (Circle No 257, 1993). The First Wesgold Mine in the West Witwatersrand Gold Field intends to take advantage of specially stabilised back-filling to act as pillars, enabling them to mine out the remaining high grade pillars (Personal Communication, 1993). The usual problem with back-filling is the increased volume due to comminution (milling), producing a bulking factor of about 1.67 (Open University, 1974).

The high porosity of the back-fill due to the loose slimes will enhance chemical reaction if the environment is conducive. Research is going on to try and eliminate such pollution in the back-fill (Appendix VII).

5.1.2 Geophysical pollution control;

Geophysical pollution control is the suitable choice of site for constructing slimes dams. The choice takes into respect the distance from the mine's ore processing unit, local drainage pattern, local wind flow (local weather) and geological structures. It is economical to convey slimes to a dam site as near as possible to the processing plant. Thatcher, (1979) states that the distance from the processing plant to the dump site is of secondary priority compared to the choice of the site itself.

i) Mine dump siting;

A badly faulted and/or karsted ground will not stand the heavy weight of the dam, which may result into the physical failure of the slimes. The essential dam structures such as impervious clay, cement or plastic base and cover will also certainly fail. The faults will consequently conduct vertical seepage of polluted water into the ground water system, polluting it.

Detailed mapping of the area, assisted by geophysical surveys such as seismic and electrical techniques will help in understanding the subsurface structures (Karsts, such as sinkholes are often found in limestones).

ii) Mine site drainage;

There will be a big problem with protection against storm water during the rain season if a mine dump is constructed in a low lying area with a big catchment area (Thatcher, 1979). Any pollution leakage will also be swept straight away into the local drainage system, giving the mine no chance to rectify the problem.

In one old lead mine in Thailand, slimes/slags from lead processing were dumped straight in a river, with the consequence of heavy down-stream metal pollution, including lead and cadmium which adversely affected both people and animals (McGarry, 1975). It is therefore advisable that the damming or dumping site be far from residential areas, public places and main roads in order to minimise damage in case of any potential pollution. Funke, (1990) and Thatcher, (1986) have mentioned other hazards that may affect the public, but can be in part prevented by proper siting. These include pulp- floods resulting from dam failure and/or circular clip and dust pollution.

iii) Dump site wind pattern;

Mine dams in a wind corridor will draught very quickly. Expenses on water will therefore be high. Rehabilitation efforts such as revegetation will be difficult. Upon mine closure, the dry slimes will generate high air pollution. Therefore low wind velocity areas, reasonably far from residential areas are recommended for slimes dams sites to prevent air pollution from affecting the public.

In the areas with strong wind such as the deserts, the dust from the dumps may be substantial. This can be prevented by keeping the active dumps wet or find means of binding the particles on the dump surface. Vegetation is often the best way, but in the desert such as at Rossing Uranium Mine area, this may prove difficult and not self sustaining mainly after mine closure. In such cases, use of the slimes as back-fill may be important, seconded by binding the dump surface particles with chemicals and mine waste rocks. Wind will definitely erode a good portion of the dump, depositing the material in a very well sorted manner, which may entail local heavy metal concentrations (similar to water transport media below).

For the people working in such areas, personal protection is necessary. This includes using respirator masks or "Airstream" helmets to prevent inhalation of the hazardous respirable dust, and overalls to protect the worker from coarse abrading-dust.

As a case study, tailings dumps at the Rossing Uranium Mine are the largest single dust source to the environment, induced by seasonal strong winds. Efforts to curb this erosion include the use of:

a) old haultruck tyres to stabilise the dump sides, by acting as windbreakers.
b) using netting material on the dump surface and

c) spraying of seepage or special organic material to form wind-resistant crust on the surface.

d) In desert environment, the most effective dump cover to date, is the use of alluvium (river sand) from nearby gorges (Rossing, 1993).

5.1.3 Use of impervious material:

Impervious materials are taken to be those that will allow very little, if at all, any water to pass through them. Clays, cements and plastics are among them. If properly utilised as stipulated in the "design, operation and closure of residue deposits" by the Chamber of Mines of South africa, some of the prevailing pollution can be reduced.

Previous attempts to stabilise the dam and dump particles from wind erosion, include the use of sludge from underground, tipping rock on the sides and spraying the surface with various substances such as molasses, salt and hygroscopic material. Application of a sludge of black valley soil has been relatively successful (Thatcher, 1979). Rock-cladding of the dump slopes with run-of-mine rock is commonly used to prevent wind-blown dust originating from the sides of slimes deposits (Funke, 1990). The following is a brief account of some of these techniques (Funke, 1990):

a) Proper choice of dam/dump site floor:

Mine dumps should be built on flat low-permeability lithologies such as black clays. Experiences at Rand Mines and others have shown that when the dam floor is made of impervious material such as the black clays, there is hardly any underground pollution since vertical seepage of polluted water from the slimes dam is blocked (Fig 5). Most of the water that reaches the dam base therefore flows through provided underdrainage structures (Funke, 1990) into treatment ponds.

b) Soil Cover;

Clay soil cover such as kaolinite and bentonite provides an impervious top cover on a dump. It saves three main purposes:

- Cuts off rain water and air supply from entering the dump (needed for facilitation of chemical reactions including acid generation and combustion inside coal dumps; US-DI, 1987).

- Reducing surface erosion caused by either rain water (storms) or wind (dust pollution).
- Anchors plants as well as supplying their food nutrient and keeps seeds of some local plants.

Care in the choice of thickness of the soil cover is necessary to avoid acidity or salinity (alkalinity) rising from the dumps, which is known to happen by **capillary action**. Both the acidity and the alkalinity are detrimental to vegetation. Acidity is worsened by high contents of dissolved heavy metals. Having a layer of limestone between the dump material and the soil cover has been found useful. This limestone layer neutralises the acid, hence reducing the need for thick soil cover. 10-30 cm thick soil cover has proved enough on most dumps in protecting young plants (RBM, 1993 and Down, 1975). Current research in the reduction of capillarity is in the use of various types of "breaker or buffer layers" (Dawson, 1993).

It is recommended that the original top soil cover should be kept for covering the dumps or back-filled mined areas. Siting the mine dumps near existing heaps of disposed soil from other large constructions (even not related to mining) is advantageous.

c) Use of hydrophobic material;

For some slimes dams, mainly small and temporary ones, hydrophobic material such as thick plastic membrane can be used to perform the same functions as in "a" and "b" above. This is mostly used during small scale acid leaching mineral extraction process (Fig 23). Synthetic rubber and bitumen are the other useful hydrophobic materials (Funke, 1990).

d) Cement;

Some cements such as the Portland Cement can be used to offer similar protection mainly in emergencies. But this may be relatively expensive, short-lived and not appealing in looks.

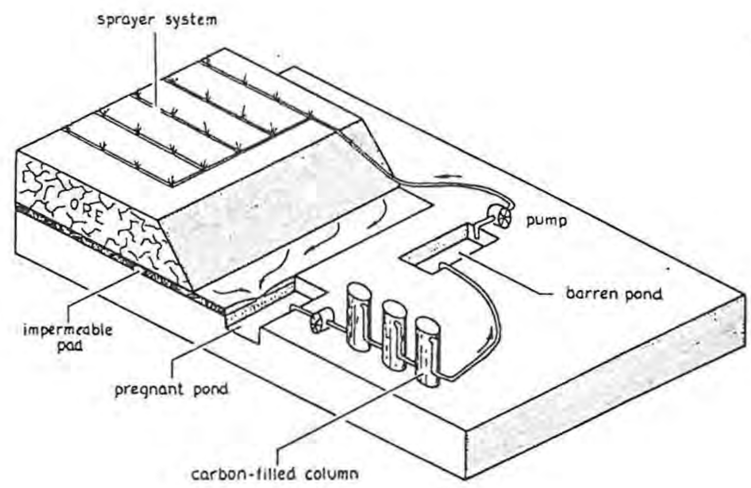


Figure 24. Principal components of a heap leaching operation (Dennen, 1989).

Various types of cementiceous chemicals are used to help in the formation of a hard outer crust.

Apart from artificial chemicals, ferrous/ferric sulphate from the weathering of pyrite react with lime present in the slimes, to produce a protective gypsum/gypsum-like product. A minimum of 0.7% pyrite is required in the slimes material for this reaction to be effective (Funke, 1990). This hardening prevents dust pollution (Sittert, 1993b). But this is not a recommendable technique since the pyrite has major negative effects too (acid generation).

5.1.4 <u>Suitable land-scaping;</u>

This is the shaping of the dumps or dams in order to prevent pollution or enable activities that will prevent pollution. It is an operation which has to be supplemented by the other activities discussed above including stabilising of dump surface by rock cladding, cementing and chemical sprays (although these are not cost-effective, durable and aesthetically unpleasing)(Funke, 1990).

Some of the landscape forms commonly used are terracing and moon-scaping (Fig 25).

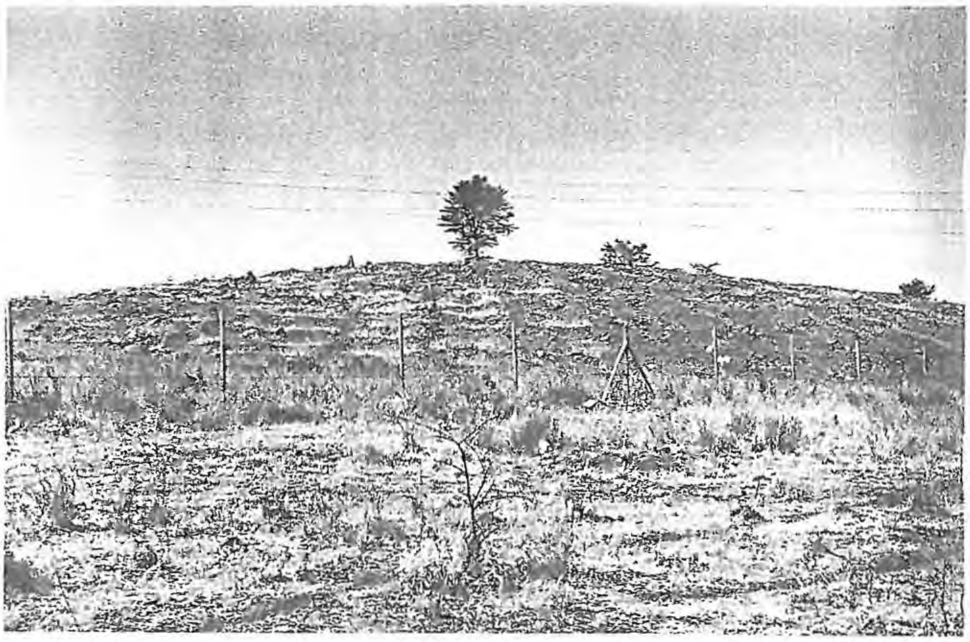


Figure 25. Moon-scaping; one of the recommended surface configurations in the rehabilitation of mine dumps (Personal interview, 1993).

5.1.5 Water management;

Water management is of cardinal importance in pollution control. Containment and on-site treatment of storm water must be provided. Storm water control measures such as cut-off drains and perimeter walls must be constructed so as to withstand major storms. There must also be provisions of sealing or preferably removing of penstocks at mine closure since the normal return-water pumping system will be no longer in operation (Dawson, 1993 and Funke, 1990).

5.1.6 Vegetating mine dumps;

Attempts to provide vegetable cover for mine dumps in South Africa can be traced as far back as 1894 in the Johannesburg area, when Adlam received seeds from the Director of Kew Gardens for trials (Thatcher, 1979). He even stated the presence of cyanide in the dumps and doubted if this **poison** would not deter the growth of vegetation.

Extensive research has shown that vegetation establishment is the most cost-effective and durable method of stabilising and preventing dust pollution and erosion, provided the surfaces are stable. A choice of the plants which will stabilise the surface as well as tolerate the toxic metals, acidity or alkalinity and local weather is crucial. For example, *Festuca rubra* grass is known to be adapted to calcareous lead-zinc waste . Two varieties of *Agrostis tenuis* are adapted to acid lead-zinc and copper wastes (Down, 1975). Planting of young trees is more successful than seeds (Funke, 1990). The top soil often contains seeds of indigenous plants which are adapted to the local weather (RBM, 1993).

In most cases, acidity and draughty conditions have to be reduced on the dam, otherwise most of the plants will not grow (Dawson, 1993 and Funke, 1990). Wind breakers have been effectively utilised in shielding young plants in windy areas such as in the desert and coastal wind corridors (Gencorama, 1985 and RBM, 1993).

The Government Mining Engineer has lain down several actions to be performed on the mine dumps in the Air Pollution Act, under Section 32. These must be implemented as part of rehabilitation of the dumps to **his satisfaction** before the mine could be furnished with a certificate of closure at the end of the mining (Thatcher, 1979). The five recommendations are:

i) The establishment of vegetation on the top and sides of the material from which the dam is constructed.

ii) The covering of the sides with an adequate thickness of waste rock and establishing vegetation on the top.

iii) The covering of the top with an adequate thickness of municipal rubbish and covering the sides with vegetation or adequate thickness of waste rock.

iv) The covering of the top and the sides of the dam with an adequate thickness of soil in which vegetation may be established.

v) Provide sufficient funds for the purpose of adequate covering the cost of controlling dust by one of the four methods outlined above.

This vegetation programme is called **reclamation** if secondary plants grow on their own, attracting other forms of wild-life, hence requiring no further servicing (RBM, 1993).

5.1.7 Proper utilisation of mine dump material

Emery, (1975) has quoted Symonds, (1863); *"It is the shortness of our time on earth, the limitation of our own powers of production that makes us stand aghast at the contemplation of what we call waste".*

As a consequence of the increasing world population (doubling every 35 years), it is forecasted that mineral consumption may double every 25 years or even less. In order to address this demand, exploration for primary mineral resources must be continuously and exponentially expanding even in the face of increasing efforts in conservation, recycling and substitution (Dennen, 1989). In most parts of the world, the easily discoverable mineral resources have already been located. The undiscovered mineral resources are less obvious, hence requiring sophisticated expensive techniques and a relatively longer period to discover (due to lesser statistical chances of striking new deposits). The increasing exploration costs combined with the difficulty of discovering new reserves and the discovery of new cheaper mineral processing techniques has lead to economical exploitation of many old mine dumps, including slags dumps as the mineral prices have gone up (McGarry *et al.*, 1975 and Funke, 1990). This is in agreement with Mining 8247, (1993). The following is a summary of some of the diversities in the exploitation:

i) With improving mineral processing technologies, reprocessing of slimes has become an economic way of utilising them, as long as minimum pollution emanates form them (Dennen, 1989 and Funke, 1990). Some of the reprocessing activities, actually, do reduce pollution potential by:
   a) Removing the pollution active minerals if they form part of the commodities required, such as pyrite (extracted for acid production). Fortunately, the pyrite removal also reduces some toxic metals such as arsenic which often co-exist with it (Fig 11). (Wits, 1992a; Wits, 1992b and Taylor, 1976).

b) In some of the old dumps, where the original dump siting was not good (vulnerable to propagating pollution), reprocessing has resulted into new safer dumping site (Funke, 1990).

ii) Mine dumps as an entity can be innovatively utilised. A good example is the drive-in cinema which was constructed on top of the Ferreira sand dump upon reclamation in the period 1960 to 1963 in the USA (Thatcher, 1979). Recreation parks have also been constructed on the dumps after rehabilitation (US-DI, 1987).

iii) Mine dumps can be commercially disposed off as source of supply of rail ballast, road construction materials and concrete aggregate, as long as they contain minimum pollutants (Funke, 1990 and Thatcher, 1979).

iv) Dumps can also be used as mine fill. An interesting application made by the Rossing Uranium Mine is the filling of a valley with the initial mine rock-waste, forming a platform on which the slimes dam was constructed. This rock-waste-base serves as a filter for any seepage from the overlying slimes dam, before entering the provided under-drainage system. The rock-waste base also forms a raised platform for the slimes against possible but rare storms in the desert.

v) The Gencor Engineering and Technology (GET) of Genmin has been involved in the detailed research on the utilisation of industrial waste materials, as an effective source of building materials (Dowling, 1993). Emery, (1975) has also covered the same field of research. Among these waste materials are slags from the smelting of various metalliferous ores, which form unpleasant sites near the smelters. In the Transvaal, the Impala Platinum has waste dumps of platinum slag in excess of about 3.6 million tonnes, and charge chrome slag of about 18.5 million tonnes (belonging to Samancor) (Dowling, 1993).

Platinum slags, which were previously utilised for shot blasting in the Marine Industry were found suitable for the manufacturing of cement-bricks (slag + cement + water) for the building industry. S.A.B.S. approval was obtained, qualifying for single storey building (SABS 0400 - 1987 of MPa). Application as a substitute for natural aggregate in concrete was also a big success. Other slags tried with equal success are charge chrome slag, ferro-manganese slag and chrome tailings (Dowling, 1993).

Enterprising entrepreneurs have already benefited from these innovations. Among the advantages which can be realised in this utilisation of slags and tailing (Dowling, 1993) are:

i) Reducing mine dumping costs.
ii) Reducing mine closure costs on rehabilitation.
iii) Reduces the need to destruct the environment to obtain equivalent materials from natural resources.
iv) Reduces dumping space required.
v) Assist the social needs of the community.
vi) Employment opportunities for making bricks.
vii) Cheaper housing.
viii) Income earner if sold.

5.2 Chemical Pollution Control

The prevention or reduction of unwanted chemical elements and/or compounds in fluid form (liquids and gases) is here called chemical pollution control. Of these, acid pollution is the commonest. Others include toxic heavy minerals and radio-activity. Gases evolved from the various types of reactions in the mine dumps also cause a proportion of pollution.

To control the chemical pollution, the pollutants must be removed from the fluids (Dvorak *et al.*, 1991). This involves various techniques which will precipitate, evolve, sorpt, neutralise and filter the pollutant (Dennen, 1989, Morea *et al.*, 1990 and Funke, 1990). In the treatment of polluted mine water, these reactions take place in specially constructed treatment ponds and wetlands. Chemical treatment is recommended for quick reactions and in such environments where wetland treatment is inapplicable.

Natural, self-sustaining usually biologically related systems such as wetlands, are proving to be more effective, more versatile and cheaper to manage than the short lived chemical treatment (inhibitors and neutralisers) on mine dumps and in treatment ponds (Thompson, 1987; Wood, 1990 and Machemer, 1992). The wetlands are better suited for slow long term acid and heavy metal drainage treatment from mine-dumps (Batal *et al.*, 1989). Wetlands can be both natural and artificial. The artificial ones are more effective because they are specially tailored to specific pollution problem.

The acid reduction and heavy metal removal are achieved through bacteria related reactions in a process called **passive treatment** (Morea *et al.*, 1990). The bacteria are encouraged to grow in favourable environment created by organic substances such as **mushroom compost** planted with *typha spp* (reed bed) (Wood, 1990; Hedin *et al.*, 1990; Morea *et al.*, 1990 and Dvorak *et al*, 1991). The chemical reactions discussed in "acid" and "heavy metal" pollution control (below) are active in wetlands.

The main concern in the mine dump related chemical pollution are the moist fine grained slimes dams and sand dumps. The waste-rock dumps are not a big worry since their coarseness does not enhance chemical reactions which generate chemical pollution (Appendix II).

It is known that acid reduction also reduces corrosion (Fig 22). This is because the basic concept of kinetics states that "the rate of a reaction can be controlled by the rate of its slowest step". This entails controlling cathodic reactions, which are much slower than the anodic ones. Research by various institutions such as Mintek and actual mine applications have confirmed that corrosion can be reduced as proposed in the above theory (Funke, 1990) by:

i) Choice of suitable non-corrosive materials for low pH areas on the mines [such as unplasticised polyvinylchloride- (uPVC) and high-density polyethylene (HDPE)] on mine dumps.
ii) Protect metals by painting or coating them with some anodic corrosion inhibitors such as chromates and nitrites.
iii) Neutralising the acid water by treatment such as by bacterial reduction or chemical neutralisation.

Recent research developments by Mining Houses and COMRO are on corrosion resistant alloys (Funke, 1990).

Wherever possible, it is advisable to divert local drainage systems, such as streams, away from the mining activity area to avoid acid pollution. A recent example is the water canal diversion from the current and future mining area at Syferfontein Colliery, near

Secunda (Circle No 245, 1993).

Care is also taken that in mining operations, potentially polluted water is treated separately (secondary system) from unpolluted natural water from the streams or canals (primary system). This practice allows treatment of any pollution originating from the mining operations to be done within the mine, leaving the nearby natural water systems undisturbed (Circle No 251).

Computer based monitoring systems are utilised in the control of the water quality operations (Circle No 236, 1993).

The following are some of the mine dump pollution control techniques:

5.2.1 Acid pollution control

Most of the mines with high sulphide mineral contents, can reduce the acidity in their mine dumps by extracting most of the sulphides from the ore for economic utilisation. This, however, is dependent on the market availability for the pyrite by-products such as sulphuric acid (Nogueira, 1980). The market can be expanded by encouraging the mineral processing methods which consume acid, with proper environmental controls. One of this, if proved economical is the acid leaching of copper sulphides in carbonate-host rocks. As Letowski, (1980) defines the technique, the acid dissolves the bulk carbonate ore, leaving behind the mineral required and the insolubles . This technique would help in reducing the size of mine dumps as well as the residual harmful minerals in the conventional mine dumps, although the massive acid quantities would require a lot of care to prevent pollution.

Acid generation requires three components namely **substrate**, **oxidant** and biological **catalyst**. Elimination of one of these will cease the acid generation. The following options can therefore be considered:

i) Removal of the concerned mineral mass such as pyrite (substrate), which is practically impossible and expensive if attempted.

ii) Alternative utilisation of the dumps should prove useful. The dump material can be used for back filling of the mine and production of other items, such as industrial acid, building blocks and roads.

iii) Exclusion of oxygen and neutralisation of acid has been attempted by using chemical reagents.

iv) Some reagents either disrupt the metabolism of bacteria or their environment. Limited success has been obtained in the use of phosphates, silicates, chlorides, lime, slow release pellets (Sanderson *et al.*, 1990) or detergents in acid reduction (Davison *et al.*, 1988). On the other hand, these are temporary remedies, requiring repeated application which eventually becomes costly (Funke, 1990).

Abatement options with a substantial biological component offer lasting self sustainable pollution control (Canby, 1993- Appendix IV). Available techniques are applicable in both chemical and physical states (Silver, 1988). Permanence or sustainability depends on the self-regeneration of the biological system. The operational objectives of such systems are to decrease acidity through neutralisation or sulphate removal and precipitation of metallic pollutants.

Sulphate is removed from acid drainage by three mechanisms;

i) Reduction to sulphide.

ii) Biological uptake and

iii) Formation of organic esters on plant decomposition products.

Bacteria sulphate reduction is the principal method. It requires pH > 5 and suitable organic substrates if in anaerobic conditions (Silver, 1988).

The sulphate reducing bacteria reduces sulphate with pyruvic or lactic acids:

pyruvic acid + $4H_2SO_4$ ----> acetic acid + CO_2 + $4H_2S$. lactic acid + $8H_2SO_4$ ----> acetic acid + CO_2 + $8H_2S$

Some molecular reducers use molecular hydrogen for this reduction:

$4H_2 + H_2SO_4 \longrightarrow 4H_2O + H_2S$

The sulphides formed may combine with heavy metals and cause them to precipitate as sulphides (Silver, 1988).

Sulphate esterification occurs in the presence of plant residues such as humic and fluvic acids, lignin, and cellulose, mediated by microbes. This mechanism may be responsible for the observed neutralisation when acid drainage passes through decomposed wood (Batal *et al.*, 1989 and Silver, 1988).

Decreasing acidity causes amphoteric metals such as Al to precipitate, while Mn precipitation is not well understood. These reactions may be **enzymatic** or **nonenzymatic**. The **enzymatic oxidations** are catalysed by manganese oxidase present in such heterotrophic genera as *Arthrobacter*, *Pseudomonas* and *Citrobacter* (Batal *et al.*, 1989 and Silver, 1988). They require organic substrate, neutral conditions and oxygen:

$$2MnSO_4 + O_2 + 2H_2O \text{ ----> } 2MnO_2 + 2H_2SO_4$$

If the Mn is oxidised by peroxidase by *Leptothrix pseudoochraceae, Arthrobacter siderocapsulatus*, and *Metallogenium*, the reaction is:

$$MnSO_4 + H_2O_2 \text{ ----> } MnO_2 + H_2SO_4$$

Nonenzymatic manganese oxidation occurs at pH 5 in the presence of oxygen and excretions from fungi or anaerobically at pH 7 in the presence of certain strains of *Bacillus* and *Pseudomonas* (Silver, 1988).

Some of these reactions yield objectionable gases and chemicals such as chlorine, fluoride and gypsum. These are often treated in evaporation ponds. If $CaSO_4$ (gypsum) is high, the water solution containing it can be used for irrigation, where the agricultural land is used as a salt sink, without severe reduction in crop yield.

i) <u>Utilisation of microbs</u> (micro-organisms):

The presence of organic substances in or near mine dumps brings about microbial activities, using the chemical energy bound in the organic compounds. Specialised micro-organisms (bacteria- Appendix IV) living in aerobic or anaerobic environments are able to decompose organic substances to water and CO_2 virtually without exception. In the presence of non-organic substances, such as minerals and liberated mineral elements (weathering products), various types of reactions take place. Changing of pH and Temperature also changes some of the reactions as well as the survival of the microbs

(Hedin *et al.*, 1989). This section will concentrate on those reaction pertaining to the neutralisation of the acid and precipitation of toxic heavy metals as sulphides.

In practice, most of the reactions are deliberately encouraged either in the dump itself or outside the dump in natural or artificial ponds called wetlands (Batal *et al.*, 1989). In these ponds, the acid water from the dump collects before entering local drainage system. This is illustrated by siting some examples world-wide (Appendices V, VI, VII and VIII). It is eventually evident that most of the mineral break-down processes, such as weathering, are associated with biological activities.

ii) <u>Acid neutralisation;</u>

Direct acid neutralisation can be done by application of lime ($CaCO_3$) on the mine dumps or its acid drainage;

$$H_2SO_4 + CaCO_3 \text{ ----> } CaSO_3 + H_2O + CO_2$$

Research by Davison *et al.*, (1988) has shown that sodium salts such as sodium hydroxide and sodium carbonate are more effective in acid neutralisation than calcium salts such as calcium hydroxide and calcium carbonate.

Precautional measures are recommended to avoid seepage under the treatment pond, into which the mine dump acid drainage water is led for neutralisation. The pond construction must include a plastic liner in the floor and walls (Smit *et al.*, 1991).

The addition of lime on the mine dumps, to neutralise the acid therein, is a common practice. Rock limestone is utilised effectively in the buffering of the mine dump soil cover from the acid in the underlying mine dump (see 5.1, iiib). In South Africa, it is reported that using agricultural techniques to vegetate about 142 hectare of slime dams on Springs Mines in 1959, about 0.9 metric tonnes of agricultural lime per 0.4 hectare was used to neutralize the acidity of pH 4.5. Grass and trees were subsequently successfully planted, aided by fertilizer and ash respectively (Thatcher, 1979).

In the areas with untreated acid water and chlorides, it is recommended (Smit 1991) to use:

a) Heavy duty uPVC pipes.

b) Stainless steel pipes coated in the inside with poly- urethane.

c) Using stainless components in pump glandseal assemblies.

d) Mechanical cleaning of deposits in the pipes.

5.2.2 Toxic and harmful metals pollution control

The biological removal of acid and cyanide such as in wetlands is known to also remove toxic and harmful metals (Morea *et al.*, 1990; Machemer *et al.*, 1992 and Canby *et al.*, 1993) (Appendices IV, V and VI). Work done by Dovrak *et al.*, (1991) has shown that the heavy metals are reduced by the formation of insoluble metal sulphides. These metal sulphides form by reacting with bacterially generated H_2S.

Toxic heavy metal pollutants can be precipitated from water by treatment with lime in a reservoir, such as an evaporation pond (Funke, 1990). This is because most of the heavy metals are soluble in acid water (Bell, 1975).

It has been demonstrated that the use of molasses can reduce heavy metal pollution in water. This is because the H_2, CO and CO_2 in the molasses anaerobically reduces the sulphate in the acid drainage. The resultant sulphide precipitates heavy metals. As high as 90% sulphate reduction has been achieved (2,500 mg/l SO_4 reduced to 200mg/l SO_4 by 3 g molasses/l in 10 h). There is excess H_2S in this reaction often which has no heavy metals to react with. This gas must be removed. The methods of removing this gas include biological conversion to elemental sulphur and chemical reaction with SO_4. Complete removal of this gas is essential since it attacks copper in electrical installations producing a nonconductive CuS layer, resulting into power failure and burnt out motors. This removal of pollution is achieved during the first and second stages of a three stage pollution reduction technique (which also removes the complex nickel cyanide) called *anaerobic/ aerobic/anaerobic* (Funke, 1990).

Seepage of manganese from tailings dams via ground water into streams, such as the Vaal River at Buffelsfontein, produced a serious pollution problem. The Mn level is now falling due to the following remedial measures;

i) Pumping out polluted ground water.

ii) Eliminating MnO_2 as oxidant in acid leaching of uranium.

iii) Ozonation and chlorination at waterworks further reduce the Mn concentration in the potable water supply to acceptable levels.

One of the countries with very active and strict pollution control exercise is Canada. Bell, (1975) summarised the Canadian base-metal (Cu, Pb, Zn and Ni) mining industry's wide ranging practices of waste control management as follows:

i) Minimisation, collection and treatment of the three main mine wastes, namely mine drainage water, mill process waste and contaminated surface drainage.

ii) Handling, segregation and disposal of solid waste.

iii) Rehabilitation of the site to minimise long-term environmental effects at least-cost, once mining has ceased.

5.2.3 Radioactivity pollution control

The radioactive mineral of much concern in the management of mine dumps is uranium. The alpha radiation from uranium cannot penetrate more than 6 cm of air. It can be completely stopped by any solid object, such as a sheet of paper or even the outer layer of human skin. This means personal protection by wearing something or putting the uranium in a container will reduce chances of exposure to radiation (Rossing, 1993).

Radiation doses to humans is measured in **millisieverts** (mSv). A human being is exposed to a total of about 1 mSv a year from the sun, earth and other background sources. The International Commission for Radiological Protection standards have set a limit for radiation exposure of employees in the nuclear industry to 20 mSv a year. In low-grade mines like the Rossing, an average production worker is exposed to about 3 mSv a year. Central to radiation protection is the philosophy of "As Low As Reasonably Achieved" (ALARA), ensuring that doses are less than the annual limits set by regulations.

As a case study, the Rossing Mine follows a strict code of practice for protection against radiation. The primary objective for establishing this code is to ensure that exposure to radiation will not give rise to unacceptable levels of risk and that the source of such exposures are identified, qualified, controlled and minimised (such as the mine dumps).

This code is based on the recommendations of the International Commission for Radiological Protection (ICRP) and the International Atomic Energy Agency (IAEA). A team of IAEA, International Labour Organisation and World Health Organisation highly recommended the Rossing Mine's radiation control efforts (Rossing, 1993).

There are several techniques which have been tested in reducing radioactive water pollution. Lime softening, ion exchange and reverse osmosis have been demonstrated to effectively remove radium from water (93-97%). It is believed that with some modifications, these methods can also remove uranium at reasonable costs (Funke, 1990).

Radon, a gas emanated from any ore body containing uranium, may be found in significant quantities constituting a health hazard to workers. It can also be transported in underground waters and released far from the point of emanation, still constituting a health hazard. The half life of radon is 3.8 days (Fig 3). Therefore much of it will have decayed while still in the mine before reaching the atmosphere if water pumping is delayed (Funke, 1990). Dissolved radon in water can be removed by:

i) Aeration and
ii) Absorption onto granular activated carbon.

Measures stipulated in the USA for remedial action at inactive uranium mill tailings include:

i) The covering of existing surface with a thick layer of earth to limit radon release to below 0.74 $Bq/m^2.s$.
ii) Deep disposal, such as mine back-fill (Funke, 1990).

Contaminants which have been recovered from a contaminated solution must be safely disposed off to avoid another pollution. If added to mine dumps, this pollution will recur. It is an accepted practice to bury contaminated structural material when a plant has been dismantled (steel, bricks, ceramics Raschig rings, rubber linings and others) (Funke, 1990).

In some underground mines, ventilation flow rates necessary for heat control have also managed to reduce radon daughter levels.

The Council for Nuclear Safety, established in 1988, has, in consultancy with the Government Mining Engineer in South Africa undertaken to establish the acceptable risk levels for the mining and processing of uranium and thorium-bearing ores (including the mine dumps), and the burning of uraniferous pyrite in sulphuric acid plants (Funke, 1990).

The reuse of water from dolomites a mining area should be subjected to approval by prior testing for radioactivity. Emphasis should be placed on educating workers in radioactive polluted mine not to drink mine service water (Funke, 1990).

Where the ground water has been badly polluted, dewatering has successfully reduced the pollution, but with undesirable consequences such as drying up of boreholes, subsidence and sinkholes.

It is recommended, therefore, that any re-opening mines containing radioactive polluted water should exercise utmost precaution in the handling and tracing the origin of the pollution. For instance, in the West Rand Goldfield of the Witwatersrand, the old huge slimes dams would be a major contributor to underground water pollution.

5.2.4 Gas and fume pollution control

There are several hazardous gases released by some minerals or their reactions such as burning in coal mine dumps. These gases include SO_2, H_2S, CO_2 and the radioactive radon and thoron (discussed above).

The following considerations are helpful in the reduction of gaseous pollution:

i) Good aeration is necessary to prevent the build up of high gas concentrations, which would constitute a hazardous pollution (Funke, 1990).

ii) The location of the dumps should be at such a site that wind blows the gases away from the mine area as well as residential area without causing air pollution (Rossing, 1993).

iii) Where accumulation of any of the gases is suspected, the employees working in such an area should wear appropriate protective clothing such as gas masks (Rossing, 1993).

iv) Many gases are inflammable. Therefore naked fire should be avoided in gas polluted areas, mainly in coal mining areas. Welding torches should not be used in such areas.

In the case of the generation of CO_2, oxygen is required in the coal mine dump to combine with the carbon from the coal (combustion reaction). These fires are dangerous because they are often not visible from the top of the dump. They can therefore keep on generating pollution for a long period without being detected. People and animals have also been reported severely burnt when they walk on them without knowing (US-DI, 1987). Experiences at some coal mines including the Kleinkopje Colliery, have shown that covering the coal dumps with impervious material such as clay will cut off the supply of oxygen from the air. This technique has successfully quenched the previously hazardous raging fires in the coal dumps (Personal Interview, 1993). The already generated CO_2 can be reduced by vegetation which utilised it in photosynthesis.

5.2.5 Noise pollution control

Noise is one of the point source energies which can only be best controlled from the origin itself (Webb, 1975). Wet slimes operations have proved very effective in many potential noise generating activities including mine dump construction activities and rock crushing. Replacement of noisy fossil-fuel-powered machines by quieter electric driven machines has been an effective noise reducer as well as money saver in running costs. This is more so important when working at night in built up areas (Davies *et al.*, 1975).

Where the noise can not be controlled from the source, installation of large noise damping (insulation) panels is favoured to cut down the transmitted noise from particular directions (Rossing, 1993). In the event that both the above precautions are inapplicable, personal protection equipment should be used. This includes the wearing of earmuffs or earplugs. New ways of personal protection from noise include the wearing of noise busters (eliminates a specific noise frequency by producing an equal but opposite signal: out-of-phase audio-cancellation; Newsweek, 1993),

5.2.6 Chemicals used in mineral processing

Mineral commodities are extracted from their ores during mineral processing by techniques involving physical and chemical processes. Some of these chemicals are harmful to human beings. It is therefore necessary to know how harmful and biodegradable the chemicals being used are. Extraction of all the chemicals used during processing, from slimes is a necessity. Recycling of the chemicals for re-use is economically advantageous.

i) Raffinate

Uranium can be extracted using solvents such as **alamine** and **isodecanol**, after oxidation and acid leaching. This results in a highly saline contaminated solvent called **raffinate**. About 1.1 to 2.0 m^3 of raffinate is produced per tonne of tailings (Funke, 1990).

This raffinate can be used, after neutralising, for re-pulping slimes for disposal as backfill material. It can also be used to monitor aged slimes prior to acid floatation (Funke, 1990).

ii) Cyanide

Cyanide is used in the extraction of some commodities such as gold during mineral processing. The best strategy of reducing its pollution is by complete replacement with other less hazardous chemicals. Nikahiro *et al.*, (1980) proposed the use of sulphation-floatation technique instead of cyanide during the separation of Pb from Zn minerals from bulk concentrates.

Since cyanide is still in use in mineral processing, there have been a lot of research to find effective techniques on how to remove any of it which escapes with the slimes to the dams. It is known that the carbon and nitrogen in cyanide are a nutrient for some bacteria. The process called **bioremediation** makes use of this fact to remove cyanide from the mine dumps and its effluents using bacteria.

Examples include the closed Homestake Gold Mines, which for a hundred years polluted streams in the South Dakota with cyanide. Bioremediation has removed this pollution (Canby *et al.*, 1993). It is very likely that this technique can also be effectively applied at the newly closed Summitville Gold Mine in Colorado (Posey *et al.*, 1993).

The character of cyanide is, however, not completely well understood. More research work is being conducted by MINTEK on the safest most efficient and economic methods of recovering and destroying cyanide. The seriousness of this work is manifested by the multinational nature of the project (Circle No 209, 1993).

6.0 POLLUTION MANAGEMENT AND LEGISLATION

Pollution management is the planning of safe handling of pollution. This can be at an international, national and local levels, depending on the spread of the pollution. Governments and concerned companies have their own approaches to pollution management. However, since companies are the ones which generate the effluents that lead to pollution, they are the first-hand handlers, while the government assumes a monitoring role. In order for the companies to effectively handle their pollution control programmes, they need to have a comprehensive, effective and efficient pollution management system. With proper management system, sustainable development with social and economic progress without the destruction of the environment, can be achieved (Mining 8247, 1993). This system is based on standards that are set by either the government or international organisations such as the WHO (Purves, 1975). These regulations or instructions constitute legislation.

Platt, (1975) has made it clear that stringent anti-pollution legislation aimed at industry is being enacted throughout the world. It is evident that the stringency of any country's legislation is usually proportional to its degree of industrialisation and there is often little logic or awareness of the issues in it.

It should be remembered that rehabilitation requires finance which relies upon metal earnings on the international market. The success of the Uraguay Round of the General Agreement on Tariffs and Trade (GATT) will enhance this trade. If this order of trade increases the prices of mining products, there will be enough money for rehabilitating mine dumps. Opponents of free trade contend that the main beneficiary of GATT reforms will be the transnational corporations and the main losers will be the environment and the poor (Mining 8244, 1993 and Mining 8247, 1993).

Historically, in South Africa, the mining industry has been concerned about air and water pollution long before there was any legislation pressure. Two Acts were promulgated in 1956, one of which is the Water Act No 54, which was constantly amended up to 1971. It partly addresses the prevention of pollution of both stream and river waters by mining effluent. Further amendments were made in the Mines and Works Act No 27. In 1957, a national committee was instituted to formulate legislation dealing with the control of atmospheric pollution, which led to the signing of the Atmospheric Pollution Prevention Act No 45 in 1965. Its part IV is devoted to dust control from industrial operations. This was amended in 1973, improving the administrative procedures, which led to the dramatic reduction in the air pollution from mine dumps such as in the Transvaal (Thatcher, 1989). It also contained the following:

i) Some areas with a particular pollution were declared control areas, such as Johannesburg was a dust control area in 1967.

ii) Where a quantity of matter in excess of 15 m^3 deposited on any land causes or is liable to cause a dust nuisance, the person responsible shall take the prescribed steps or adopt the best practicable means to prevent such dust becoming dispersed.

iii) The responsibility of payment of the costs will be borne jointly by the state, the local authority in whose area the material is dumped and the owner or occupier, in such proportions as decided upon by the minister.

iv) The Government Mining Engineer, when he is of the opinion that a mine is likely to cease mining operations within a period of five years, shall in writing advise the Minister of Mines and the owner of the mine accordingly and forward a copy of such advice to the Minister of Health.

v) No mine shall dispose off any major asset before it is in possession of a certificate from the Chief Officer stating that all necessary steps have been taken to prevent the pollution of the atmosphere by dust arising from any matter emanating from that mine or that an adequate sum of money has been set aside for this purpose for use when required, otherwise they shall be guilty of an offence.

Some old mines were actually forced to close due to the pollution they caused. A good example is the Ugababa heavy mineral-bearing sand on the south coast of Natal (Hammerbeck, 1976). It has several tens of millions of tons of the heavy sands containing 9% ilmenite, 2% rutile, zircon, garnet and traces of monazite. The mining plant beneficiation activities released effluent which tinted sea water red. Unfortunately, this was a popular coastal resort. Therefore public resistance to this pollution, apart from technical problems, forced the mining to stop.

6.1 <u>South Africa</u>

Pollution in South Africa is mainly caused by the manufacturing, agriculture and mining industries (Thatcher, 1989). Both chemical and physical pollution are produced. In order to handle the pollution caused by the mine dumps, the South Africa Mining policy is examined, as well as the other concerned government departments.

Mining legislation in a country, like many other matters of national interest, depends on the priorities of the presiding government. In South Africa, the current political changes are bringing a lot of commotion and speculations in the mining sector. With the wide national expectation that the Africa National Congress (ANC) may win the April 27 -1994 elections, pressure has been mounting on the ANC to spell out their mining policy. In a preliminary address to 300 delegates at a conference on "Mineral Rights and Small Scale Mining in a Future South Africa", the deputy head of the ANC's Department of Economic Planning (Tito Mboweni), indicated that the application of the **Roman Dutch Law**, which requires that the ownership of mineral rights was vested in the owner of the land, is unacceptable in South Africa just like in many other countries. He outlined the following three disadvantages;

i) It had entrenched the racial bias in the mining industry against the majority of the population,

ii) It was very complex and

iii) It had resulted in the sterilisation of large tracts of land under the control of the large mining houses.

The consequence is that the development of the essential small and medium scale mining sector was severely restricted. This is in agreement with Hayden, (1993). In the ANC's Freedom Charter, it is stated that the mineral wealth belongs to all the people of South Africa. This is, therefore, expected to address the land access problem experience by the small scale mining sector. There is also a possibility of replacing the mineral rights with mineral licences, retention taxes on sterilised land and a new simple procedure for prospecting licence and acquiring prospecting information. The ANC welcomed advice on its policy from the mining sector.

The news media in South Africa has, of late, indicated that the ANC's apparently favourable economic policies may result into a high influx of foreign companies investing in South Africa. As such it is emphasized here that South Africa's environmental policy, regardless of which government is in power, must be realistically and attractively presented to avoid exploitation by, or repulsion of foreign investors (Hayden, 1993).

Betty, (1993) reported that SA environmental legislation falls far short of where it should be. SA will have to fall in line with worldwide environmental legislation in order to succeed both on the local and foreign market. He noted that this will also help in pressurising SA companies, which are responsive to pressure. In a survey carried out by Deloitte and Touche, they found that 28% of SA companies reported environmental pressure from the public. But less than a quarter of the respondents reported pressure from environmental pressure groups, law-enforcement agencies and customers (Betty, 1993). It is here proposed that apart from the specialised enforcement agencies, the multidisciplinary approach should empower every member of the society to be aware and accountable to environmental issue.

Among the recent trends mining is taking, Dalton, (1993) outlined that;

i) Countries are having a greater desire to conserve their natural resources. The result is the increasing national parks, ecological reserved areas and aboriginal lands. This tendency has effectively reduced accessible land for mineral development. If careless environmental management is practised the increased public role will reduce the accessible land even more. There must therefore be public involvement and good environmental management right from the beginning of the mining to avoid such problems.

ii) Permits to mine should be issued only after all mine plans and environmental plans are approved. The later includes reclamation and rehabilitation, which is a major problem in the developing countries because of lack of specialists mainly with the government to review, monitor and enforce the plans and regulations. Training of the local scientists is therefore recommended in this field.

It is very important to know that with the increasing population in SA, there will be need to utilise each piece of land fully. Any pollution will therefore reduce the available land to the public (whose population is increasing), resulting into more noise from the mining critics. Goussard, (1993) recorded that within 25 years, the population in SA will double, from 29.1 in 1985 to 59.7 million in 2010, unless the excessively high growth population rate is dramatically reduced. Losing any piece of land to pollution (including of mining origin) will definitely be inhuman and hence unacceptable.

6.1.1 Chamber of Mines of South Africa Pollution Policy.

The South Africa Minerals Act (No. 50 of 1991) states that it is necessary for the holder of a mining authorization to carry out the rehabilitation of the surface of land concerned in mining. This is in accordance with the rehabilitation plan (now superseded by the Environmental Management Report) submitted to and approved by the Regional Director of the Department of Mineral and Energy Affairs. This is therefore a legislation requirement which must be fulfilled in consultation with the Department of Water Affairs, Environmental Affairs and Agriculture and others before mine-closure can be achieved (DMEA, 1992 and Thatcher, 1989).

The goal of mined land rehabilitation is to convert the areas affected by the mining operations (including waste deposits generated by the mining operations) into a stable and useful land surface. This means the rehabilitated surface should be non-polluting in terms of any form of pollution except the physical site occupation (DMEA, 1992).

The rehabilitated areas should also conform as closely as possible to the pre-mining land capability (not necessarily land use). Therefore before the mining starts, land capability classification must be determined. Any sensitive impact sites must be investigated up to about 3 km away from the planned activities. This will be the standard of reference to be achieved during rehabilitation (Sittert, 1993a; DMEA, 1992 and Dawson, 1993).

6.1.2 Department of Mineral and Energy Affairs (DMEA)

DMEA has put forward an Aide-memoire for the preparation of environmental management programme reports for prospecting and mining. This is a legally binding document which aims at the following:

i) To meet the environmental requirements and directives under the Minerals Act, No. 50 of 1991, and its regulations.

ii) To provide a single document that will satisfy the various authorities concerned with the regulation of the environmental impacts of mining. (These authorities, which were also involved in the preparation of this document are; the Chamber of Mines of SA, Aggregate and Sand Producers' Association of SA, South African Agricultural Union, DWAF, Department of Agriculture, Department of Environmental Affairs, Department of National Health and Population Development and the Department of Finance).

iii) To give reason for the need for, and the overall benefit of, the proposed project.

iv) To describe the relevant baseline environmental conditions at and around the proposed site.

v) To describe briefly the prospecting or mining method and associated activities so that an assessment can be made of the significant impacts that the project is likely to have on the environment during and after the mining.

vi) To describe how the negative environmental impacts will be managed and how the positive impacts will be maximised.

vii) To set out the environmental management criteria that will be used during the life of a project so that the stated and agreed land capability and closure objectives can be achieved and a closure certificate issued.

viii) To indicate that resources will be made available to implement the environmental management programme (DMEA, 1992).

For dust specific legislation, there are two pollution legal standards (Sittert, 1993b):

i) **The control of respiratory dust to which workers are exposed**. In this category, the composition of the dust is as important as the concentration. The regulations are promulgated in terms of the Minerals Act of 1991 Threshold Limit Values, accepted internationally.

ii) **Dust from mine dumps or other surface workings to which the public at large are exposed**. The Department of National Health and Population Development is responsible for standards in this regard and have adopted the American Standards for atmospheric pollution. These standards are:

    a) For respirable dust containing more than 5% silica the standard is the same as for worker exposure, bearing in mind that exposure is for 24 hours against an 8 hour shift exposure.

    b) For respirable dust containing less than 5% silica, i.e. relatively harmless dust, an average concentration of 50 micrograms per cubic meter over a full year, with a maximum of 150 micrograms per cubic meter over a 24 hour period is permitted.

c) For coarse dust (total dust), the standard is 150 micrograms per cubic meter per year with a maximum of 350 micrograms per cubic meter for a 24 hour period.

These standards are based on internationally accepted limits.

The Atmospheric Pollution Prevention Act, 1965, calls for the "best practicable means" to be applied to prevent any atmospheric pollution from mine dumps. This pollution can only be controlled from the source (Sittert, 1993b) and cannot be corrected at a later stage.

The Mineral Act requires that rehabilitation of the surface be carried out simultaneously with mining operations. This implies that slimes dams be vegetated concurrently with mining. Vegetation is presently regarded as the best practicable means available for dust pollution control as it is effective, permanent and pleasing to the eye.

6.1.3 Department of Water Affairs and Forestry (DWAF) Policy.

The DWAF is a custodian of a limited national resource, which has to be judiciously managed to ensure continued adequate water supplies of acceptable quality for all recognised uses. The custodianship includes the **inland** ground and surface water resources, as well as **coastal** marine environments. The Water Act, 1956 (Act 54) identified the main uses of water as domestic, industrial, agricultural, environmental and recreation (DWAF, 1991).

Human activities are the main cause of the deterioration of the water quality, resulting into salination and eutrophication (enrichment of water with plant nutrients; nitrate and phosphate). A minor component of the pollution is caused by natural geological elements, such as the salination of some of the rivers in the Western Cape. Therefore the DWAF's major overall water quality management goal is "the maintenance of the fitness for use (requirements of particular users) of the SA's water resources on a sustained basis" (DWAF, 1991).

Until recently, the DWAF applied the Uniform Effluent Standards approach to water pollution control by enforcing compliance with the General and Special Effluent Standards (Appendix III). To counter the continuing deterioration of water quality and to meet the challenges of the future, "the Receiving Water Quality Objective" approach was adopted for non-hazardous substances (maintaining the general fitness for use goal). For hazardous substances, "the Pollution Prevention" approach was adopted (specially tailored control packages for each situation) (DMEA, 1992). Anticipatory or precautionary principal of environmental protection is also embodied (action to avert danger and minimise risk to the environment). The hierarchy of water quality management goals is as follows:

i) Voluntary source reduction, recycling, detoxifying, and neutralisation of waste to be encouraged.

ii) There is no alternative to the discharge of the effluent, the effluent must meet minimum standards (agreed upon).

iii) If the application of the minimum standards is not enough to maintain the fitness, stricter "site specific" standards will be applied.

iv) Exemptions from the minimum standards will be issued if the receiving water quality body has enough assimilation capacity (absorb waste without affecting its fitness).

In the development of water quality, some of the issues to consider are as follows (DMEA, 1992):

i) The SA Water Act, like that of the developed countries, does not require the water authority to ensure that the quality of marine and fresh water resources should remain in a pristine state, unless justified for the purpose of meeting requirements of one of the recognised water uses.

ii) For pollutants that are a hazard and a threat to the environment, by virtue of their toxicity, persistence and extent of bio-accumulation, precautionary approach should be followed. This should be aimed at minimising or preventing their entry into the water environment.

iii) Increasing environmental, awareness and the growing public involvement on issues concerning protection of the ecology. It is necessary, therefore, to gain their confidence by making the pollution control systems simple and effective for their appreciation.

The DWAF has concluded that (DMEA, 1992):

i) In a choice between effluent disposal options, DWAF will support the best option from an economical, technological, social, political and environmental point of view.

ii) The **polluter pays** principle requires dischargers of effluent to meet the cost of treating their effluent, and/or repairing the consequences to the environment of their discharge. This will be a last resort to the wilful and/or negligent offenders. Note that exemptions are also granted when necessary.

iii) Incentive-based pollution control strategies are being investigated upon, to supplement the polluter pays principle.

iv) Apart from point source pollution, non-point source pollution (storm-water run-off such as from mines and urban areas) is also being planned to be dealt with.

In South Africa, water pollution caused by mining is mainly from coal mining in the Eastern Transvaal and Northern Natal. This is due to wide spread acid drainage and sulphate from coal waste dumps (DMEA, 1992). Unfortunately, some of the mining companies which produced this pollution are no longer operational. A proposal was therefore put forward, in terms of section 58 of the Water Act, 1956, to set up water pollution control works at the abandoned coal mine in the Witbank and Ermelo district in 1993. This was funded by the government of SA in the financial years 1993 and 1994 (DWAF-2, 1992).

Monitoring of surface water has been done with relative ease compared to ground water. This is because the Water Act classifies ground water as private. However, it is necessary to closely monitor ground water quality since its pollution, is slow to incur, not easy to detect and yet very difficult to remove (DMEA, 1992).

Siting of the industries that release hazardous effluents should be carefully done. A low lying faulted basin structure has a wide water catchment area, which will carry the effluents into the ground through the faults. This will pollute the ground water. The DWAF prefers situating such industries at the coast, where they can discharge their effluent into the sea (with high assimilation capacity) than the limited interior fresh water resources. This is obviously a problem with inland mines because moving ore for long distances to the sea would render mining uneconomical. The option is therefore to properly handle and treat mine dump drainage effluents (DMEA, 1992).

It should be noted that the main cause of alarm in water quality is hazardous effluents, rather than non-hazardous load such as clay (DWAF, 1991).

6.2 Namibia's Environmental Assessment Policy

The Namibia's Mineral Prospecting and Mining Act of 1992, contains a whole section devoted to environmental protection, including rehabilitation requirements. In order to exert more control, the Ministry of Wildlife, Conservation and Tourism recently established a Directorate of Environmental Affairs, which ran a workshop in 1992 to develop a "National Environmental Policy for Namibia." The same team also had to develop a comprehensive piece of environmental legislation (Walmsley, 1993).

Care must be taken to ensure that the onus of compliance does not stifle development (as in the USA and Canada).

Among the statements defining the Environmental Policy declared by the Government of Namibia are the following (Namibia, Republic of, 1993):

i) There is a list of policies, programmes and projects, which includes mining, which whether initiated by the government or the private sector, should be subjected to the established Environmental Assessment (EA) procedure.

ii) The EA procedure will, as far as is practicable, set out among other things to:

   a) Better inform decision makers and promote accountability for decisions taken.
   b) Strive for a high degree of public participation and involvement by all the sectors of the Namibian community in the EA process
   c) Take into account the environmental costs and benefits of proposed policies, programmes and projects.
   d) Incorporate internationally accepted norms and standards where appropriate to Namibia.
   e) Ensure that the EA procedure is paid for by the proponent.
   f) Promote sustainable development in Namibia, and especially ensure that a reasonable attempt is made to minimise anticipated negatives and

maximise the benefits of all developments.

iii) This policy recognises the inherent need to incorporate adequate provisions to achieve "reduction-at-source" in the areas of pollution control and waste management.

iv) The proponent shall enter into a binding agreement based on the procedures and recommendations contained in the EA report. This will help ensure that the mitigatory and other measures recommended in the EA, and accepted by all parties, are complied with. This agreement should address the construction, operational and decommissioning phase as applicable, as well as monitoring and auditing.

v) The EA procedure will, at the cost of the proponent, include the ongoing monitoring of policies and projects to ensure that they conform with the recommendations in the EA report as well as the agreement between the proponent and the Environmental Board (Namibia, Government of, 1993).

The concept of "Integrated Environmental Management" (IEM) has been applied successfully in some mines in Namibia without the government's enforcement. Such proactivity could lead to the quietening of the critics of the mining industry (Fig. 23) (Walmsley, 1993).

IEM is an important concept. Betty, (1993), noted that only 5% of the public in SA believe in a company's statement, but about 75% accept those made by "green" groups. Their full involvement will certainly make them believe in what the company says and co-operate with it. Good examples are those of Integrated Environmental Management for the Okanjande Graphite Project in Namibia, Richards Bay Sands and the Namaqua Sands project in SA (Walmsley, 1993 and Paton, 1993).

6.3 <u>United States of America's Mining Law</u>

The United States of America's Mining Law, as summarised by Dennen, (1989) and Bullock *et al.*, (1975) states that mining is ranked as a private industry to be fostered and regulated as any other industry, a grant or conveyance by the federal government carries all minerals unless expressly reserved, and upon conveyance mining land becomes

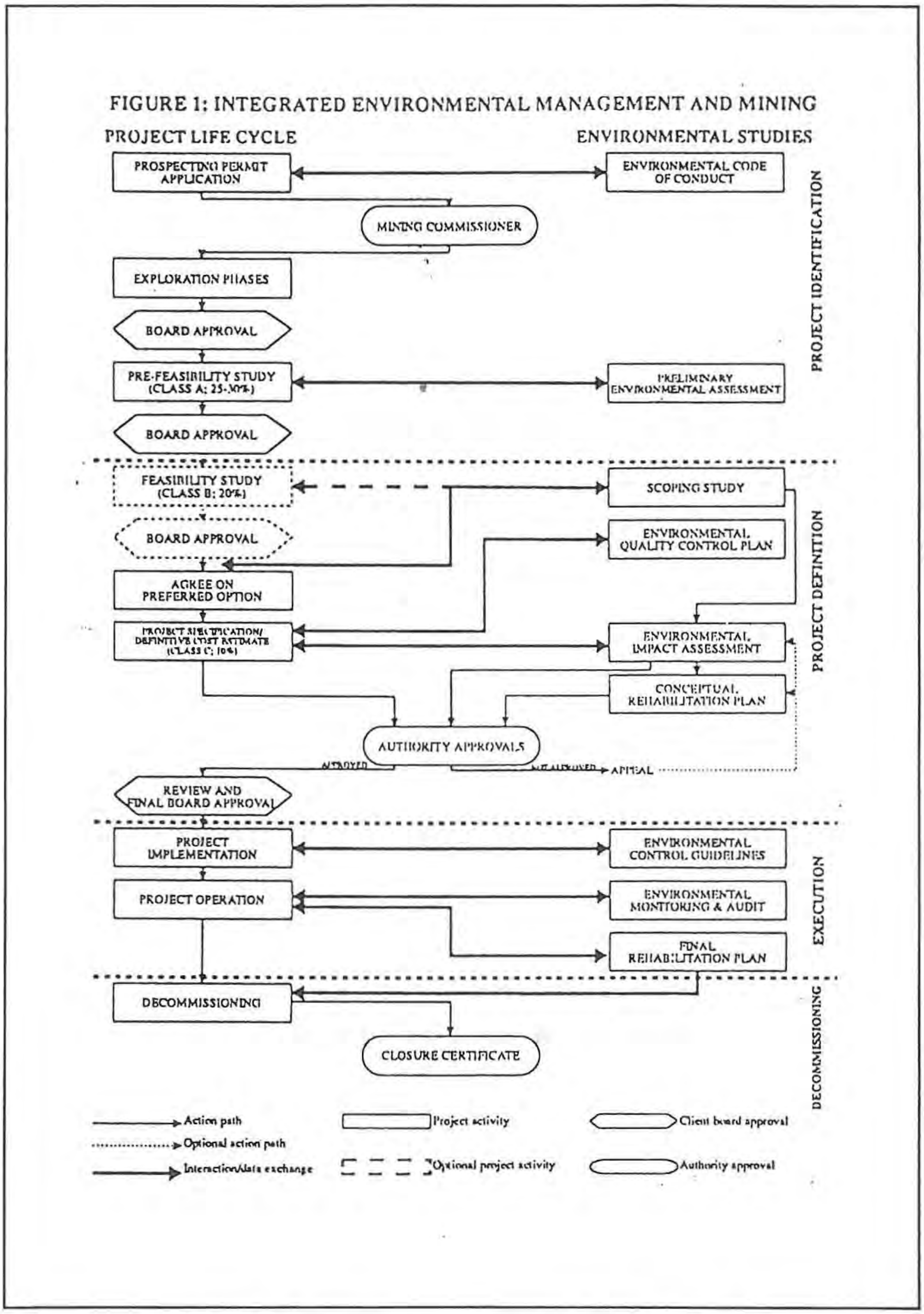


Figure 26. Stages in the "Integrated Environmental Management and Mining" (From Walmsley, 1993).

private property subject to the same rules of law as other real property. Therefore transfer of land to a mining company from a private owner is by mutual agreement including the separation and reservation of surface rights, mineral rights and right of access. Claims may be staked on public lands of some states, with their own concessionary arrangements.

There are three major mining laws that authorise and state the policy of the federal government (Dennen, 1989) with respect to private exploration and development of minerals on public lands in the USA:

i) The general mining law of 1872, "An act to promote the development of the mining resources of the USA", declares that valuable minerals on public lands are open to private exploration and purchase. The size of individual claims is established as being parallelograms with sides of about 200 and 500 m.

ii) Mineral leasing Act 1920 was enacted in recognition of the impracticality of working small claims for bulk minerals commodities and authorised the federal government to act as a lessor to private parties for deposits of coal, oil, gas, oil-shale, phosphate and sodium (salt) on public lands. Later amendments added potash, sand, clay, gravel, stone and sulphur.

iii) The Mining and Mineral Policy Act of 1970 (Public Law 91-631) states that "The Congress declares that it is the continuing policy of the federal government in the national interest to foster and encourage private enterprise in the development of economically sound and stable economic domestic mining, minerals, metals and mineral reclamation industry ...." Unfortunately, this clear policy has not been vigorously pursued.

Set against these enabling laws are numerous statutes, that restrict mineral exploration and development on certain public lands and environmental laws that limit and control mining irrespective of its location in the USA (Dennen, 1989). The major federal actions that limit mineral development on public lands include:

i) Forest and Rangeland Renewable Resources Planning Act of 1974.

ii) Reclamation Act of 1902.

iii) National Wildlife Refugee System Administrative Act of 1966.

iv) Archaeological and Historical Preservation Act.

The environmental laws, an uncoordinated group of special purpose statutes to protect and improve the quality of the air, water, land and aesthetic values of the overall environment (Dennen, 1989 and US-DI, 1987) are:

i) The National Environmental Policy Act of 1969.
ii) Clean Air Act and Clean Air Act Amendment of 1966.
iii) Federal Water Pollution Act.
iv) Water Quality Improvement Act of 1970.
v) Clean Water Act Amendment of 1977.
vi) Safe Drinking Water Act.
vii) Federal Resource Conservation and Recovery Act of 1976.
viii) Noise Control Act of 1972.
ix) Toxic substance Control Act.
x) Uranium Mill Tailings Radiation Control Act of 1978.
xi) Surface Mining Control and Reclamation Act of 1977.
xii) Refuse Act of 1980.

Such restrictive statutes are not unique to the USA; legislation, confining mining to approved methods and in approved places is to be encouraged worldwide. Obviously, competent legal advice regarding ownership, mining statutes, and environmental and other inhibitory legislation should always be sought, for any contemplated mining activity (Dennen, 1989).

The mining industry contributes a great fraction to the USA tax revenue (Bullock *et al.*, 1975). Companies are levied on profit basis by both the federal and state governments. Taxation is necessary to help run national development activities including the reclamation of some pollution sources such as the old mine dumps and attend to emergencies (US-DI, 1987, 1990 and Dennen, 1989). The basis of the USA company taxation are income, production and property (Dennen, 1989 and US-DI, 1987). These crown into the following taxes:

i) Income tax.
ii) Depletion allowance.
iii) Royalty payments.
iv) Products tax.
v) Property tax.

The USA Internal Revenue Code regarding the extraction of natural resources are designed to deliver a subsidy to mining activities (Dennen, 1989). This is done by allowing exploration and development costs to be deducted rather than capitalised and recognising an ore body's wasting nature by according an allowance for depletion. This is a motivation to the companies reclaiming their mine dumps if regarded as a development cost.

Companies are also encouraged in their reclamation efforts by awarding them with recognition of excellence in reclamation achievements. For such awards, considerations made include evidence of effective research and innovations accomplished by the company, as part of the rehabilitation efforts. The Interior Department's Office of surface Mining initiated the following awards to give well-earned public recognition to the outstanding achievements in environmental practices (US-DI, 1990):

i) Excellence in Surface coal Mining and Reclamation Awards (annually from 1986).
ii) Director's award (from 1988).

6.4 International Funding Agents

Mining does require very high initial capital. Most of the mines start with part of their capital borrowed from banks and other international funding agents. These funding agent have their set of requirements before committing themselves. For example, the World Bank, among its requirements before funding a mining venture include (McGarry *et al.*, 1975; Ericsson, 1993 and Betty, 1993);

i) Mining legislation should be attractive to foreign investors and also be stable and transparent.
ii) Regulations concerning environmental, health and safety should be reviewed, and presented in a comprehensive way (such as the Environmental Assessment Report and the Environmental Impact Report).

These demands have also helped in the development of the mining industry in Africa.

Unfortunately, most of the Environmental Reconnaissance Reports do not present accurate facts of the areas concerned (McGarry *et al.*, 1975 and Bullock *et al.*, 1975) because;

i) Environmental studies are usually contracted to foreign consultants, who have inadequate knowledge of the local conditions and hence rely heavily on scant and often inaccurate secondary data.

ii) The value of such studies is minimised by the fact that these "impact statements" are financed by the project proposer; those having inherent interest in withholding information regarding potential environmental damage from the venture requiring the funding.

iii) The hierarchical power structure and political systems are such that these studies seldom receive a public hearing; all negotiations are conducted on an in-house basis.

Recent significant successes in the effectiveness of some of the "Environmental Impact Reports" (EIR) drawn by local experts in South Africa are supporting the above facts. The use of experts in local institutions such as universities has helped in reducing costs and yet still obtaining high quality EIR. Such reports include the Namaqua Sands Impact Assessment report, which was carried out on the western coast of Namaqualand in South Africa by the University of Cape Town for Anglo America Corporation (AAC, 1990; Namaqua Sands, 1993 and Palmer *et al.*, 1993). The mining of these sands will commence in 1994, there being little voiced foreseeable adverse impact from the public.

The other, more fascinating and long lived contention is that of the Lake St Lucia, where the Richards Bay Minerals want to mine heavy sands along the eastern coast of Natal in South Africa. The environmentalists including the Natal Parks Board want it designated for natural conservation and ecotourism (RBM-2, 1993; NPB, 1993 and Koch, 1993). A comprehensive Environmental Impact Assessment (EIA) was conducted, whose summary is in CSIR, (1993). Concluding the study of the EIA in its recommendation to the government, the presiding panel proposed banning mining in this area, in favour of declaring St Lucia, a national heritage park (Koch, 1993). It is now up to the government and any local and international funding agencies concerned to make a final decision.

Note that even in on-going mining activities, periodic EIA may still be required by the funding agents or the company itself as a monitoring tool. In some cases it is the usual environmentalists who build the pressure leading to such reviews. An example is the diamond pumping operations on the littoral and shallow sub-littoral benthos along the

South Africa West Coast. Environmentalists and fishermen thought an observed decrease in lobsters population is due to the mining. An EIA carried by the University of Cape Town revealed that there is no correlation between the two activities, hence no direct mining implication (Barkai *et al.*, 1992).

In a case study, comparing Zimbabwe with Namibia, Ericsson, (1993) demonstrated that government's involvement in the mining industry plays a big role in attracting investors, as well as how effective the existing mining companies will operate. As an example, the easier legislation process and availability of government's assistance has attracted a lot of outside companies and small scale local operators in Zimbabwe, with respect to Namibia. If the government control over such blossoming mining industry is to be realised, Dalton, (1993) states that there should be well developed policies, laws and programmes. There should also be a mechanism to ensure their adequate implementation, monitoring and enforcement. He proposes that *legislation should recognise the high risk nature of mining and ensure that companies will have adequate return on their investment.*

6.5 Multidisciplinary Approach Concept

The above section's activities show that the environmental aspect of any nation or company are multidisciplinary. Burritt *et al.*, (1993) states that "in the 1990s, business cannot ignore the relationship between commercial and environmental factors. Management accountants, in particular, have a role to play in this." They also site incentives which the Federal taxation regime in Australia offers to companies which seek allowance for environmental related expenditures. Basing on ships spilling oil near the Australian shores, they have illustrated that a reduction in pollution (spills) was observed when taxation was imposed on the shipping companies according to the amount of pollution. A similar argument is also raised by Markris, (1992). Regarding mine dump related pollution, those companies concerned should be levied a special tax until when they put in place the right pollution control measures.

A complementary lesson can be learnt from the Chinese population campaign, where it is compulsory to have one child per couple, and there is a financial benefit for not producing a child (Goussard, 1993). With respect to the mine dump related pollution, those companies containing their pollution properly should get some form of incentive, such as exemption from a portion of tax and publicly awarded with excellent performance token (US-DI, 1990).

It is also not until the 1970s that insurance policies contained some form of pollution inclusion clause, and 1985 that most of environmental (pollution) claims were excluded. This is because "insurance cannot be taken out to protect against criminal activities." That is, polluters are taken as a criminals (Burritt *et al.*, 1993).

Burritt *et al.*, (1993), in agreement with Jones, (1992), and Mining 8247, (1993) urge management accountants and the international metal market to base their budgetary decisions and metal pricing upon full costs, which should include environmental damage or management. "Until the full costs of restoration are accounted for, there will be a reluctance to undertake precautionary investment, and this will be to the detriment of all of us."

Betty, (1993) points at another critical issue. This is that companies should also consider their product's impact in the customer's environment, apart from the pollution the products may cause on the company's own environment. This is important in the alternative utilisation and recycling of the mine dump material. Slimes producing pollution on the dam site will very likely also release the same pollution in a secondary environment such as in a building-wall if used for making building blocks.

Therefore, if the reduction of the pollution caused by mine dumps is to be successful, a full account, utilising the multidisciplinary approach should be adopted. Proper pollution status and rewards (such as tax impositions or deductions) must also be accorded accordingly to the companies concerned.

It is recommended herein therefore that both government and companies concerned should involve all their departments in combating pollution issues, in this case, control of the pollution caused by mine dumps. To start with, education should be given to all the staff on the pollution and the staff's role in controlling it (Makris, 1992 and Burritt *et al.*, 1993).

6.6 Company Policy

The objective of any mining operation is to realise a profit on the shareholders' investment. With profit as a yardstick, a mining operation can be profitable, marginally profitable or unprofitable. In the profitable and marginally profitable operations, there is a margin of profit available for research, development and innovation. Many mines, mostly the marginally profitable ones tend to consider the cost of pollution control an unnecessary burden. Such companies will find themselves forced to divert funds away from production to exercise pollution control, as government legislation is enforced on them. For some mines, this is an era of pollution-awareness in which the cost of pollution control is increasingly being seen to be essential (Platt, 1975).

Although the government can set up comprehensive pollution control policies, it is the companies which do the mining that releases the pollutants. It is therefore best fitting that these companies have clear, effective and realistic pollution control (environmental) policy. This has to be in line with the government's policy, with due respect to all the interested parties.

As Platt, (1975) states, all mining companies must prepare for anti-pollution legislation before it overwhelms them: "Mining industry must take action on its own- or have action thrust upon it". A good example is that by RTZ company and its subsidiary, Rossing Uranium (Appendix X).

Seriousness on **decommissioning plans** from the beginning of the mining venture and its execution must be strongly enforced on the mining companies. They should understand that mine dump rehabilitation should go simultaneously with mining, instead of waiting until the end. This is because some of the companies will not even have enough money for rehabilitation at their decommissioning stage (Appendix IX) (Posey *et al.*, 1993).

Modern mining companies are actually able to manage reclamation activities because their initial operational budgets include both benefits and costs (including reclamation) (Cruickshack, 1975).

7.0 CONCLUSION, GENERAL COMMENTS AND RESEARCH RECOMMENDATIONS

7.1 Conclusion

Mine dumps, in particular sand dumps and slimes dams do pro duce both physical and chemical pollution. This is a result of the generation of undesirable products inherited from ore and the mineral processing stage. These undesirable products, which form in special conditions include acid, toxic heavy metals, dust and radioactivity. Mine dumps are also associated with some forms of pollution such as noise and electromagnetism. With proper detection of the pollutants, their source and transport, it is possible to reduce their levels to those acceptable (safe level) by local, national and international standards. Pro-activity, on the part of the mining industry and active monitoring (of their rehabilitation efforts including financial commitments) on the part of the government and the concerned parties including the public are recommended. Multidisciplinary approach and empowerment of the public in environmental issues constitute the formulae to the modern successful pollution control management.

7.2 General Comments and Recommendations

From the above discussion, it is clear that although pollution caused by mine dumps and its control has been studied for a long period (over 60 years in case of South Africa), there are still a lot of loose ends. Personal interviews with mining officials during the various 1993 field visits on this M.Sc. course revealed how confidential most of pollution data is in companies. It appears most of the mining houses are afraid that if the public, government or whoever they are afraid of, knows the pollution they are causing, a dreadful action will be taken against them. Looking at it from another angle, it appears those who are afraid of divulging their pollution status are actually doing nothing to address an existing bad situation. Those who are facing the problem head-long are finding it beneficial to discuss with the public, solisting more innovations, hence their unprecedented successes.

With this back-ground, the following proposals are put forward for further research in order to excel in the pollution management:

1. Pollution often spreads far and wide. Many living beings are affected. As such,

there should be no confidentialities in the pollution caused by a mining operation and the interventions being undertaken.

2. The fear instilled in the mining sector may have originated from a genuine character of the government and/or voluntary social bodies. The consequent cover up of pollution by some of the mining companies does not help in the end. This is a drastic time bomb. As evident in the foregoing revelations, pollution control is more effective and economical in the early stages. In other words, this is merely, postponing an exponentially increasing problem in its extent and complication, which in the end will be virtually impossible to handle, or even burden the tax payer.

3. The government and social authorities responsible for pollution monitoring and control should know that this is a matter of life or death. Being so serious, more tactical strategies are required in order to be effectively addressed. Probably more education on pollution is required for the mining authorities. It is only after proper understanding that the companies will be pro-active. Consequently, there will be lesser monitoring burden on the concerned government and social environmental authorities. As Bullock, et al., (1975) proposes, the government or institution put responsible for the environmental monitoring, should also be empowered to penalise, whenever necessary.

4. Acid generation control should, as much as possible utilise the natural control techniques. Most of these techniques are more effective, self-sustaining and cheaper to manage although often taking a longer period to act than the artificial chemicals (such as SLS). In the instances when the chemicals have to be used, such as in emergency (cyanide spills, excessive sudden pollution leakage), the impact of the chemical itself on the environment should be well understood and controllable.

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NELSON MFUMU CHIKUSA

"I want you, and those who may come after you to do more than I have done"

APPENDIX I

Sulphur and Pyrite (Taylor, 1979)

Sulphur and sulphide minerals (such as pyrite) are sought in the mining industry because of their demand in industry for the sulphur component. Sulphur is used in the manufacture of fungicides, vulcanising of rubber and in the manufacture of matches, gunpowder and fireworks. Its main use is in the manufacture of sulphuric acid (H_2SO_4). This acid is used in the manufacture of fertilisers, rayon, dye-staffs, lead-acid batteries, titanium oxide, explosives, a large number of chemicals, in the extraction of uranium from its ore and in the paper-pulp industry. It is, hence said that a country's degree of industrialisation can be measured by its consumption of sulphuric acid (Taylor, 1979).

To produce the sulphuric acid, the pyrite is burnt and reacts with air:

$$4FeS_2 + 11\ O_2 \text{ ---> } 2Fe_2O_3 + 8SO_2$$

Pyrite (FeS_2), nick-named "fool's gold" is found in numerous deposits all over the world, while elemental sulphur is found in a few natural deposits, none of which is in South Africa. Sulphur occurs in various colours including shades of yellows, rarely greenish and reddish. Sulphur has a relative density ranging between 2.05 to 2.09. It is a bad conductor of electricity and fuses and burns easily. It is often associated with gypsum ore. Sulphur is a major constituent of several minerals including gypsum, anhydrite and pyrite. These minerals are hence exploited for sulphur in chemical industry. Pyrite contains 53.4% sulphur, the rest being iron. It is pale brass-yellow in colour, and a density ranging between 4.95 and 5.10. It occurs in rocks of all ages, but usually associated with other sulphides. Arsenic, a toxic metal commonly found in pyrite (Fig 11) is required not to exceed 0.4% in the pyrite for sulphuric acid production (Taylor, 1979).

Most of the pyrite occurrences can not be economically exploited for pyrite alone. It is often recovered as a byproduct when recovering the main commodity such as gold and base metals.

In the Witwatersrand, the West Rand Consolidated mine was the chief pyrite producer from the auriferous conglomerates since the First World War to 1950. The in-situ pyrite grades were as high as 2.7%.

From the 1950s, the demand for uranium increased enormously, consequently increasing the demand for sulphuric acid, used in the uranium leaching process, hence the recovery of the raw material, pyrite. It is reported that in 1972, 10 South African mines produced 438,577 tonnes of pyrite as a byproduct for the acid production industry (Taylor, 1979).

In the Berberton Mountain Land, all the auriferous deposits are pyritic. The presence of arsenic makes most of then unsuitable for sulphuric acid production. At Areachap, 32 km north-west of Upington, pyrite was mined in series of cupriferous lenses, in zones of fissuring in quartz schist of the Kheis System. Occurrences of pyrite in varying grades are found in many other types of ores including gold/antimony deposits (such as at Murchson Range), dolomites and tin bearing ores (such as Rooiberg Mineral Development Co), coal deposits and carbonaceous shales (such as Pretoria Series), oil desulphurisation, and gypsum (Taylor, 1979).

Interesting in pollution control are the efforts of some companies to recover pyrite from slimes dams, and sulphur from smelter gases (such as Parabora Mining Co) and during copper, platinum, and zinc processing (Taylor, 1979).

APPENDIX II

Increase of Surface Area due to Grinding

It is a known fact in chemistry that grinding of a solid increases its surface area with respect to the original one.

The mechanical process of reducing the size of particles or aggregates is also called **comminution** . The (Gennaro, 1985) increase in surface area is desired because it is this surface onwhich chemical reactions take place. Therefore its increase, increases the rate of chemical reaction.

In mine dumps, this increased rate of reaction is not desired. It is one of the critical factors which causes rapid breakdown of minerals containing hazardous and toxic elements such as sulphides (pyrite and arsenopyrite). Burlage *et al.*, (1963) have stated that for many slightly soluble compounds, the surface area of the particles will have direct bearing on one or more properties, such as rate of solution, solubility, and adsorption.

It is necessary to understand this comminution concept because it is required in the search for techniques for fighting against the dreadful acid and heavy metal pollution from mine dumps. Particle surface area is only a property which enables the interaction of the active components in the acid production. These active components include moisture, oxygen, suitable type of bacteria and the mineral itself. Prevailing pH and temperature are also important.

In the fight against acid and heavy metal pollution, keeping the mine dump material as coarse as possible is recommended. A possible future research field is in the reduction of the available surface area available for chemical reaction. This can be done by coating the concerned mineral grains (slimes) with a cost-effective substance that will halt the reaction. Similar current efforts are centred on the inhibition of the growth of the acid producing bacteria. Unfortunately, this increased surface area enhances adsorption of the chemical inhibitor on the mineral-particles, rendering it unavailable for the intended reaction (Appendix IV, V and VII).

Note that no references detailing this concept were found. However, related to this process is the Rittinger's Law, which states that "the work used for particulate size reduction is directly proportional to the new surface produced" (Gennaro, 1985). The following is a simplified table illustrating this concept of increasing the surface area with reduction in particle size:

Table A1. Showing that particle comminution increases total surface area.

Total mass (g)	Particles crushed (x)	particle size (y) square	Particle area (y^2)	Total area (xy^2)	Area/ mass $y^2/g=1$
m	2^0	y	y	y	1
m	2^3	0.5y	0.25y	2y	2
m	2^6	0.25y	0.0625y	4y	4
m	2^9	0.125y	0.0156y	8y	8
m	2^{12}	0.0625y	0.0039y	16y	16
m	2^{15}	0.03125y	0.00097y	32y	32
m	2^{18}	f	f^2	64y	64
m	2^{21}	g	g^2	128y	128
m	2^{24}	h	h^2	256y	256
m	2^{27}	j	j^2	512y	512

It is demonstrated in the above figure that while the total mass being comminuted is constant:

i) The number of individual particles freed increases.

ii) The total surface area for the initial mass increases exponentially with crushing.

iii) The amount of area gained per mass increases exponentially with crushing.

Therefore it can be stated that the total surface area of a given mass (mineral block) varies exponentially with comminution. Note that this is the author's simplified version of demonstrating the concept. It may not be the standard form.

APPENDIX III. : *GENERAL AND SPECIAL EFFLUENT STANDARDS*

GOVERNMENT GAZETTE 18 MAY 1984 NO 9225

REGULATION No. 991 18 May 1984

REQUIREMENTS FOR THE PURIFICATION OF WASTE WATER OR EFFLUENT

By virtue of the powers vested in me by section 21(1)(a) of the Water Act, 1956 (Act 54 of 1956) I, Sarel Antoine Strydom Hayward, in my capacity as Minister of Environment Affairs and Fisheries, hereby prescribe the following requirements for the purification of waste water or effluent produced by or resulting from the use of water for industrial purposes.

1. SPECIAL STANDARD:

Quality standards for waste water or effluent arising in the catchment area draining water to any river specified in Schedule I or a tributary thereof at any place between the source thereof and the point mentioned in the Schedule, in so far as such catchment area is situated within the territory of the Republic of South Africa.

1.1 Colour, odour or taste:
The waste water or effluent shall not contain any substance in a concentration capable of producing any colour, odour or taste.

1.2 pH:
Shall be between 5,5 and 7,5.

1.3 Dissolved oxygen:
Shall be at least 75 per cent saturation.

1.4 Typical (faecal) coli:
The waste water or effluent shall contain no typical (faecal) coli per 100 millilitres.

1.5 Temperature:
Shall be a maximum of 25^0C.

1.6 Chemical oxygen demand:
Not to exceed 30 milligrams per litre after applying the chloride correction.

1.7 Oxygen absorbed:
The oxygen absorbed from acid N/80 potassium permanganate in 4 hours at 27^0C shall not exceed 5 milligrams per litre.

1.8 Conductivity:

1.8.1 Not to be increased by more that 15 per cent above that of the intake water.

1.8.2 The conductivity of any water, waste water or effluent seeping or draining from any area referred to in section 21(6) of the aforementioned Water Act shall not exceed 250 milli-Siemens per metre (determined at 25^0C).

1.9 Suspended solids:
Not to exceed 10 milligrams per litre.

1.10 Sodium content:
Not to be increased by more than 50 milligrams per litre above that of the intake water.

1.11 Soap, oil or grease:
None.

1.12 Other constituents:

1.12.1 Constituents:

	Maximum concentration in milligrams per litre
Residual chlorine (as CP)	Nil
Free and saline ammonia (as N)	1,0
Nitrates (as N)	1,5
Arsenic (as As)	0,1
Boron (as B)	0,5
Total chromium (as Cr)	0,05
Copper (as Cu)	0,02
Phenolic compounds (as phenol)	0,01
Lead (as Pb)	0,1
Soluble ortho phosphate (as P)	1,0
Iron (as Fe)	0,3
Manganese (as Mn)	0,1
Cyanides (as Cn)	0,5
Sulphides (as S)	0,05
Fluoride (as F)	1.0
Zinc (as Zn)	0.3
Cadmium (as Cd)	0.05
Mercury (as Hg)	0,02
Selenium (as Se)	0,05

1.12.2 The waste water or effluent shall contain no other constituents in concentrations which are poisonous or injurious to trout or other fish or other forms of aquatic life.

2. SPECIAL STANDARD FOR PHOSPHATE:

Waste water or effluent arising in the catchment area within which water is drained to any river specified in Schedule II or a tributary thereof at any place between the source thereof and the point mentioned in the schedule, in so far as such catchment area is situated within the territory of the Republic of South Africa shall not contain soluble orthophosphate (as P) in a higher concentration than 1,0 milligram per litre.

3. GENERAL STANDARD:

Quality standards for waste water or effluent arising in any area other than an area in which the SPECIAL STANDARD is applicable, as described in paragraph 1.

3.1 Colour, odour or taste:
The waste water or effluent shall not contain any substance in a concentration capable of producing any colour, odour or taste.

3.2 pH:
Shall be between 5,5 and 9,5.

3.3 Dissolved oxygen:
Shall be at least 75 per cent saturation.

3.4 Typical (faecal) coli:
The waste water or effluent shall not contain any typical (faecal) coli per 100 millilitres.

3.5 Temperature:
Shall be a maximum of 35°C.

3.6 Chemical oxygen demand:
Not to exceed 75 milligrams per litre after applying the chloride correction.

3.7 Oxygen absorbed:
The oxygen absorbed from acid N/80 potassium permanganate in 4 hours at 27°C shall not exceed 10 milligrams per litre.

3.8 Conductivity:

3.8.1 Not to be increased by more than 75 milli-Siemens per metre (determined at 25°C) above that of the intake water.

3.8.2 The conductivity of any water, waste water or effluent seeping or draining from any area referred to in section 21(6) of the aforementioned Water Act shall not exceed 250 milli-Siemens per metre (determined at 25°C).

3.9 Suspended solids:
Not to exceed 25 milligrams per litre.

3.10 Sodium content:
Not to be increased by more than 90 milligrams per litre above that of the intake water.

3.11 Soap, oil or grease:
Not to exceed 2,5 milligrams per litre.

3.12 Other constituents:

3.12.1 Constituents:

	Maximum concentration in milligrams per litre
Residual chlorine (as CP)	0,1
Free and saline ammonia (as N)	10,0
Arsenic (as As)	0.5
Boron (as B)	1,0
Hexavalent chromium (as Cr)	0,05
Total chromium (as Cr)	0,5
Copper (as Cu)	1,0
Phenolic compounds (as phenol)	0,1
Lead (as Pb)	0,1
Cyanides (as Cn)	0,5
Sulphides (as S)	1,0
Fluoride (as F)	1,0
Zinc (as Zn)	5,0
Manganese (as Mn)	0,4
Cadmium (as Cd)	0,05
Mercury (as Hg)	0,02
Selenium (as Se)	0,05

3.12.2 The sum of the concentrations of the following metals shall not exceed 1 mg/*l*: Cadmium (as Cd), chromium (as Cr), copper (as Cu), mercury (as Hg) and lead (as Pb).

3.12.3 The waste water or effluent shall contain no other constituents in concentrations which are poisonous or injurious to humans, animals, fish other than trout, or other forms of aquatic life, or which are deleterious to agricultural use.

APPENDIX IV

INTRODUCTION TO BACTERIA

"This is a heady time to be a microbe"

(Canby *et al.*, 1993)

With clever coaching from microbiologists, bacteria and other "bugs" are being put to work in wondrous ways. "We've always been good at domesticating plants and animals. Now we are learning to domesticate bacteria" (Canby *et al.*, 1993 quoting J. Caulder of the Mycogen Corporation of San Diego).

Microbe, sometimes called "Bug" is merely a convenient name for any of hundreds of thousands of species of microscopic organisms that flourish on earth; of which bacteria is the most numerous (Fig 1).

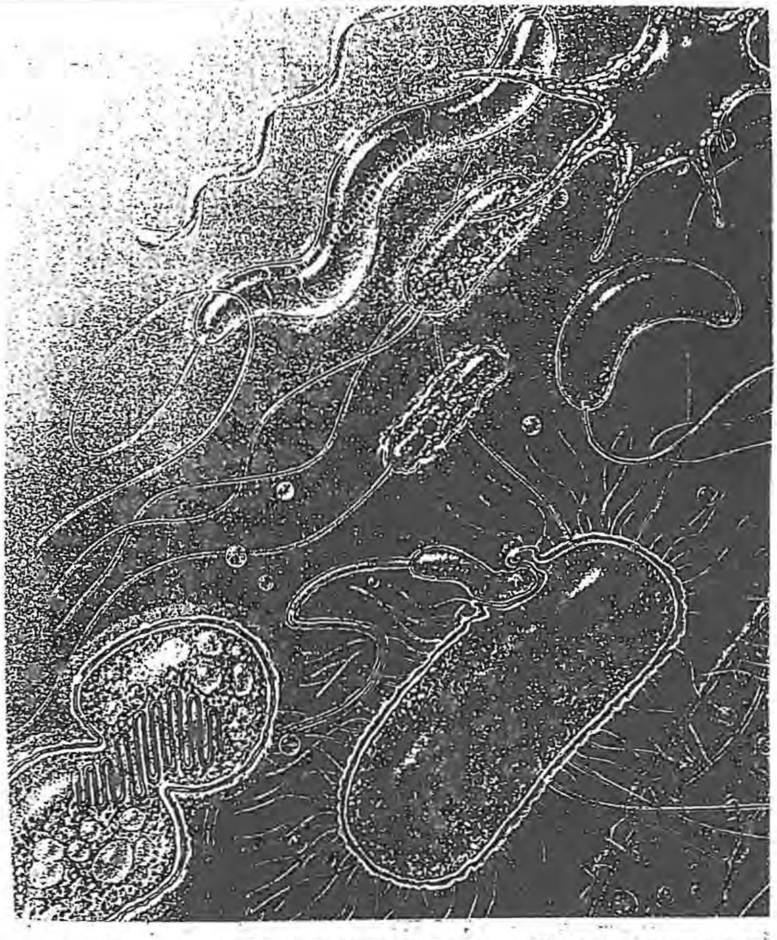
Some microbes serve as factories- making pharmaceuticals, pesticides, solvents, plastics, plants resistant to some diseases, snow and fermenting (making bread, beer, cheese and wine). Some help in rejuvenating tired wells and separation of copper and gold from ores (reducing the need for hazardous chemicals like cyanide). Billions of these bacteria constitute about a quarter of a pound in a human being, helping in food digestion and even excavating cavities in teeth (Fig 2)(Canby *et al.*, 1993). Some microbes are, of cause, age-old enemies, the invisible messengers of tuberculosis, cholera and other scourges. Naturally, there is one of these pathogens (germs) in every thousand microbes. Some of the microbes are yeast, moulds, fungi, amoeba and protozoan. Apart for the pathogens, neither the people nor the planet would live without them. They are known to be the oldest form of life (for two billion years on earth) (Nash, 1993). They make what we want and they get rid of what we do not want (Canby *et al.*, 1993).

These tiny workhorses of biotechnology share a common characteristic: They can live as a single cell. They are structurally, the simplest, which unlike the other microbes, do not have cell nucleus. They reproduce by fission, that is they multiply by dividing.

Figure 1. Bacteria on a head of a pin (From Canby *et al.*, 1993)

These microbes therefore, which dwell among us and within us in astronomical numbers, are the planet's most abundant, most varied, most versatile, and most useful organisms- among which are, unfortunately, the most deadly (Canby *et al.*, 1993).

The ability for microbes to breakdown matter (both natural and man-made), helps explain why the world is looking at them anew. They are nature's recyclers, a property which earns them a rank in the environmental process of cleaning up the environment. This has found a lot of application in cleaning up pollution in water since they survive well in wet environments.



Menagerie in miniature

Nature's most diverse life-form, bacteria have adapted to almost every environmental niche. Some, like *Ancalochloris* (1), *Aquaspirillum* (2), and *Chromatium* (3), live in water, where *Aquaspirillum* may use its magnetic particle chain to find food-rich sediment. *Haloarcula* (4) thrives in salty places. *Pyrodictium* (5) seeks hot spots. *Rhizobium* (6) colonizes plant roots and produces a form of nitrogen vital to its host. Other types of bacteria, including *Escherichia* (7), *Streptococcus* (8), and *Treponema* (9), can cause disease in humans.

Metabolic needs sometimes bring together disparate species. *Methylococcus* (10), an aerobic methane consumer, may be drawn to *Methanosarcina* (11), an anaerobic methane producer; *Desulfovibrio* (12), a hydrogen sulfide producer, attracts *Ancalochloris*, *Beggiatoa* (13), and *Chromatium*.

Figure 2. Some of the types of bacteria (From Canby *et al.*, 1993)

A particular type of bacteria can perform a specific function. Genetic engineering has also successfully removed some undesired genes or added some desired ones to a particular bacteria variety (gene splicing and cloning), to enable it perform a specific duty. Therefore by encouraging or producing new varieties, it has been possible to solve many pollution and other problems in a sustainable way. The mechanism is simple; the **bacteria eat the contamination and live on one another's excretions**. They also adapt to adverse conditions by secreting enzymes (Canby *et al.*, 1993).

Excellence in pollution cleaning has been achieved in the pollution fields that include breaking down hazardous chemical such as cyanide and acid from mine effluent; ridding soil of its contaminants such as dirty oil and fuel from leaking petroleum station tanks; destroying oil spills on water; removing and decomposing paint; manufacturing of soap for dirt removal, manufacture of biosensors which detect the presence of harmful material by the interaction of bacteria and electronics; reduction of sulphur from coal before it is burnt (coal desulphurisation), hence reducing acid rain and in sewage-treatment (Canby *et al.*, 1993).

How safe are microbial release? Scientists believe that there is enough safeguard through both legal and adherence to time-tested research standards. Several research institutions such as the EPA in the US are also looking into some more refined standards. These measures should prevent "the Australian rabbit problem happening" (Canby *et al.*, 1993).

APPENDIX V

Case Study I

Kleinkopje Colliery Acid Pollution and Control
-South Africa;
(AMCOAL Company, 1993)

As a result of fracturing and pulverising of the rocks associated with strip mining, the ground water is exposed to fragments of various types of rocks such as argillaceous and arenaceous sediments, dolerites and various types of ores. The following is a short account of the experiences by AMCOAL Company, (1993) at **Kleinkopje Colliery**:

i) Pollution Generation

The arenaceous sediments and the dolerites are chemically inactive and have very little effect on chemical changes which may occur. Argillaceous sediments, however, contain high percentage of elements which can be released through base exchange or dissolution. Similarly, coal may also contain elements which can, within a short period, be released into ground water flowing in the area of strip mining. These sources of contamination are referred to as **short-term pollution sources**. Another source of pollution is that of chemical degradation of ground water through chemical reaction taking place over the **longer-term**. An example of this kind of pollution is the oxidation of pyrite, which is commonly found in the South Africa Coal-Fields, and worldwide. A lot of work has been done in the USA and the UK to try and solve this pollution.

More than 50% of SA's sedimentary rocks are argillaceous. They have very low permeability but often high porosity, which contains vast amounts of resident water. Due to the long period the water has been locked in the pores, it contains high amounts of dissolved matter, including salts. Large quantities of cations are also adsorbed onto the clay particles. Upon exposure of the shales/ mudstones to the air and water, the pore water as well as the adsorbed cations, can be released. This is called the **interstitial** and **ion exchange** release, and constitute the **short-term** pollution. The contaminants are released into the ground water.

The disintegration of the exposed shale/mudstone is a continuous process as the **interstitial** ground water flows through the fractured medium. This process will continue until all the interstitial ground water has been released. Vast amounts of contaminants can therefore be released within a short period. Under natural conditions this process of contamination is extremely slow. In the event of the shale fragments being deposited on a mine dump (mainly in slimes because of the wetness) soon after stripping, the contaminants are released therein. Any water used to keep the dump wet will wash this contamination to further places.

Clay particles, which are normally negatively charged due to broken bonds along the edges of their structural units, have consequently got high **ion exchange**. In this ion exchange process the negative charge is neutralised by cations which are adsorbed onto the clay's aqueous film near the clay surface (diffuse layer). In their order of preference, the anions adsorbed are calcium > magnesium > potassium > sodium. Divalent cations are commonly preferred to monovalent ones.

Long-term pollution effects on ground water flowing into strip mines and mine dumps can be classified as **acid mine drainage**. This is the untreated mine drainage characterised as acid with high iron content. The amount and rate of acid formation and quality of discharge from the system are functions of;

a) The amount and type of pyrite in the coal and the adjacent sediments, and
b) The amount of water and air available for chemical reaction.

This pollution can be devastating. For example, in the USA, it is reported that productivity of over 17,000 km of streams has been destroyed by acid pollution. This has also been reported by US-DI, (1987).

In the SA coal, pyrite is the commonest sulphide. Upon exposure to water, air and bacteria, pyrite oxidises to;

$$2FeS_2 + 7O_2 + 2H_2O \text{ ----> } 2FeSO_4 + H_2SO_4$$

Ferrous sulphate is resistant in the presence of sulphuric acid. Therefore leaching action of the mine water carries with it most of the iron and sulphur in ferrous sulphate form. After some time, there is further oxidation by atmospheric oxygen resulting in the following reaction;

$$2FeSO_4 + O + 2H_2SO_4 \text{ ----> } Fe_2(SO_4)_3 + H_2O + H_2SO_4$$

When the sulphuric acid concentration is diluted by receiving streams, the ferric sulphate hydrolyses as follows;

$$Fe_2(SO_4)_3 + 6H_2O \text{ ----> } 2Fe(OH)_3 + H_2SO_4$$

All the sulphur from pyrite therefore ends up in the receiving stream as sulphuric acid.

Bacteria activity plays an important role in the acid formation. Sulphur-oxidising bacterium, *Thiobacillus ferrooxidans*, was detected in many localities where investigations into acid formation have been performed.

Thiobacillus ferrooxidans has been reported to inhabit the extreme environments in mine waters and sediment such as acid mine drainage, but not in fresh waters. Experiments in the USA have shown a marked drop in pH of acid water (2.6 to 2.1) and oxidation of up to 98% ferrous iron after 15 days in the presence of *Thiobacillus ferrooxidans*. Control experiments (with no bacteria) showed very little change. This is possible because of the high rate of multiplication and respiration of the bacteria. It is actually known that generation times of *Thiobacillus ferrooxidans* at room temperature is 8-16 hours and respiration rates range from 240-984 micro-litres oxygen uptake per mg cell per hour.

It is therefore likely that in mine dumps, the interstitial and ion exchange short-term pollution-release produces the low pH values required for the Thiobacillus ferrooxidans to start growing, in the process generating more sulphuric acid.

ii) <u>Pollution Control</u>

Short-term ground water contamination during mining is not a major problem in strip mining due to its short residence time in the mine. It can be pumped straight into streams within Industrial Effluent Regulations. The problem is how to control ground water pollution in mined out and back-filled areas.

Mine dumps have been used to fill (rehabilitate) the mined out areas. In these rehabilitated areas, the water table rises back to normal, integrating the mine pollution into the ground water flow. In all the SA Coal-Fields, the experience is that ground water moves from high lying areas to low lying local streams or rivers.

Since the fractured shale slimes or waste from the dumps is the sources of dissolution-elements which causes pollution, their exclusion will reduce the pollution. Also minimising infiltrating ground water from the surface will reduce transportation of these elements.

If it were possible to remove all the pyrite from the mine dumps, acid pollution would be terminated. An attempt can be made by physically reducing the rock-fragments which contain pyrite. These are mainly the remnant coal fragments and the shale. It is, however practically impossible to remove all such coal fragments, hence this method may not succeed.

Use of detergents that will inhibit the growth of bacteria have been considered (Sanderson, 1990), but these would very likely pollute surface and ground water if excessively applied.

Immediate flooding of the newly rehabilitated areas can help reduce acid generation by cutting oxygen supply required for the growth of the acid generating bacteria. This may be an easier option, but it is not known if such artificial flooding is possible. Those mines in arid or semi-arid areas would find this technique impossible. (AMCOAL Company, 1993).

APPENDIX VI

CASE STUDY No II

Waste Dump Ground Water Pollution (Germany):
(Golwer *et al.*, 1971).

Golwer *et al.*, (1971), worked on ground water pollution from waste dumps in Germany. They found that the process of decomposition of organic substances gives rise to the following biochemical zonation (away from the source of pollution) due to varying Eh and pH :

i) The zone of most severe pollution is characterised first by the absence of dissolved free oxygen which is used up in the biochemical reactions. Beyond that, the micro-organisms take oxygen by reducing nitrate and sulphate. High values of ferrous iron (up to 700 ppm) and ammonia (up to 1460 ppm) are consequently found in this zone. This is a **reduction zone**, with negative Eh values.

   The sulphates are reduced by specific bacteria, such as *Desulfovibrio desulfuricans*, to hydrogen sulphide and elemental sulphur. Hydrogen sulphide is further more produced by sulphur bearing organic compounds. The hydrogen sulphide is used by other bacteria for their metabolism. The species *Beggiatoa and thiothrix* found in this zone are able to store elemental sulphur in their cells. Nitrates are similarly reduced. The total microbial count is raised considerably in the reduction zone (up to a hundred times). The biochemical process of degradation will give rise to much CO2 gas and to a warming of the ground water.

ii) Away from the reducing zone is a zone of such a decreased biochemical decomposition (of organic matter) that the oxygen brought in by diffusion from the soil air or dissolved in seepage water is not used up any more. The surplus of oxygen will oxidise the inorganic substances, raising the Eh to positive values. This is the **oxidation zone**.

iii) Between the two zones is a **transition zone** where free dissolved oxygen is found temporarily.

The transition zone is characterised by the precipitation of dissolved ferrous iron, in a typical reaction where ferrous iron is oxidised to ferric iron. This is accomplished through the bacteria action (*Crenothrix* sp., *Leptothrix* sp., and *Gallionella* sp.). In the oxidising zone, the micro-organisms decompose the remaining pollutants.

In all the biochemical zones above, inorganic substances are precipitated and co-precipitated at measured pH values of between 6 and 8. The main precipitate in the reducing zone is iron sulphide, accompanied by heavy metal sulphides. In the transition and oxidation zones, hydroxides of ferric ion and manganese are precipitated. Other poorly soluble elements, which include most heavy metals and compounds such as copper, lead, zinc, arsenic, tungsten, vanadium, fluoride and phosphates are coprecipitated and thus eliminated from ground water.

Adsorption and ion exchange play a big role in the reduction of pollution. **Adsorption** is the accumulation of organic and inorganic substances at the surface of any solids out of a solution without emission of other substances into the solution. **Ion exchange** is the exchange of bound ions against an equivalent quantity of dissolved ions.

Permeable sediments, containing small quantities of clay or humic substances form aquifers with the best exchange characteristics, relative to gravel free or silt and karstified rocks (fissures). Microbial slimes which form on the surface of the soil particles of the aquifer may also serve as permanently regenerating sorptive medium. The **self-purification** by adsorption and ion-exchange will therefore be particularly effective in sand and gravel, where hydroxides of ferric iron and large density of microbial growth yield a permanently regenerating sorption capacity.

The gases, evolved in the reactions, which include carbon dioxide, methane and nitrogen join the soil air and get released into the atmosphere. Permaeble strata above the ground-water table is effective in this gas release. These strata also serve to finally filter suspended matter from the water. The mixing of this purified water with the fresh ground water dilutes any remaining pollutants to almost ground levels. Golwer *et al.*, (1971) found that there was no pollution in the ground water beyond 650 m away from the waste dump. The ground-water was sampled through test wells drilled to a maximum of 11 m depth.

APPENDIX VII

CASE STUDY No III

Investigations on Gold Mine Sand Dumps and Coal Waste Dumps (South Africa). (Loos *et al.*, 1990)

Concern about the production in mine waste dumps of acid drainage water containing high levels sulphate and metal ions initiated the research. The aim was to explore into the possibility of using chemicals to inhibit the growth of the bacteria responsible for the acid generation in mine dumps.

Research in the USA indicated that such treatment of mine dumps might be effective. Two types of dumps have been investigated, namely, gold mine sand dumps and coal waste dumps. The project involved a contract by the Water Research Commission (finacer) with the Department of Microbiology and the Institute for Polymer Science of the University of Stellenbosch (researchers) and the Chamber of Mines of South Africa (support services).

i) Gold Mine Sand Dumps

The following are among the main findings and conclusions from the evaluation of the possibility of inhibiting acid drainage-producing *Thiobacillus ferrooxidans* or chemolithotrophic iron-oxidising bacteria in gold mine sand dumps by treating the dumps with chemicals active against these bacteria (Loos *et al.*, 1990).

a) The seepage of acid water from the Witwatersrand gold mine sand dumps, which released an estimated 50,000 t of salts into the Vaal Barrage during 1985 showed the characteristics of acid drainage as found in other mine waste deposits elsewhere in the world. The pH of the water was below 3. Sulphate constituted a large proportion of the tonnage of salts in the acid drainage. The brown colour of the seepage water and precipitates in and around seepage pools indicated the presence of oxidised iron. This iron oxidation was by chemolithotrophic iron-oxidising bacteria which was 10^6 to 10^7/ml in drainage water, and 10^3 to 10^6/g in the in the brown coloured soil of the seepage area. This is *Thiobacillus ferroxidans* bacteria.

b) The gold mine sand dumps appear not to be a favourable growth environment for the *T. ferrooxidans* and other possible chemolithotrophic bacteria of acid seepage. Increasing proportion of an oxidised sand (where pyrite is oxidised) increasingly retarded the growth of *T. ferroxidans*. **The drying of the mine dumps resulted in rapid destruction of large inoculum bacteria populations from acid seepage**. The destruction being more rapid in an oxidised sand than in an un-oxidised sand containing pyrite substrate.

c) Of the compounds tested in laboratory cultures as possible inhibitors of *T. ferroxidans* and mixed populations of chemolithotrophic iron-oxidising bacteria from sand dump acid drainage, the most effective was the anionic detergent sodium lauryl sulphate (SLS). The other detergents tested are alkylbenzene sulphonate (LAS), Ceepryn, benzoic and sorbic acids (food preservatives), sodium lignosulphonate and polyacrylic acid.

d) The outer orange-coloured 10 m layer of sand dumps away from seepage zones contained almost no iron-oxidising bacteria. This is probably due to the loss of pyrite (bacteria growth substrate) through weathering, and the dryness of the sand. Therefore the bacteria inhibitors must be delivered in inhibitory concentrations at this 10 m depth to control the acid production in the dumps.

e) The dryness concept makes the pyrite oxidation seasonal. It is possibly negligible in winter, as drying of the sand dumps results in rapid death of the iron-oxidising bacteria.

f) Sand adsorbs the inhibitor. Therefore the amount and rete of application of the inhibitor should take into account this adsorption.

g) It is questionable whether such applications are justified in view of the probable complete processing of the sand dumps during the next 20 years (recovering some commodities when technology improves).

ii) <u>Coal Waste Dumps</u>

Not much work has been done on the extent of pollution and environmental impact of acid mine drainage from coal waste dumps in South Africa. Loos *et al.*, (1990) have summarised work by Kemp, (1962) and Rude, (1973) who showed that there is a high concentration of

In this exercise, Loos *et al.*, (1990) were interested in reducing acid mine drainage by chemically inhibiting the growth of acid drainage-producing bacteria. These bacteria are *Thiobacillus ferroxidans* and/or other chemolithotropic iron-oxidising species. The following are some of the finding:

a) Examination of the coal waste dumps near Witbank showed the occurence of acid drainage water in the lower parts of the dumps. This was associated with the presence of large populations of chemolithotrophic ferrous iron-oxidising bacteria, presumed to be *T. ferrooxidans.* A drainage water sample and a coal waste sample (from within the outer 25-30 cm of the dumps) from the Douglas Colliery with pH 2.4 and 2.4 to 3.88 respectively, contained 4.64 * 10^3 to 2.83 *10^6/ml or g of iron-oxidising bacteria. Freshly deposited coal waste, with pH 6.98 had no iron-oxidising bacteria. This also applied to the burned waste which had a pH value of 7.99. It therefore looks that acid mine drainage is mainly restricted to the outer 25-30 cm of mine dumps. These facts indicate that there is a possibility of inhibiting acid-mine-dump-drainage formation by the application of suitable antibacterial chemicals.

b) Differing particle size (up to 11.5 mm diameter) of the coal waste had a profound effect on the ferrous iron concentration.

c) Of the inhibiting chemicals tested, SLS and sodium benzoate were successful on laboratory scale. On the actual mine dumps, the SLS was not successful at all. This was discovered to be due to the development of **resistance** to the treatment by the bacteria. There was also the heterotrophic filament fungi and yeast, among which was an **SLS-degrading** species. There was also higher **adsorption** levels by the coal waste of the SLS than the sodium benzoate.

d) Even at as frequent the rate of application as fortnightly, the bacteria was not inhibited. This frequency and the original cost of the chemicals renders this technique expensive. In 1990, the cost was estimated at R29,040 and R12,922/ha for SLS and sodium benzoate, respectively.

e) Their overall conclusion from both laboratory and pilot scale studies on coal waste is that sodium benzoate seems to have the best potential of the inhibitors studied to inhibit the acidification of pyrite. However, the cost and effectiveness of the chemical is yet to be proven.

<u>NB</u> There is need before going further with this chemical inhibition to evaluate the potential of chemical leakage pollution impact on the ground and surface water. This is essential since while there may be chances of solving the mine dump acid drainage problem, chemical pollution would be introduced. Their biodegradability should also be examined (Jones *et al.*, 1992).

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APPENDIX VIII

CASE STUDY No IV

THE SUMMITVILLE MINE: A State's Perspective- USA
(Posey *et al.*, 1993)

Huyck, (1993) comments; "The recent closure of the Summitville mine and related environmental concerns have received extensive media coverage and have intensified debate regarding the **relative benefits versus environmental costs of mining** in the United States of America (USA). The following summary of the closure of the Summitville Mine (Posey *et al.*, 1993) offers a recent classic case study in a developed country of the need for pollution control.

On December 4, 1992, Summitville Consolidated Mining Company Inc., a wholly owned subsidiary of Galactic Resources Limited (GRL) of Canada, announced bankruptcy of the Summitville Au-Ag mine in the San Juan Mountains, southern Colorado. In the wake of the bankruptcy was left a 45 acre, 12 million ton heap leach pad containing cyanide processing solution. This solution had 2 m of freeboard in the heap, acid- and metal-producing waste-rock covering more than 100 acres and a free-draining adit. All of these were on 527 acres of disturbed, partially claimed ground.

On January 27, 1993, partly in response to actions against it, GRL announced bankruptcy as well. The Colorado Division of Minerals and Geology had no emergency response capability. Seeing the most formidable mine-clean-up task ever faced by the state of Colorado, joined with the Colorado Department of Health in requesting that the EPA take over the remediation efforts at the Summitville mine site. On May 10, EPA proposed **Superfund Listing** for the site and, as of mid-1993, the listing request was awaiting public comment.

The Summitville Mine situation offers clear lessons in mining and regulations. Many of the problems at Summitville could have been avoided if the operators and regulators had paid closer attention to the geology, surface and ground water hydrology, and the climate of the area prior to permitting the operation. A review of the situation provides certain insight that can help others avoid similar problems.

The Summitville deposit has a history similar to many mines in Colorado and, indeed, in the USA. Discovered in the 1870s, the deposit was worked under various companies until about 1950. In the early days, free gold was mined near the surface, and within the first few years of operations, mining went underground, where copper and zinc were recovered along with the gold. A series of adits were driven both for access and for drainage (popular in the 1900s). To date, many of these adits are point source discharges of acid and heavy metals.

The basic remediation task at Summitville is to control surface and process waters containing acid, base metals and/or cyanide. It was decided that treatment would be done until a permanent solution is found.

Examination of the geology and mineralogy reveals that both the acid and base metal problem would have been predicted. Summitville is a Tertiary acid sulphate epithermal deposit hosted by a volcanic dome emplaced along the margins of the Summitville-Platoro caldera. Acid alteration of the quartz latite porphyry host rocks prior to ore mineralisation produced vuggy silica, quartz-alunite, illite-kaolinite and montimorillonite-chlorite alteration zones, grading outwards from fractures. Sulphide-rich mineralisation was then deposited in the altered host rock. Pyrite, copper sulphides and energite compose most of the ore mineralogy. Also present are sphalerite, galena, numerous trace metals and native sulphur.

The engineering designs and implementation of the Summitville site proved to be substantially inadequate. Negligence placement of the heap leach pad and part of the waste rock as valley fill created two problems:

i) The heap leach hydrophobic base liner incurred a leak within the first month of operation. It should have been repaired at that moment. To date, there is leakage of cyanide solution into the underdrain.

ii) The waste rock pile, which lies up-gradient of the heap and contains considerable amounts of the sulphur minerals, was constructed over a wetland. the ground water which would normally exit as springs in the drainage, now enters the lower portion of the waste rock, where it reacts with the sulphide to generate acid and dissolved metals.

The Reynolds adit which lies below the ore body drains acid water. The water quality is known to have deteriorated over the mine's life. A good understanding of the following issues may solve the problem at Summitville and other similar mines:

i) Draining adits.

ii) Valley centre drains.

iii) The mineralogy and rock chemistry of both ore and waste rock.

To ensure against future problems like the Summitville, the Colorado Legislation's "Mined Land Reclamation Act" was amended. A separate regulatable class of mineral deposits which should meet more stringent permitting requirements was created. This includes uranium and other metallic commodities, and operations that use toxic or hazardous materials (such as cyanide), or the processes that produce acid or toxic materials.

The new legislation also empowers the Mined Land Reclamation Board to ensure that mining applications have satisfactory public health or environmental concerns. It also extends the period of reclamation liability to 5 years and gives more power to the state to act accordingly with respect to reclamation costs, such as recouping from a polluter whether bankrupt or not.

APPENDIX IX

CASE STUDY No VI

Integrated Environmental Management (IEM)
for the Okanjande Graphite Project.
-Namibia (Walmsley, 1993)

i) Project Description;

The Okanjande Graphite Project is located amongst some low hills 14 km southwest of Otjiwarongo in north central Namibia. Graphite ore will be mined at an initial rate of 420,000 tpa. The ore will be processed in a plant situated adjacent to the pit. 20,000 tpa of high quality, large flake graphite will be bagged at the plant and shipped from Walvis Bay. The Okanjande Project is developed by Rossing Uranium, a Rio Tinto Zinc (RTZ) group company.

The environment at Okanjande is characterised by thin, but fertile soils, dense vegetation which supports a rich and diverse fauna, and very little water, whether on surface or underground. Summers are hot , with most of the rain falling in short, high intensity storm events. The mean annual precipitation is 421 mm but annual totals can fluctuate widely. Winters are cool, dry and windy. The geology of the area is highly complex and the ore body is characterised by extensive sulphide mineralisation.

Walmsley Environmental Consultants (WEC) was commissioned by Rossing at an early stage of exploration to conduct the preliminary environmental assessment and subsequent studies of IEM.

ii) Application of IEM;

Within a typical mining project, there are four distinct phases:

a) Project identification.
b) Project definition.
c) Project execution.

d) Decommissioning.

These phases all require different level of input and degree of accuracy (Fig 25 in main text). The stages of the IEM which fall into each of these project phases require a corresponding level of input and degree of detail:

Phase I: Project Identification Phase

Almost all mining projects will have at least one exploration stage and some form of pre-feasibility study to determine the viability of the mine. In terms the Minerals Prospecting and Mining Act 1992 in Namibia, the application for a prospecting permit must be accompanied by some indication of what environmental control methods will be used. This includes roads, waste disposal and the measures which will be taken to rehabilitate exploration sites.

The Preliminary Environmental Assessment (PEA) should be done simultaneously with the prefeasibility study and at the same level of detail. This is the most important step in the entire IEM process because this is when various options are being evaluated and various layout plans are being considered. The aim of the PEA is to undertake a preliminary assessment of the environment using available data as far as possible. This exercise allows one to identify the key issues, sensitive areas and major data deficiencies. Through regular meetings with the project design team, these issues can be discussed and acted upon.

At Okanjande, the PEA made recommendations for temporary and permanent rehabilitation of exploration sites. The PEA also included a baseline environmental study. Available data on climate, land use, hydrology (limited), water quality (limited), geology, geochemistry, and the socio-economic structure of the region were collated and some limited surveys were undertaken of the soils, fauna, flora and archaeology of the area. All the data were then interpreted in relation to the project and the key issues were identified. The potential problems were found to be:

a) Water pollution from the tailings dam, waste dumps and the open-pit due to the high levels of the pyrite and pyrrhotite in the ore body.
b) Dust from the tailings dump.
c) The impact on farming operations.

The local farmers and the key interested parties were contacted at very early stage in order to take note of their concerns and to establish lines of communication with the local community. Similarly, the other parties such as the design consultant, Rossing and the government were regularly contacted.

Phase II: Project Definition

Some projects include a feasibility study, which typically includes a pilot plant operation, production of the product samples and on-going marketing. This is when **scoping** is done, by formally approaching the interested and affected parties (I&AP), in order to obtain their input to the scope of work in the EIA. The scoping study needs to be done before agreement is reached on the preferred options, if a feasibility study is not done, to avoid presenting the public with a "*fait accompli*".

In the feasibility studies at Okanjande, meetings were held with the I&AP, where by raised issues were incorporated into the scope of work for the EIA (including dust, social, conflict, rehabilitation and other forms of pollution). The final scope was circulated among the I&APs for final comment and approval. During this phase of the project, some revegetation trials were started on the pilot plant tailings dam in order to establish which species will grow on the tailings and what soil adjustments will be required. The early start made with these trials will mean rehabilitation of the tailings could start immediately after deposition commences and thus minimise dust and water pollution.

Phase III: Project Execution

This phase starts with construction, followed by commissioning and then on-going mining operation. This is the next most important step in the entire IEM process when environmental control is done during construction, by translating the recommendations in the EIA into practice. These are included in the contract and someone is put responsible on site on day-to-day basis, using a well developed set of on-site environmental control guidelines on rehabilitation, monitoring and other activities. These will actually be included in the tender document. Annual environmental audit will also be done to monitor progress against annual targets.

Phase IV: Decommissioning

It is prudent to develop a decommissioning plan for a mine long before closure is contemplated so that pre-emptive action can be taken while the mine is still in production. The decommissioning plan should be a comprehensive document which includes environmental aspects such as final rehabilitation, long-term pollution control and monitoring.

iii) CONCLUSION

Adoption of Integral Environmental Management (IEM) as an integral part of mine development and operation would result in less need for prescriptive and restrictive legislation. By being proactive in this regard, the mining industry could lead by example and quieten its critics. IEM is really only good planning, and **good planning is cost-effective**.

APPENDIX X

CASE STUDY No VII

Environmental Policy of RTZ and its subsidiary- the Rossing Uranium Mine; Namibia, 1993.

(Rossing, 1993)

The environmental policy of RTZ and its subsidiary- Rossing Uranium is summarised. RTZ's fundamental declaration of intent is that all group companies must be managed so that their activities are acceptable to the local communities and any adverse effect on the environment be reduced to the practicable minimum. RTZ sees its responsibility towards the environment as essentially good business practice; an integral part of the day-to-day operations, as well as long term strategies. RTZ requires all group companies to comply with relevant rules of national and international rules and regulations as a starting point. RTZ expects its companies to build on this basic compliance and to improve on these standards wherever this is possible. This applies at each stage from operation from exploration to closure (Rossing, 1993).

The Rossing Uranium Limited in turn has a comprehensive health, safety and environmental management programme in place. This is set out in a detailed "Policy Statement on Health, safety and Environment" signed by the Managing Director and endorsed by the Rossing Management. This Policy Statement is based on the following:

a) Rossing believes it is the right of every employee to work in safe conditions and that the general public, as well as employees, must be protected from potential health hazards associated with the operations of the company.
b) Rossing undertakes to conform with the highest standards appropriate to the circumstances of the operation and the area in which it is located (Rossing, 1993).

In anticipation of mine closure after the ore is mined out, the Rossing decommissioning plan, which in 1992 was estimated at R162.2 million (revised annually), sets out appropriate action to be taken. These deal with aspects such as radioactivity, water and air quality and the rehabilitation of the mine sites (Rossing, 1993). The main elements of decommissioning are:

a) Stabilising the tailings and covering them with a layer of crushed rock.

b) Cleaning, dismantling and removing all man-made structures.

c) Landscaping the site of the processing plant area and covering it with waste rock and alluvium.

d) Fencing the mine area.