POST CLOSURE ENVIRONMENTAL IMPACTS OF ASBESTOS MINING IN PENGE, LIMPOPO PROVINCE, SOUTH AFRICA

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A research report submitted to the faculty of Science, University of the Witwatersrand, Johannesburg, in partial fulfillment of the requirements for the degree of Master of Science.

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DECLARATION

I declare that this dissertation is my own work and has not been previously submitted for any degree or examination at any university. It is being submitted for the Degree of Master of Science at the University of the Witwatersrand, Johannesburg.

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Mr Gift Matsabatsa
School of Plant, Animal and Environmental Science,
24 July 2009.

ABSTRACT

Asbestos mining in South Africa has been carried out for more than a century. The Penge Mine started operations in 1914 and was closed in 1992. Following closure of the mine, the houses and mine buildings were used for residential purposes by former workers and by local inhabitants. The Department of Minerals and Energy (DME) conducted rehabilitation of the asbestos mine dumps, following rehabilitation, the Limpopo Local Government proposed to declare the mine village a formal living area and this concerned a number of stakeholders, especially the Asbestos Relief Trust (ART). Dr Stephen Donohue, a former principal specialist in the Department of Health and Social Development, conducted a site visit to Penge in December 2006 to assess plans for development of the village and hospital. He found that the Penge area was heavily contaminated with amosite asbestos and was not suitable for human occupation.

The objectives of this study were to review literature in order to explore and compare case studies from around the world on asbestos dump rehabilitation, to analyze and interpret soil, fauna and flora data collected by Rehabilitation Design and Construction (REDCO) Services and to critique the DME guidelines on rehabilitation of asbestos mine dumps. The results of the study highlighted that asbestos mining results in environmental contamination and health problems. The review of the case studies showed that the most common asbestos mine dump rehabilitation method is capping, whereby topsoil (asbestos free) is used to cover the mine dumps and indigenous vegetation is planted. Communities living in the vicinity of contaminated areas are either temporarily relocated during rehabilitation or they are permanently relocated in their best interests and the environment. Rehabilitation areas are usually fenced to restrict access to humans and animals. It was also noted in the case studies that extensive monitoring programs were developed in order to assess the success of the rehabilitation process. Asbestos fibres can contaminate the environment for many decades and monitoring programmes need to be of a long-term nature.

Analyses and interpretation of the data collected by REDCO highlighted poor record keeping by DME on rehabilitation measures implemented at Penge, information was either incomplete or was not available. The dumps were capped with 300 mm topsoil and available information indicated that three different treatments were applied with respect to re-vegetation: 1) Dumps 1 and 2 were planted by spreading manure containing *Dichrostachys cinerea* and *Acacia tortilis* seeds; 2) Dumps 3, 4, 5, 6, 7 and 8 received no treatments; 3) Dumps 9, 10 and 11 were planted with *Euphorbia tirucali*. No manure was applied. No grasses and forbs were planted during the rehabilitation of the dumps. There are no data on where the soil was sourced or its properties, hence, there was no baseline data for this study. Soil, fauna and vegetation data were collected by REDCO from the dumps in 2007. Whilst there were very few treatment effects, the results did indicate that significant amounts of vegetation had established on the dumps. It was noted that carbon levels were low and that organic matter should be added to the system for long term sustainability.

The DME formulated technical guidelines on the rehabilitation of asbestos mine dumps in South Africa. Although the guidelines where formulated after rehabilitation of the mine dumps was complete, the dumps were rehabilitated according to the requirements of the guidelines. However, the requirement of monitoring following rehabilitation was not followed through in Penge. The DME guideline requirements are similar to the rehabilitation efforts implemented in other parts of the world. Dispersement of allocated funding from the DME to consultants and contractors limits rehabilitation of dumps in South Africa. Although the guidelines were not completely followed, this study identified some positive outcomes. The results presented in this project should be utilised as a baseline for future studies in order to determine the success or failure of rehabilitation efforts. Overall the study indicated that the Penge community was at risk of contracting asbestos related diseases and that the best solution for the local community would be permanent relocation. In addition, continuous monitoring should be conducted at Penge to monitor the success or failure of rehabilitation in the long term.

This research report is dedicated to

God Almighty

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ABBREVIATIONS AND ACRONYMS

PRU:	Pneumoconiosis Research Unit
DME:	Department of Minerals and Energy
ART:	Asbestos Relief Trust
REDCO:	Rehabilitation Design and Construction Services (PTY) LTD
USEPA:	United States Environmental Protection Agency
ANOVA:	Analysis of Variance
NAS:	National Asbestos Summit
I&APs:	Interested and Affected Parties
RPI:	Rehabilitation priority index

1. INTRODUCTION

1.1 Study Background

Asbestos has been mined and used in a range of applications for many years. Asbestos usage started as early as the 19th century when asbestos fibres were mixed with cement to form asbestos cement (Laurie, 2006). In South Africa, asbestos production started in 1893 (McCulloch, 2002). By 1930, following several years of asbestos mining across the world, there were already strong fears that asbestos posed significant health risks. However, many countries continued to mine and use asbestos material, disregarding the health impacts, including South Africa, where amphibole asbestos was mined until 1992, whilst serpentine asbestos mines continued with operations after 1992 (McCulloch, 2002). Mining of amosite asbestos in Penge started in 1914 and stopped in 1992. Between 1920 and 1992, Penge was the largest amosite asbestos mine in the world (Anso, 2001; Morris, 2007)

This study was undertaken to investigate the extent of the success of rehabilitation of the asbestos mine dumps in Penge which was completed in 1996, as well as the impacts posed by the dumps on human health and the surrounding environment.

Chapter 1 describes the study area, asbestos types and common asbestos health effects associated with asbestos exposure. The objectives and the framework of the study will also be presented and described.

1.2 Study Area

Penge is a town situated approximately 80 km north of Burgersfort, in the Greater Tubatse Local Municipality and Greater Sekhukune District Municipality of the Limpopo Province, in the northern part of

South Africa. It is located south of the Pietersburg asbestos fields (Sluis-Cremer, 1965). A map indicating the location of the site in South Africa is presented in Figure 1 and an aerial photograph indicating the location of mine dumps identified by dump numbers is presented in Figure 2. The Pietersburg fields extend in an 80 km arc from Malisdrift in the north-west to the confluence of the Olifants and Steelpoort Rivers in the south-east (Hall, 1930). The Penge asbestos mine and village are located in the south eastern extremities of the Pietersburg asbestos field (Davis *et al*., 2004).

1.3 History of Asbestos Mining in Penge

Small scale asbestos mining began in Penge in 1914 and it is estimated that by 1949 there were approximately 23 very dusty asbestos mills in the Penge area (Anon, 1953). During this mining period, mine dumps were formed by waste rock and waste material from the mills. Site buildings and residential quarters were constructed for mine workers. According to a survey conducted by the Pneumoconiosis Research Unit (PRU) of the area in 1962, everyone who lived in the area was at risk from asbestos contamination. The survey concluded that all people in the area were at risk even though some had no industrial asbestos exposure (PRU, 1963). The mining company GEFCO started rehabilitation of asbestos mine dumps in 1986 until closure of the mine in 1992. Following closure of the mine, approximately 250 houses and other buildings previously belonging to the mine were used by local people and former mine employees for residential purposes (Donohue, 2007).

Figure 1: 1: 5 500 000 map indicating the location of Penge in South Africa (South African Map Studio, 2004)

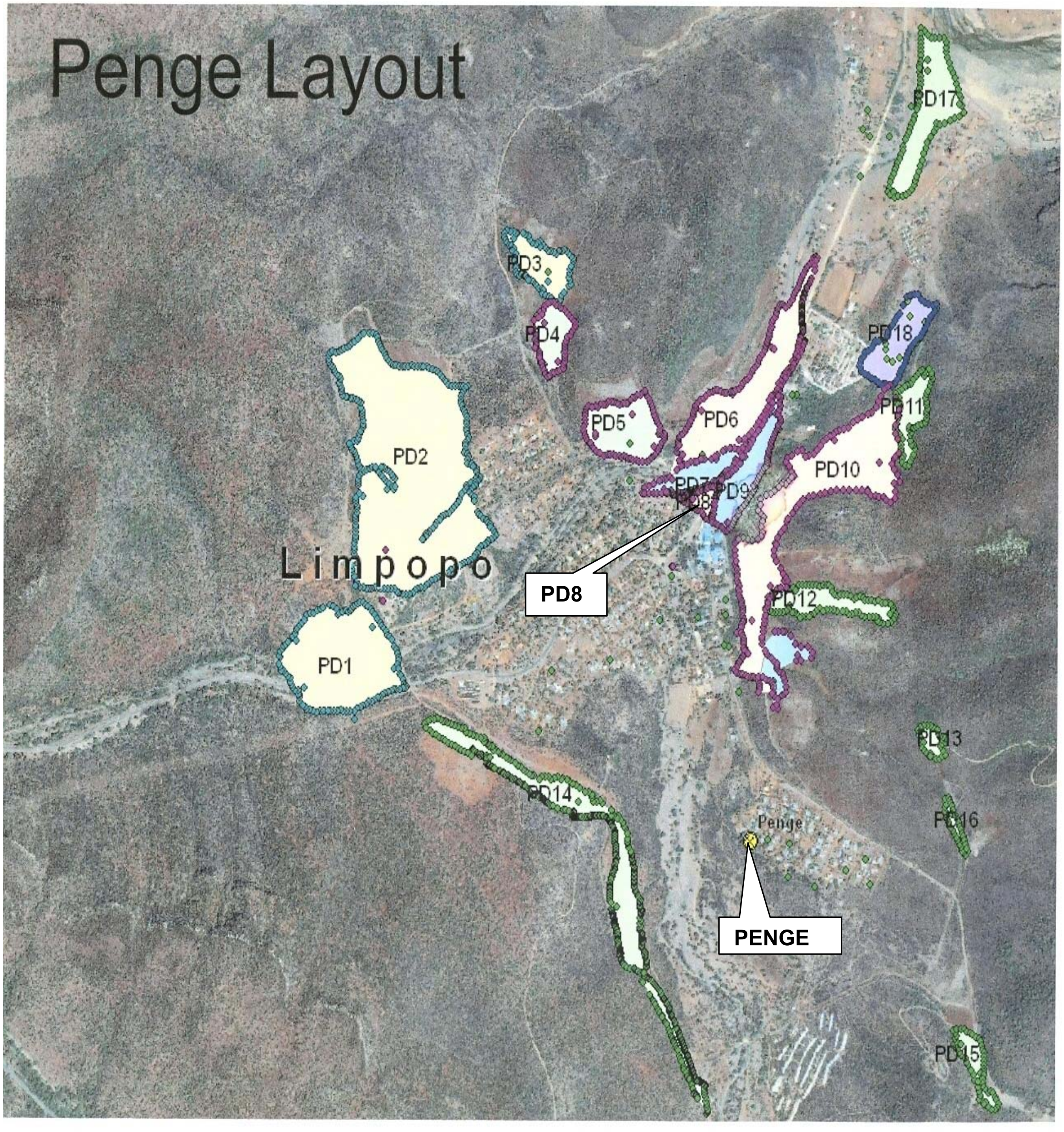

Figure 2: Aerial photograph of the layout of Penge town and mine dumps with mine dump numbers as identified by the Department of Minerals and Energy (Not to scale)

1.4 Asbestos and its Health Impacts

Asbestos is a name given to a class of mineral silicates which crystallize into fibres which may be long and thin in an ore body (Harrington and McGlsham, 1998). It is a highly resistant mineral that can withstand heat and corrosive chemicals and this is the characteristic which gives it its name, derived from a Greek word meaning "inextinguishable, unquenchable or inconsumable" ("Asbestos Facts"). Asbestos fibres can be divided into two mineral groups, namely amphiboles and serpentines (Ross et al., 1984), and can be further divided into three commercial varieties all of which have been mined in South Africa. These commercial types differentiated according to their characteristics are: chrysotile asbestos, a white curly fibre, amosite, a brown or grey straight fibre and crocidolite asbestos, a blue straight fibre (Harrington and McGlsham, 1998; Virta, 2002).

Uses of asbestos include insulation material, braking for automobiles and building materials (Ross et al., 1984). Not withstanding the benefits offered by asbestos, the mining, processing and utilization of asbestos and its products, have negative consequences on health effects and can cause significant environmental degeneration. Exposure to asbestos dust poses a health risk to a population residing in close proximity to asbestos dust sources. Three common asbestos related diseases are as follows:

1. Asbestosis – the scarring of lungs leading to breathing problems and heart failure. Asbestosis is caused by inhalation of asbestos fibres which are not fully removed from the lungs and may cause fibrosis (scarring) and chronic breathing difficulties (McCulloch, 2002);
2. Lung Cancer – Inhalation of asbestos dust particles can cause lung cancer, accounting for approximately 80% of asbestos related cancer cases. Smoking greatly increases the chances of lung cancer to people exposed to asbestos (Agency for Substances and Disease Registry, 2007), and

3. Mesothelioma – Rare cancer of the chest lining (pleura). Mesothelioma occurs when the inhaled asbestos fibres move through the lungs into the lining where they form aggressive tumors. This cancer is slow and painful (USEPA, 2008).

Many people have lost their lives due to illness which resulted following occupational and environmental exposure during mining and milling of asbestos (Sluis-Cremer, 1970). New asbestos related infections in some areas continue even after the closure of mines. This is as a result of inadequate rehabilitation of mine dumps, or the use of land previously contaminated with asbestos for residential development. Asbestos fibres from un-rehabilitated or poorly rehabilitated mine dumps are lifted and transported in the air to communities living in the vicinity of the old mines (Le Roux, 2007). People living in former mining areas are affected long after the closure of the asbestos mines. Rehabilitation of asbestos contaminated areas is difficult and it would be impractical to say that once contaminated areas can be free of asbestos fibres (Otness *et al*., 2003). The South African Government spends millions of rands in an effort to rehabilitate inadequately rehabilitated mines and mine dumps which pose a threat to the environment and communities in surrounding areas. One of these areas on which rehabilitation efforts have been directed is Penge. Although the mine dumps in the area were rehabilitated by the Department of Minerals and Energy (DME), a site investigation conducted by Dr Donouhue in December 2006 revealed that the area was highly contaminated and was unfit for human occupation (Donohue, 2007; Sithole, 2008). The Limpopo local government proposed to establish the former Penge asbestos mine area and mine village as a formal township. This proposal raised concerns with the Asbestos Relief Trust (ART), an organization that was formed in March 2003 to distribute compensation for victims of asbestos exposure and to prevent further infections (www.asbestostrust.co.za). The proposal of the local government was viewed by the ART as a set back to efforts made in the prevention of new infections and management of existing infections. Establishing a township in the former mining area where asbestos contamination is still present, allows opportunities of renewed infections with undesirable health and economic consequences. Dr. Steven Donohue had advised the local government regarding the high asbestos contamination levels present at the site. Taking into consideration the highly contaminated environment of Penge and the proposed establishment of the area as a formal township which is likely to result in immigration of people into the area, ART is concerned with future hazardous exposure, and the socio-economic impacts thereof.

1.5 Objectives of the Study

Objectives of the study are as follows:

- To review literature in order to explore case studies on asbestos dump rehabilitation for comparative purposes;
- To analyze and interpret the data which have been collected by Rehabilitation Design and Construction (REDCO) Services, in order to document the impact of rehabilitation on soil and microbial properties as well as on plant species, and
- To critically review the technical guidelines on rehabilitation of asbestos mine dumps in order to provide recommendations to improve the environmental condition at Penge

The research is broadly based on the analysis of existing data collected by REDCO from the site, from documents supplied by the DME and from published and unpublished material, which will be used to meet the above objectives.

The research report is structured as follows:

Chapter 1: Introduces the topic and gives a description of the study area and information on health impacts of asbestos and asbestos types.

Chapter 2: Reviews the literature on rehabilitation of asbestos mine dumps using case studies from around the world on rehabilitation of different types of asbestos.

Chapter 3: Reviews literature and data on the impacts of asbestos mining on the soil, fauna and flora, and human health. Presents materials and methodologies used during the research and discusses the results of the investigation.

Chapter 4: Reviews the unpublished DME standard protocol and guidelines for rehabilitation of derelict/ownerless asbestos mine residue deposits in South Africa.

Chapter 5: Presents a general discussion on the literature review and results of the research.

Chapter 6: Presents a list of references reviewed during the study.

CHAPTER 2: CASE STUDIES ON ASBESTOS REHABILITATION

2. CASE STUDIES ON ASBESTOS REHABILITATION

2.1 Introduction

The health impacts of asbestos were identified as early as in 1899 by Dr. Montague and public concern of asbestos health impacts also started at the same time, however, asbestos mining continued with limited regard of the health impacts until around 1971, when North America introduced dust legislation (Tweedale & Hansen, 1998; Cudgell & Kamp, 2004). The significance of the health impacts posed by asbestos fibres prompted rehabilitation of asbestos dumps and other asbestos contaminated areas. Experiments have been conducted around the world on the rehabilitation of asbestos contamination in former mining areas and this has led to various methods being implemented in different parts of the world to address asbestos contamination. A number of rehabilitation approaches, case studies and procedures are presented below.

2.2 Rehabilitation of Asbestos Contaminated Areas

2.2.1 Pano Amiantos Asbestos Mine, Cyprus

Pano Aminantos is located within the Republic of Cyprus which is situated approximately 75 km south of Turkey (Dimokratia, 2008). The Republic of Cyprus covers an area of 9 251 km^2. Pano Aminantos lies east of the Olympus town in the mountain range of Troodos (www.panoamianodos.org). The mine site is located between the Livadhi and Loumata Valleys.

The asbestos mining operation initially occupied a small area and by the time the mine was closed, an area of approximately 220 hectares had been mined (Pearce *et al*., 2007). Asbestos mining in Cyprus was conducted between 1904 – 1988. Chrysotile asbestos was mined over an area of 6.5 km^2 using the open cast mining method (Kyrou & Petrides, 2005). In 1947 asbestos produced from the mine had reached 35 000 tons per year, resulting in approximately three to five million tons of waste production per year. The mining operations gave rise to the development of Pano Aminantos Village. During the early stages of the mining operations, in the 1930's, the mine employed more than 10 000 people. When the mine was closed it had a population of approximately 650 people and the number declined further as the years passed and in 2001, the population of the village was only 61, as people had moved in search of employment (Pearce *et al*., 2007).

Operation of the mine boosted the economy of Cyprus extensively, providing employment to the local people and attracting workers from neighbouring villages. The mining operations in the area also had negative impacts. The major environmental impacts that were identified with the closure of the mine were the open pit, waste tips and contamination of soil and surface water posing a health risk to people. Large tracts of flora and fauna were destroyed during the operations. The waste material from the mine was scattered across the mining area. The presence of the exposed mine dumps posed a health and environmental risk .

The council and ministers decided that rehabilitation work had to be undertaken. Rehabilitation of the mine started in 1995. Priority was given to the stabilization of the waste tip slopes which posed a safety risk to properties below the mine and pit area. Washing away of asbestos material by surface water was also a concern and so were the angles of the slopes. The final outcome was expected to be a reforested area with limited or no asbestos contamination (Pearce *et al*., 2007).

Liquefaction resulting in the waste possibly sliding down to a nearby village was taken into consideration during the rehabilitation of the slopes. Liquefaction is a condition whereby material becomes fully saturated and is mobilized due to events such as earthquakes. Tsuchida (1970) noted that uniformly graded fine sands and silts have a high potential to become liquefiable. Observations were made by

Seed *et al*., (1984) that according to empirical correlations based on standard penetration resistance, liquefaction is not possible in these soils by earthquakes of magnitudes below 7.5 on the Richter scale.

A slope stability analysis was conducted for static loading and earthquake loading. The first step of rehabilitation was to ensure that the slopes were stabilized. Slopes on the mine dumps were reprofiled with the objective of ensuring that inclines did not differ significantly from others in the area and to ensure that the slopes would be safe. The mine dumps were graded to create a gradient of 2:1. The design of the mine dump profiles ensured that the surface water was intercepted to prevent erosion of the dumps. More than 3.6 million m^3 of asbestos waste material were handled during reshaping of the dumps (Pearce *et al*., 2007).

Following reshaping of the slopes, reforestation efforts were implemented. The initial preparation was the construction of 0.8 metre (m) deep trenches at 5 m apart in the flat area, to allow trucks access to the dumps for the delivery of top soil. The top soil was used to fill the trenches. On the slopes, two secondary terraces 1.2 m wide were constructed. The mine dumps were then capped with approximately 30 cm of fertile top soil. Monitoring systems were installed to measure surface and groundwater movements in the waste; results indicated that movements were more pronounced during wet winter months (Pearce *et al*., 2007).

Planting was then carried out on the terraces and trenches. Seed sowing was applied in the other areas of the prepared dumps using different species. Species used for planting along the trenches and terraces were *Pinus brutia, Cedrus breuifolla, Rhus coriaria, Rabinia psedoacacia, Cupressus sempervirens, Quercus alnifolla, Arrbutus andrache, Sorbus aria, Juniperus foetidissima, Clematis vitalb* and *Pistacia terebinthus.* Other areas of the dumps were sown with *Pinus brutia, Robina psedoacacia, Rhus coriaria, Allanthus altissima, Alyssum cypricum, Eschscholzia califorrica, Alcea roses, Solvia willeana, Pterocephalus multiflorus, Helichrysum ilalcum, Cistus cretica, Cistus salivifollus, Phytolacea pruirosa* and *Vicia tenuifolia*. Species used for planting and sowing were collected from plants growing in the region.

The capping of the dumps and reforestation proved to be successful. Vegetation established in the applied top soil and most of the rehabilitated areas were covered (Kyrou & Petrides, 2005).

This case study emphasised the importance of ensuring correct reshaping of the slopes to limit soil erosion and enhance establishment of the vegetation. Since asbestos contaminated soil inhibits plant growth, it is imperative that a suitable substratum is provided for the vegetation. The soil used for capping the dumps should preferable be planted with indigenous species. This will ensure that the vegetation will survive in the local environment.

2.2.2 Millington Asbestos Processing Plant, New Jersey, USA.

Millington is situated in New Jersey, in the eastern United States of America. The processing plant is located at 50 Division Avenue, Millington.

The site consists of 4.4 hectares of land which was used as an asbestos processing plant and for the disposal of asbestos and asbestos containing material. Millington had a population of 7 800 people in 2007 (USEPA, 2007 a).

Chrysotile asbestos processing operations at the site started in 1927 and stopped in 1978 (USEPA, 1988). Water from the plant was impounded at the site in dams. Sediments containing asbestos material were removed from the pond and disposed of on site. Waste generated from the processing plant was also dumped at the site over an area of two hectares. Over time, waste production at the site exceeded the waste storage capacity and additional waste was transported off site for disposal. Approximately 68 400 million m^3 of asbestos materials had been dumped at the site by the time the plant stopped operating (USEPA, 1988).

The asbestos dumps were identified to pose a health risk through inhalation and ingestion of asbestos fibres. Asbestos dumps were also found to be too close to the rivers in the area posing potential contamination. Soil assessments conducted at the site also revealed elevated concentrations of mercury and nickel at the site (USEPA, 1988).

During the rehabilitation of the site, a retaining wall was constructed at the foot of the mine dump close to the river. The retaining wall was constructed using a pre-cast concrete mat. Water diversion channels were constructed around the dumps to prevent them from being washed away. A 0.60 m soil cover was applied over the mine dumps. The area was fenced off and warning signs placed at the site. Access to the site was restricted. The rehabilitated area was vegetated with native species. Monitoring of rehabilitation efforts was to be conducted over a 30 year period and are currently underway. Over the monitoring period, some areas had to be rehabilitated due to the exposure of fibres by erosion, while in other areas revegetation had to be implemented as the vegetation had failed to grow (USEPA, 2007 a).

Rehabilitation efforts are constantly undermined by erosion of the cap material which results in the exposure of the underlying fibres. This project demonstrates the need for ongoing rehabilitation efforts to ensure success. In addition, for satisfactory results, a rehabilitated area may require fencing to limit disturbance to the rehabilitation process.

2.2.3 Coalinga Asbestos Mine, California, USA.

The City of Coalinga is situated in Fresno County, California and lies west of Central San Joaquin Valley. The asbestos mine site is located approximately 27 km from Coalinga in Fresno County (USEPA, 2007 b).

The Coalinga asbestos site covers an area of approximately 300 hectares. A chrysotile asbestos mine and milling plant operated at the site from 1963 and the last operations were conducted in 1974. The operations resulted in the formation of asbestos mine dumps and two open pits that covered an area of 50 hectares. Asbestos from the milling site was transported to the city of Coalinga for storage and shipping, resulting in contamination of an area of 268 hectares in the city (USEPA, 2007 b).

Coalinga Asbestos Mine is located within a rural area. The asbestos tailings created at the site posed a health risk to residents in the former mining area and to people visiting the area. Asbestos fibres were also found to be washed away during rainy periods, into water courses posing an environmental and health risk.

Rehabilitation efforts started in 1993 after the potential impacts were identified to be significant. Asbestos tailings were graded to stabilize the dump slopes. Diversion of rivers that ran close to the asbestos dumps took place to prevent washing away of asbestos fibres. The existing sediment trapping dam was improved to further limit washing away of tailings into rivers. The graded asbestos tailings were capped with clean fertile soil. A pilot project for revegetation of the mine dumps with indigenous species was conducted at the site. The project was considered to be a success and all the mine dumps were revegetated with indigenous species. Following completion of the rehabilitation, the area was fenced off and access restricted (USEPA, 2007 b).

Monitoring investigations conducted in 2007 following rehabilitation, indicated that the rehabilitation measures implemented at the site were successful and access was still restricted (Envirostor, 2007).

This case study confirms that asbestos fibres in waste dumps can be transported over long distances by running water. To restrict the spread of asbestos fibres by water, a settlement pond can be constructed to ensure that minimal asbestos fibres find their way into water ways. Constant monitoring and fencing of the site also contributed to the success of the rehabilitation.

2.2.4 The City of Coalinga, California, USA.

The City of Coalinga is located within the Fresno County in California, approximately 27 km south of the Coalinga Asbestos Mine. The city had a population of approximately 1700 people in 2007 (Envirostor, 2007).

Mining activities of asbestos and chrome ore in the vicinity of the city resulted in the development of an industrial area within the city, where these materials were milled, manufactured, stored and transported out of the city. This industrial area is located along the Highway 198 on the south western end of the city (USEPA, 2001).

The operations of the area as a handling and storage site, resulted in the accumulation of asbestos waste and ore material. The contamination covered an area of approximately 268 hectares between the intersection of Lucille Avenue and Highway 198. The area was covered by approximately 15 200 m^3 of asbestos, chrome and nickel contaminated soil (USEPA, 2007 b). Health impacts associated with the inhalation of asbestos dust and contamination of soil was identified at the site and rehabilitation measures formulated.

As a temporary measure in response to the identified potential environmental and health risk, the contaminated area was closed off allowing restricted access. Dust emissions were suppressed using a biodegradable sealant and by covering waste ore with plastic sheeting. Permanent rehabilitation measures were implemented in 1989. A waste disposal unit was constructed at the site by excavating a portion of the site. Asbestos contaminated materials were removed and consolidated. Buildings in the area were also decontaminated. The consolidated waste materials were disposed of in the waste disposal unit. Following disposal, the surface of the waste disposal unit was capped. The capping process was conducted by compacting soil over the waste materials and then an impermeable clay mat was compacted over the base soil. An additional soil layer was finally added. Indigenous vegetation was planted over the rehabilitated area (USEPA, 2007 b).

Monitoring of the rehabilitation efforts indicated that the soil and air in the area were clean. The area of the waste unit was fenced off and access restricted. Additional monitoring conducted at the waste unit area identified damages to the unit, caused by burrowing animals. Vegetation was found to grow successfully and be self sustaining with no irrigation required. Significant erosion impacts were noted on the rehabilitated area which were caused by rainwater. The site was maintained on a monthly basis whereby vegetation growth was monitored, fertilizer was added where required, deep rooted vegetation was removed and the burrow holes filled. After five years the site was declared fully self sustaining, requiring infrequent monitoring (USEPA, 2007 b).

The City of Coalinga asbestos rehabilitation project highlighted that asbestos mining and its associated impacts is not only limited to the mining and milling areas. Asbestos dumps are also generated at the manufacturing and storage plants located away from the mine area. This case study highlights variations in the application of the capping method. At this site asbestos wastes were found to have significant health impacts and a short term solution, which was the implementation of a dust suppression technique, to limit asbestos exposure during and before rehabilitation was implemented. Permanent rehabilitation of asbestos material at the site was undertaken by excavating an area where the asbestos was disposed of and a soil layer added. For additional in protection, three layers of soil were added with two layers being compacted, forming an impermeable layer. This limited the process of erosion and increased the stability of the capping layer. In addition, it was noted that deep rooted vegetation could also pose a threat to the success of a rehabilitation plan. Vegetation with deep roots had to be monitored and removed if suspected of posing a risk to the capping surface.

2.2.5 Atlas Asbestos Mine, California, USA.

Atlas asbestos mine is located approximately 20 miles north west of the City of Coalinga in Fresno County, California. The mine site is situated 4.8 km west of the Coalinga Asbestos Mine (USEPA, 2006).

Chrysotile asbestos mining was conducted on a 350 hectare site. Asbestos operations were carried out from three open pit mines. Asbestos was milled on site before being moved to the City of Coalinga for distribution to consumers. The mining operations started in 1967 and were closed in 1979. The mining and milling operations resulted in the development of 2.3 million m^3 of asbestos tailings (USEPA, 2006).

Elevated levels of asbestos fibres were detected in 1980 in water samples collected from the California aqueduct. Water analysis from rivers in the area and from the air also revealed increased asbestos concentrations. The source of the asbestos fibres was identified as the Atlas Mine. It was decided that remedial action was to be implemented at the site. Rehabilitation efforts were directed at eliminating release of asbestos fibres into the air and into local rivers. Rehabilitation activities started in 1994 (USEPA, 2006).

Rehabilitation measures implemented at the site, included stream diversions, sediment trapping, grading of asbestos tailings and revegetation. Several sediment ponds were constructed at the site to retain sediments from stormwater runoff. Sediment storage areas were also constructed close to the settlement ponds. The mine dumps were graded to stabilize the slopes. Water diversion channels were constructed around the graded mine dumps diverting water into impoundment ponds. The main access road to the site was paved with a double bituminous cap and a soil stabilizer was applied on the access roads to the ponds, to limit dust emissions. The rehabilitated area was then revegetated with indigenous species. The area of the site was fenced off to limit access (USEPA, 2006).

Trials were conducted to assess the plant species and soil to be used for the treatment of the site. Approximately 2 356 m^3 of soil were added to an area of 7.4 hectares and 10 000 individual plants were planted. Hydro seeding was applied to approximately 3.7 hectares of the rehabilitated land. During the treatment and planting processes, the soil applied to the area was mixed with organic compost, slow releasing fertilizer and gypsum. Shrubs were planted in contours and grass seeds applied in the form of a hydro seeded slurry (USEPA, 2006).

Follow up monitoring investigations conducted in 2005 at the site, revealed that soil erosion was taking place in some areas of the site and these areas were attended to by recapping the exposed soils. Vegetation monitoring revealed that vegetation was growing in a satisfactory manner. Vegetation efforts were deemed successful as new vegetation had established in the rehabilitation area and outside the vegetation area (USEPA, 2006). Self dispersal of vegetation was also taking place at the site.

The Atlas case study highlights the importance of ensuring that rivers in asbestos contaminated areas should be diverted away from the dumps to limit erosion of the dumps and contamination of the rivers. Impoundment dams should be constructed in areas where rivers are located close to the mine dumps and in areas which have a high erosion potential, to capture material eroded from the dumps. This rehabilitation technique requires continuous monitoring, as the ponds need to be dredged to prevent sediment build up. The study also highlights that asbestos contamination is not limited to the dumps of the mine, but extends to other areas close to the mine such as roads. Movement of vehicles on contaminated roads may release asbestos fibres into the air and the roads should be capped with a hard surface to prevent release of the asbestos fibres.

2.2.6 Southern Quebec, Canada.

Quebec is situated in Canada to the north of Montreal, lying along the river Becanour of the Appalachins (Dubios & Mailhot, 2008). The asbestos mining area is located in the southern parts of Quebec.

Chrysotile asbestos has been mined in southern Quebec from 1877 and is the largest open pit asbestos mine in the world (Kuyek, 2003). More than 125 000 tons of asbestos has been produced in the area since 2002. The mines in the area produced almost 40% of the world's asbestos (Ross, 1967). Asbestos mining in the area resulted in the formation of large volumes of asbestos tailings and in some areas houses had to be relocated to make space for the mining operations. Asbestos waste of approximately 5.5 km^2 has been in existence for up to 60 years, with no vegetation or limited vegetation growing on these dumps (Kuyek, 2003).

The asbestos mining activities in the area resulted in the deterioration of health conditions within the local community. Asbestos mining still continues in the area. Recent air and soil sampling conducted at the site indicated that there were high concentrations of asbestos fibres in the area (www.cbcnews.ca). The state government benefits significantly from the asbestos operations in the area and, therefore, health and environmental impacts were not publicised. Limited rehabilitation efforts have been implemented. A study was conducted by Moore and Zimmerman (1977) on flat topped and sloping asbestos mine dumps to assess factors that inhibited plant growth in these areas, and to find solutions that could be used to improve plant growth. The study aimed to specifically study the effects on plant growth by adding inorganic and organic fertilizer to the contaminated soil.

Nine 4 x 4 m plots, divided into two subplots of 2 x 4 m, were established on the asbestos dumps. A mixture of agricultural fertilizer containing ammonium nitrate, potassium sulphate and super phosphate were added to the mine waste at different rates of 0, 0.1, 0.25, 0.5 and 1 kg/m^2. Farmyard cow manure was also applied at 1 kg/m^2 or 4 kg/m^2. The amalgam was applied to the upper 5 to 10 cm layer of the mine dumps and seeded with a mixture of common agricultural grasses and legumes at a rate of 20 g/m^2 (Moore and Zimmerman 1977).

The results of the experiment revealed that the combination of 1 kg/m^2 of fertiliser and 4 kg/m^2 of manure was the most successful treatment resulting in more than 90% plant cover. Plant growth and health were more pronounced on the flat tops than on the slopes. The dominant grass species were perennial rye-grass (*Lolium perenne), Poa pratensis, Elymus junceus, Bromus inermus, Poa palustris* and *Hordeum Jubatum.* The most successful legumes used were *Trifolium hybridum* and *Melilotus alba*. The most suitable grass species, *Elymus junceus*, was the only species that produced roots extending more than 10 cm into the untreated asbestos waste. Treatment of asbestos waste resulted in sustainable vegetation growth on the mine dumps (Moore and Zimmerman 1977).

The southern Quebec case study highlights the fact that asbestos tailings inhibit growth and if not treated, the mine dumps will remain exposed. Some mine dumps in the case study have been in existence for more than 60 years and only have limited vegetation. The study conducted by Moore and Zimmermann (1977) showed that the treatment of asbestos tailings with large amounts of fertilizers improved vegetation growth. In addition, certain vegetation species may require treated soil during the early development stages and once established will continue to grow on asbestos tailings. This was observed with *Elymus junceus* which extended its roots more than 10 cm into the untreated asbestos waste. Such species are likely to require limited maintenance.

2.2.7 Libby, Montana, USA

Libby is a small town located in the north-western corner of Montana, 56 km east of Idaho and 105 km south of Canada in Lincoln County. To the east of Libby are the Zolite Mountains. The town sits close to the bed of the Kootenai River which flows from Canada towards the Columbia River. The Libby area boasts a population of less than 3000 with approximately 1200 people living within a 16 km radius of Libby (USEPA, 2003).

Vermiculite was mined and processed in Libby employing more than 1900 people from 1919 to 1990 (USEPA, 2007 c). During its operation, Libby mine produced 80% of the world's supply of vermiculite. Vermiculite is heated at high temperatures until it pops in order to create pockets of air in the material, making it suitable for use as insulation material and for soil amendments. Vermiculate was also processed to create zonolite (Walker *et al*., 2002). The vermiculite mined in Libby was contaminated with tremolite-actinolite series asbestos, a type of asbestos which is relatively uncommon and often referred to as tremolite, libby asbestos or libby amphibole. The waste rock and waste from the mills was stockpiled within the vicinity of the different operations. Asbestos dust from the waste dumps was blown to other areas of Libby where it settled, covering buildings and other infrastructure. The asbestos contaminated vermiculite is estimated to have affected more than 3 500 properties (Walker *et al*., 2002).

Several residents and former employees of the vermiculite mine and processing plant died and others became ill. The adverse health effects on the communities were blamed on the presence of asbestos from the vermiculite mined and processed in the area.

The United States Environmental Protection Agency (USEPA) began investigating asbestos contamination of properties in 2002 and libby asbestos dust was found to pose environmental and health risks. The major source of asbestos were determined to be from the mine and from the screening and exporting plants. Investigations were conducted by visual observation of vermiculite material on buildings and plots. Visual identification of libby asbestos is more difficult than that of the vermiculite material. Vermiculite sampling produced a 70 % presence of libby asbestos within each sample and based on the observations, it was concluded that cleaning up of vermiculite greatly assisted with the removal of libby asbestos. The USEPA initiated emergency remediation work to eliminate the risk to human health.

Soil sampling commenced in 2002 and contaminated areas were identified. Contaminated waste was safely removed from the major sources in August 2002 (USEPA, 2007 d). Contaminated soil was excavated from each property and removed for safe disposal off-site at a mine shaft. Dust and other contaminated materials found on buildings were removed for disposal. During the cleanup period residents were temporary relocated until the rehabilitation was completed. Excavations were then filled with top soil. Following the cleaning of the area, asbestos contamination was found to be within acceptable levels. Asbestos contamination in the town continues to be monitored closely (USEPA, 2007 d).

The Libby vermiculite mine case study highlights that rehabilitation of asbestos impacts should not only focus on the dumps, as dust fibres can be transported by air and water to other areas in the vicinity of the dumps. Rehabilitation efforts should also include, decontamination of properties in the vicinity of the mine dumps.

2.2.8 Wittenoom, Australia

The town of Wittenoom is located in Pilbara, Australia (www.asbestos-post.com). The town developed in 1937 due to asbestos mining activities in the area, and by the late 1940, it was the largest town in north-western Australia. Wittenoom was the main source of blue asbestos in Australia. The towns people were relocated in the late 70s and already more than 40 people had died from asbestos infections and others had been infected with asbestos related diseases. The air quality of the area had been determined not to be suitable for human occupation. The Australian government had been trying to close the area down since 1970 and only managed to remove the last person in 2006 (Parsons Brinckerhoff, 2006).

Approximately 150 000 tons of blue asbestos was mined between 1937 and 1966. Asbestos was mined from three mines namely the Yampire, Wittenoom and Colonial asbestos mines, which resulted in over three million tons of asbestos tailings. Asbestos was blown across the mining area over a distance of approximately 10 km^2 (Parsons Brinckerhoff, 2006).

In order to determine an intervention plan for the asbestos contamination, a risk assessment process was adopted to determine the asbestos concentrations, exposure of people and the level of risk posed to the community in the area (Parsons Brinckerhoff, 2006). The results of the risk assessment exercise revealed that the area was extremely contaminated and a response plan was structured.

Rehabilitation efforts included capping of tailings with rock fragments, shaping of steep slopes to avoid erosion, diversion of surface water away from the dumps and establishment of vegetation on the prepared tailings. In river courses, asbestos contamination was removed and stream beds reshaped to limit erosion. Contaminated areas were fenced off and warning signs erected. The town area was evacuated and people permanently relocated. Access to the contaminated areas was limited to a few carefully planned roads (Parsons Brinckerhoff, 2006).

Residential developments within close proximity to asbestos dumps and where contamination levels are high, need to be relocated permanently to ensure that health impacts are reduced and to make rehabilitation successful. In Wittenoom, the residents were initially relocated temporarily for rehabilitation of the area. However, following resettlement of the communities, it was discovered that the rehabilitated fibres were exposed, again posing a threat to human health and the environment. This resulted in the permanent relocation of the town. This permanent relocation and restricting access to the contaminated area could be the best sustainable solution for cases similar to Wittenoom.

2.2.9 Mountain View Mobile Home Estates, USA

The Mountain View mobile home estate site is located in the state of Arizona. Mountain View is situated approximately 114.26 km west of the town of Globe in Gila County. The town was developed as a result of blue asbestos mining in the area (USEPA, 1983). Approximately 300 people lived in the town during the initial phases of mining.

Blue asbestos was mined in the area from 1953 to 1974 and the operation was shut down in 1974 owing to the poor air quality resulting from the mining and milling of asbestos. The poor air quality of the area was found to exceed the Gila-Pinal Counties air quality standards. Following the closure of the mine the asbestos tailings were leveled and used as landfill material. The leveled area was then subdivided into 55 plots and 47 of the plots were eventually used as residential property for approximately 130 people. The state and local health officials discovered asbestos contamination of soil and air in 1979 at the subdivided plots (USEPA, 1983).

The area was declared unfit for human occupation in 1980 and the people were temporary relocated while their properties were decontaminated. Rehabilitation measures implemented at the properties were demolishing of mill buildings and on-site burial of all contaminated material. The rehabilitated area was then capped with a 1.5 m protective soil cover to eliminate migration of asbestos fibres (USEPA, 1983).

In 1981, asbestos fibres were determined to be exposed by erosion and human activities, posing a health and environmental risk. The Arizona Department of Health Services concluded that a more permanent solution had to be found. The USEPA started temporary relocation of people in 1983, in order to carryout remedial investigations and feasibility studies. Remedial investigations commenced in April 1983 and were conducted over a four week period. The options considered, included the abandonment of the site, removal of asbestos contamination from the area and the construction of a cap over the contaminated tailings and soil. The final draft report was completed in May 1983. Remedial investigations revealed that the population of Mountain View mobile homes was exposed to asbestos contamination from the contaminated soil and potentially from the adjacent Jaquays asbestos mill (USEPA, 1983).

The investigations determined that the best permanent solution for the Mountain View estates was site abandonment and permanent relocation giving specific considerations to cost effectiveness, feasibility and the best protection of public health and the environment. Temporary relocation of residents pending finalisation of permanent relocations commenced by May 1983. Permanent relocation included the purchasing of the affected properties, burial of the contaminated mobile homes on site and capping of the contaminated areas. Residents of Mountain View Mobile homes were permanently relocated in 1985 (USEPA, 2007 e). Homes and other infrastructure at the site were subsequently demolished and buried on-site. To limit erosion impacts, which had previously and negatively impacted on rehabilitation measures implemented at the site, drainage channels where constructed. The whole site was covered with a filter fabric to limit further erosion. A clean soil cap was placed over the fabric and compacted. The soil was then overlain with crushed rock and the area fenced off. A twenty year monitoring plan was recommended. Monitoring investigations conducted in 1988, 1991 and in 2005 revealed that the rehabilitation measures were successful, as vegetation was establishing and the cap was still intact. The cap provided adequate protection to human health and the environment (USEPA, 2007 e).

The mobile homes case study indicates that rehabilitation of asbestos contaminated areas require constant monitoring. Following rehabilitation, the site was determined to be clean, however, with time, erosion due to water run off and human activities exposed asbestos fibres buried at the site. Surface water is a major problem to rehabilitation of asbestos dump rehabilitation as it destroys the cap placed to limit dust emissions. The restriction of access to the site is also important for the success of asbestos dump rehabilitation.

2.3 Discussion

Limited information could be obtained on the rehabilitation strategies used in South Africa for the rehabilitation of asbestos mine dumps. Documentation on rehabilitation efforts implemented on several mine dumps across the country are not published and are kept by the Department of Minerals and Energy (DME) where access to these documents is highly restricted. For this study, efforts made to request permission to utilise the documents were unsuccessful, as a result, no comparison of case studies from South Africa could be drawn.

From the case studies obtained from other parts of the world, it was evident that rehabilitation of mine dumps required stabilization of the waste material by reducing the slope angles of the dumps. Fertile soil is then placed over the asbestos waste to form a “cap” on which indigenous vegetation is planted. In some areas, excavations are carried out into which the asbestos waste is disposed and the excavated material is used to cover the buried waste, after which indigenous vegetation is planted. In areas where there is severe asbestos contamination in close proximity to communities, residents are temporarily relocated during cleanup operations and, depending on the effectiveness of the clean up exercise, the residents either reoccupy their homes if deemed suitable or are permanently relocated to a contamination free area. The environment is continuously monitored following rehabilitation and, should there be evidence of an increase in contamination, communities are permanently removed and access to the area restricted. A summary of different rehabilitation measures implemented in the reviewed case studies is presented in Table 1.

Table 1: Summary of rehabilitation measure implemented in different case studies

Site	Asbestos Type	Affected Area	Erosion Prevention	Soil cap	Monitoring systems	Vegetation treatment	Community management	Waste management	Outcome
1. Pano Amiantos Asbestos Mine, Cyprus	Chrysotile	6.5 km^2	Planting in terraces	30 cm clean soil	Seasonal monitoring	• Indigenous vegetation planted in terraces and rows • 26 Species planted on dumps	No information	• Runoff impounded in dams • Some asbestos waste removed off-site • Construction of retaining wall close to rivers	Vegetation successfully established
2. Millington Asbestos Processing Plant, New Jersey, USA	Chrysotile	4.4 hectares	• Water diversion channels constructed around dumps	0.60 metre clean soil	Monitoring conducted over 30 years	Revegetation applied continuously in failed areas	Area fenced off and access restricted	• Runoff impounded in dams • Retaining wall constructed close to river • Soil cover checked and applied where required	Vegetation successfully established in some areas whereas in others areas continuous revegetation was applied
3. Coalinga Asbestos Mine, California, USA	Chrysotile	50 hectares	• Dumps graded to stable slopes • Diversion of rivers running close to dumps	No information	No information	Planted indigenous vegetation	Area fenced off and access restricted	• Sediment trap dam created and continually maintained	Vegetation successfully established on dumps
4. The City of Coalinga, *California, USA*	Chrysotile	268 hectares	• Dust suppression measures using	• Fertiliser applied to soil where required	Monthly monitoring over more than 5 years	• Planted indigenous vegetation	Area fenced off and access restricted	Excavation of waste pit and dumping asbestos into the pit and	Self sustaining vegetation successfully established

Site	Asbestos Type	Affected Area	Erosion Prevention	Soil cap	Monitoring systems	Vegetation treatment	Community management	Waste management	Outcome
			biodegradable sealant and by covering waste ore with plastic sheeting			• Revegetation of areas damaged by burrowing animals • Deep rooted vegetation continuously removed		capping with soil over the waste materials and then an impermeable clay mat was compacted over the base soil. An additional soil layer was finally added.	over waste pit
5. Atlas Asbestos Mine, California, USA	Chrysotile	7.4 hectares	• Stream diversions • Dumps graded to stable slopes • Main roads paved to limit dust emissions	• Approximately 2 356 m^3 added to an area of 7.4 hectares • Soil used for capping mixed with organic compost, slow releasing fertilizer & gypsum	Continuous monitoring	• Planted with indigenous vegetation • 10 000 individual plants planted • Shrubs and grass applied in the form of hydro seeding slurry	Area fenced off and access restricted	Sediment trap dams created	Vegetation successfully established on dumps and outside the vegetation area (Self dispensing)
6. Southern Quebec, Canada	Chrysotile	5.5 Km^2	No information	• A mixture of agricultural fertilizer containing ammonium nitrate, potassium sulphate and super phosphate were added to the mine waste at different rates of 0, 0.1, 0.25, 0.5 and 1 kg/m^2. Farmyard cow manure was	No information	Soil cover seeded with a mixture of common agricultural grasses and legumes at a rate of 20 g/m^2	No information	None	Vegetation successfully established on dumps

Site	Asbestos Type	Affected Area	Erosion Prevention	Soil cap	Monitoring systems	Vegetation treatment	Community management	Waste management	Outcome
				also applied at 1 kg/m^2 or 4 kg/m^2. The amalgam was applied to the upper 5 to 10 cm layer of the mine dumps					
7. Libby, Montana, USA	Vemiculite contaminated with tremolite-actinolite series asbestos	No information	No information	Clean soil was used to cover excavations on site	Continuous monitoring	No information	Residents temporary relocated during clean up	Contaminated soil was removed from the area and disposed off at a mine shaft	Asbestos contamination successfully removed in some areas.
8. Wittenoom, Australia	Crocidolite	10 Km^2	• Dumps graded to stable slopes • Diversion of rivers running close to dumps • River beds reshaped to limit erosion	• Capping of dumps with rock fragments. • Soil treated before applied on dumps	No information	Planted indigenous vegetation	• Area fenced off, signs put up and access restricted • Residents temporary relocated during clean up • Permanent relocation of residents	Asbestos removed from river beds	Vegetation successfully established on some dumps
9. Mountain View Mobile Home Estates, USA	Crocidolite		• Drainage channels constructed across the site • Filter fabric material applied over the waste	1.5 m soil used to cap asbestos	• Annual during initial rehabilitation • Monitoring over a 20 year period following permanent relocation	Planted indigenous vegetation	• Residents temporary relocated during clean up • Residents finally permanently relocated	• Asbestos tailings levelled and used as landfill material • Demolishing of contaminated buildings	Vegetation successfully established on contaminated areas

CHAPTER 3: PENGE: A CASE STUDY OF REHABILITATION WITH PARTICULAR REFERENCE TO SOIL, SMALL MAMMALS AND PLANT PROPERTIES

3. PENGE: A CASE STUDY OF REHABILITATION WITH PARTICULAR REFERENCE TO SOIL, SMALL MAMMALS AND PLANT PROPERTIES

3.1 Introduction

Asbestos has been mined and processed for more than 2000 years (Hart, 1988). The largest production of asbestos occurred in the USSR and Canada. Other known asbestos producers include South Africa, Brazil, Zimbabwe, Italy, China, Greece, USA, Swaziland, Cyprus, Turkey, Colombia, Japan, North Korea, Bulgaria, Australia and Egypt. Impacts of asbestos mining have affected not only the employees of the mining companies but also residents living in close proximity to mining areas. In the United States of America tens of millions of dollars have been paid in compensation, a large number of the claimants had not worked in asbestos mining environments or handled asbestos products. This was further proved by a study conducted by the Pneumoconiosis Research Unit (PRU) on residents from Prieska, Koegas, Kuruma and Penge in 1963, who concluded that people who lived in close proximity to these mining areas were in danger of contracting asbestosis although they had no direct exposure to industrial asbestos (PRU, 1963). Contracting asbestos-related diseases such as mesothelioma is relatively easy and requires minimal exposure. The impacts will take some time before indications of the disease are evident. The latency period of mesothelioma can be up to 40 years (McCulloch, 2002).

An investigation conducted by Madhunita *et al*., (2003) in the mining area of the Chaibasa Region in India, revealed that the asbestos mining activities left a legacy of abandoned mine sites and dumps in the Roro Mountain, which posed a serious threat to the health of the local community and environment. The extent of the asbestos impacts has increased beyond the mining area sites by monsoons and winds which transport asbestos material downslopes to new areas. Few plant species were able to survive on these hills.

Rehabilitation of mine dumps should aim to ensure that contaminated soil is covered to prevent exposure of asbestos dust fibres to the environment. Such rehabilitation measures could include permanent land cover in the form of buildings, roads and car parks which gives the land a beneficial alternative land use. Asbestos cannot completely degrade in the environment and thus will remain in the disposal area for a long time until asbestos fibres are exposed and mobilised by anthropogenic activities. An experiment to examine asbestos in the air resulting from wind erosion conducted by Van Der Walt and De Villiers (1996) revealed that the concentration of asbestos fibres in the atmosphere was directly proportional to the wind speed at a point in time. The higher the wind speed the higher the concentration of asbestos fibres. Asbestos dust cannot be completely eradicated, it is advisable that future land uses should be inspected periodically to monitor and ensure that buried asbestos is not exposed (Otness *et al*., 2003).

3.2 Flora and Fauna Impacts

Natural habitat loss as a result of land uses such as agriculture, mining and urban development is the single most important threat to biodiversity (Rippley *et al*., 1996; Wilcove *et al*., 1998). Mining activities require clearing of vegetation in an area for the construction of mining shafts, auxiliary infrastructure and mine dumping areas and these activities may result in the permanent loss of soil required for habitats (May *et al*., 1995; Ward, 1998; Wilcove *et al*., 1998;). The loss of natural habitats inevitably results in the loss of fauna and flora communities.

Fauna affected by loss of habitat due to mining activity include microbial organisms found in the soil. These microorganisms are also affected by the changes to the soil conditions which may occur as a result of changes in the characteristics of the vegetation in an area or the total removal of vegetation. The flora and fauna systems are interlinked and as a consequence, changes in one system result in changes in the other system. Microorganisms for example are key factors in soil biochemical processes, contributing significantly to soil fertility (Cundell, 1977; Tate, 1984). Soil biota are important for decomposition of plant material and soil nutrient status through processes such as nitrogen fixation (Russell, 1973; Hunt *et al*., 1977; Higa and Parr, 1994). Vegetated soil will have higher microbial dehydrogenase activity compared to bare soil, as microorganisms are attracted to plants by the availability of surfaces for microbial colonisation, and the presence of plant exudates which microorganisms utilise as nutrients and as sources of energy (Russell, 1982; Lynch, 1990). Soil with vegetation is expected to be fertile due to the presence of microorganisms attracted by the flora. The decomposition rate of litter material depends on the quantity and quality of litter available and this in turn has a significant effect on soil enzymic activity and composition of microbial communities (Seastedt, 1988; Gomez *et al*., 2000).

Large fauna species are also affected by the loss of habitat and changes to the characteristics of habitats. The removal and destruction of vegetation in mining areas results in fragmentation of habitats (Saunders *et al*., 1987). The word fragmentation has been used by different authors with diverse definitions (Fahrig, 2003), however, for this study, habitat fragmentation will be defined as the transformation of a habitat into smaller patches separated by a matrix of habitats different from the original (Wilcove *et al*., 1986). Habitat fragmentation has several effects on fauna such as a reduction of the total area available to fauna and the restriction of movement of some animals between their preferred habitats (Mader, 1984; Lovejoy *et al*., 1984; Haila & Hanski, 1984; Wilcove *et al*., 1986). Species requiring large territories and those that exist in low densities will be the most significantly affected by habitat fragmentation. The survival of these species will then depend on the longevity of individuals (Karieva, 1987). Should individuals within the habitats be vulnerable, species loss may occur. The restriction may have significant impacts on the ability of species to find food previously accessible within its territory. Highly mobile species will move away from degraded habitats to find more suitable habitats resulting in loss of these species in the degraded areas. However, fauna can also be found in degraded areas as a result of migration across these areas or as a result of adaptation of the fauna to the new surroundings (Karieva, 1987).

Fauna can have an impact on the habitats they live in, in either a positive or negative manner, e.g. grazing. Grazing can contribute to plant growth through enhancing nutritive value, removing excess litter and accelerating nutrient cycling, whereas overgrazing on the other hand has a negative impact on vegetation by decreasing photosynthesis and reducing root growth and seed production (Tainton, 1984; Lemaire & Chapman, 1996; Sharma, 1997).

3.3 Soil Impacts

Mining has destructive impacts on soil quality. The soil quality concept looks into the health of ecosystems as a whole (Schoenholtz *et al*., 2000). The chemical properties of asbestos have a negative impact on the growth and survival of plants and hence limited plant growth occurs on asbestos mine dumps. Soil contaminated by serpentine asbestos is normally infertile, as the asbestos is toxic to plants and this is referred to as the serpentine factor (Brooks, 1987). During mining activities, the fertile upper layer of soil is stripped off the land during excavations and in other areas waste material from the mining activities is dumped over fertile soil. The waste material will replace the soil as available substrate on which plants have to grow. The soil quality, which is determined by the quality and quantity of nutrients present in the soil, will determine the functioning of the ecosystem. Nutrients can be divided into micronutrients and macronutrients. Macronutrients are those chemical elements consumed by plants in larger quantities, these include nitrogen, phosphorus, potassium and sulphur (Elandor & Rolfes, 2007). Micronutrients on the other hand are those chemicals required in small quantities such as manganese, copper, iron and zinc. Although these chemicals are required in small quantities, they are necessary for plant development. Micronutrients may become toxic if taken up in large quantities by plants. Commonly, soils will have sufficient quantities of micronutrients (Schulze *et al*., 2004). Hence, addition of micronutrients is normally not required. Macronutrients on the other hand may require supplementation where they are found to be insufficient. A list of some plant macronutrients and their importance to plant function are presented below.

- Carbon: This is the most important component of the plant and forms the backbone of bio-molecules in most plants, creating the opportunity for storage of energy within plants. Carbon forms part of the carbohydrates produced during photosynthesis and stored in the plants (Millar, 1955; Mohr & Schopfer, 1995)

- Calcium: This nutrient plays a significant role regulating nutrient absorption into the plant and translocation of nutrients within the plant (Millar, 1955)
- Magnesium: Is an alkaline cation which forms part of chlorophyll in plants (Mucina & Rutherford, 2006)
- Potassium: This is a key macronutrient in the formation of flower buds and fruits. It promotes the movement of sugars within plants and increases the overall resistance of plants to adverse weather conditions and diseases. The requirements for potassium are higher than those for calcium or magnesium (Schulze *et al*., 2004)
- Phosphorus: Is a primary macronutrient required in the establishment of young plants, root growth and flowering of plants. It is a key element in the energy metabolism of all living organisms (Mucina & Rutherford, 2006)
- Sulphur: Is a chemical forming part of plant proteins, vitamins and enzymes. Sulphates assist plants to absorb potassium, calcium and magnesium. (Millar, 1955)
- Nitrogen: Which is usually found in organic forms following decomposition of dead vegetation material becomes available as nitrate and ammonium through the action of microorganisms (Begon *et al*., 1990).

A list of some plant micronutrients and their importance to plant development are presented below.

- Copper: This is a heavy metal similar to iron, zinc and boron which are not very mobile. It is required for plant chlorophyll formation and activation of enzyme activity. Only limited quantities are required and can be poisonous to plants in high concentrations. Plants in copper deficient soil will have poor root development (Tomulescu *et al*., 2004; Mucina & Rutherford, 2006)
- Zinc: This chemical is required for enzyme activity, chlorophyll formation, protein synthesis and membrane integrity by plants (Millar, 1955; Welch *et al*., 1982; Ender *et al., 1983*; Pinton *et al.,* 1993)

- Boron: Is a chemical component which does not have a clear function in plant growth, however, it is known to be used in sugar transportation, root elongation, cell wall synthesis and cell division in plants (Millar, 1955; Marschner, 1995; Barker & Pilbeam, 2007).
- Sodium: Is a non-essential element which contributes to the resistance of plants to diseases and wilting (Millar, 1955). It is a beneficial element required to stimulate plant growth (Marschner, 1995)

Metals available for plant uptake in the soil do not only affect vegetation but also microorganisms and microbial processes in soil (Giller *et al*., 1998). This was confirmed by a study conducted by Epeilde *et al*, on the impacts of metals on soil microbial communities, which revealed that soil dehydrogenase activity correlated with soil metal bioavailability (Epeilde *et al*., 2008). Microorganisms are affected by metals through protein denaturation and destruction of cell membrane activity (Leita *et al*., 1995). Metals in the soil are commonly increased by human activity such as mining.

For adequate rehabilitation of a contaminated area, the soil quality needs to be improved to promote plant development and fauna establishment. The ultimate goal for rehabilitation must, therefore, not only be to remove contaminants from the soil but should most importantly be to restore the capacity of the soil to perform or function according to its potential (Hernandez *et al*., 2006).

3.4 Human Health Impacts

The presence of asbestos fibres in the environment poses a health risk to humans. Asbestos exposure pathways include ingestion, skin contact and inhalation of fibres (Tweedale & Hansen, 1998; Cudgell & Kamp, 2004; Renner, 2005). Skin exposure to asbestos has been known to cause harmless epidermal skin overgrowths (Luus, 2007). The inhalation of asbestos fibres is known to cause bilateral interstitial pulmonary fibrosis causing asbestosis (Mossman & Churg, 1998). The significance of the health impact posed by asbestos has been identified to be a function of the fibre characteristic. These properties include the size, type, durability and dose of asbestos fibre (Schraier, 1989). The rod-like amphibole fibres cause the most significant health impacts compared to the curly serpentine fibres (Stayner *et al*., 2007). The rate of mesothelioma infections has been identified to be related to asbestos type. Several studies have linked amosite asbestos, the type mined at Penge, with increases in rates of mesothelioma infections (Suzuki *et al*., 2005). Chrysotile asbestos for example, which accounts for more than 90% of total asbestos mined in the world, has been found to be less potent than amphibole asbestos (Mossman, 1990). The mineralogy and morphology of brown asbestos makes it more bio-persistent and bio-chemically reactive, making it highly dangerous to human health and can cause malignant mesothelioma (Gibbons, 1998; Webber *et al*., 2006). However, amosite asbestos is not the most potent according to an investigation conducted by White *et al*. (2008) which revealed that although amosite was mesotheliomagenic, crocidolite asbestos was the most potent. Investigations conducted by Ross (Ross, 1981) further indicated that mesothelioma infections are very rare where amosite asbestos is mined. Nevertheless, amosite asbestos also contributes to mesothelioma infections, and prolonged exposure to amosite fibres can increase the rate of mesothelioma infections. Lung cancer and asbestosis can be caused by exposure to chrysotile, amosite and crocidolite asbestos fibres. The impact of lung cancer and asbestosis is further compounded in persons who smoke. Not all asbestos exposure will result in infections, most infections occur as a result of heavy and prolonged exposure (Ross, 1981). However, it should be borne in mind that some asbestos exposure in low concentrations can result in significant health impacts (Pasetto *et al*., 2005; Webber *et al*., 2006).

3.5 Materials and Methodology

3.5.1 Introduction

This chapter of the research report looks at the treatments implemented at the site during rehabilitation of the mine dumps and the methodology used by REDCO to collect the data for this study. Analysis and interpretation of the data were carried out by the author of this research report. Site investigations which included collection of soil samples, trapping of small mammals and vegetation assessment were conducted in September and October 2007 by REDCO on behalf of the Department of Minerals and

Energy (DME). The extent of the investigations and selection of analyses were greatly influenced by financial constrains of the DME.

3.5.2 Rehabilitation of Penge mine dumps

Rehabilitation actions at Penge started in 1986 and the rehabilitation work was completed in December 1996. The majority of the rehabilitation took place between 1986 and 1992, with formal closure being declared in 1995. The DME carried out further activities in 1996 to address flood damage. There was no systematic documentation of rehabilitation efforts implemented at Penge. For the study purposes, information on the rehabilitation of mine dumps in Penge was collected from a database kept by REDCO, which was also found to be incomplete. It appears that each individual component of the rehabilitation was well planned and executed by the various contractors. However, the overall project management carried out by the DME could have been vastly improved. When rehabilitation was conducted at Penge, the DME did not have documented guidelines for managing asbestos mine dumps. The current rehabilitation guidelines were developed after rehabilitation work had been completed at Penge.

It is claimed by REDCO that the dumps were rehabilitated according to the DME guidelines, however, it appears that the guidelines which were used were in the initial stages of preparation and there were a number of parties involved. The overall project was not well managed, some of the information was kept with the DME and other information was kept by the various contractors. Available information indicates that asbestos mine dumps were reshaped to slopes of 18 degrees. The reshaped mine dumps were then covered with imported soil material to a minimum depth of 300mm. There are no data on where the soil was sourced or its properties. After extensive discussion with REDCO it was established that three different treatments were applied with respect to re-vegetation: 1) Dumps 1 and 2 were planted by spreading manure containing *Dichrostachys cinerea*, and *Acacia tortilis* seeds; 2) Dumps 3, 4, 5, 6, 7 and 8 received no treatments; 3) Dumps 9, 10 and 11 were planted with *Euphorbia tirucali* but no manure was applied. No grasses and forbs were planted during the rehabilitation of the dumps.

3.5.3 Site visit

A site inspection was conducted by myself over a one day period on 10 October 2008 to physically view the site area and to become familiar with the area and its current environmental conditions. In addition, the investigation was conducted to review the conditions on site as reported by Dr Donohue (Donohue, 2007). During the site inspection, authorisation to inspect the hospital grounds was requested from Matron Mfeyana who was in charge at the time. Matron Mfeyana assigned a security officer to accompany me during the inspection, to indicate areas where asbestos waste had been previously stored.

3.5.4 Fauna investigations

A small mammal assessment was undertaken by REDCO by setting traps in trapping grids in a 5 x 5 m pattern, placed 10 m apart at each rehabilitated mine dump and adjacent areas. All traps were checked daily for two consecutive days. The assessment was used to estimate the abundance of small mammals at the rehabilitated sites. The type of traps used are unknown and it is recognized that the period of sampling was extremely brief and cannot hope to give the full picture of all the small mammals at the site. The investigation probably only addressed rodents and not small mammals.

3.5.5. Soil investigations

A total of 66 soil samples were collected from the eleven mine dumps. At each mine dump, three sampling points were selected and two soil samples were collected from each sampling point. One sample was collected from near the surface at a depth of 100 mm below ground level for microbiological testing and a second sample was collected at 300 mm below ground level for chemical and physical analyses. Soil for microbiological assessment was conducted at a shallow depth as microbial activity decreases with an increase in depth (Ekelund *et al*., 2001; Taylor *et al*., 2002). During soil sampling, the depth of soil cover over the dumps was also measured.

The soil samples were analysed using standard chemical procedures. An assay of microbial activity was conducted on the surface samples using a standard dehydrogenase assay. Dehydrogenase activity is a measure of the activity of micro-organisms in the soil and is correlated with intracellular processes that occur in every viable microbial cell (Dick, 1997; Nanniepieri *et al*., 2002). In this case a vital stain was used and the degree of precipitation of the stain in the microbial cells was used. Micro-organisms are used as biological indicators of soil ecosystem function as they are sensitive to changes in the soil (Doran *et al*., 1994).

3.5.6. Vegetation investigations

The vegetation assessment was carried out using the random quadrat method as described by Barbour (1987), to measure vegetation cover including crown and basal features and vegetation density. Plant densities in the quadrats were determined by counting the individual plants growing in each quadrat and a comprehensive list of plant species occurring within the quadrates was compiled. Three quadrats were placed randomly on each of the eleven dumps and the absolute crown cover and crown heights estimated. In areas where woody species were planted during rehabilitation of the mine dumps, a quadrat size of 2 x 2 metre (m) was used and in areas where herbaceous species were planted a 1 x 2 m quadrat was used.

3.5.7 Statistical analysis

Analyses of the results were performed using Stastica$^{©}$ to conduct an analysis of variance (ANOVA) in the treatment groups. The post-hoc Tukey test was performed to determine statistical variance between specific group pair.

3.6 Results

3.6.1 Site visit

During the investigation of the hospital grounds it was noted that waste previously stored at the site had been removed and the areas were covered by soil. No asbestos fibres were noted on the hospital grounds. An inspection of the roads and buildings around the Penge town revealed no visible asbestos fibres even within the sections of roads which were damaged. Asbestos fibres were exposed in a pit dug on the side of the road which indicated that asbestos material in the area had been covered up. This may have been done after the site visit performed by Dr Donohue, explaining why asbestos material noted during his visit was not found during my site investigation. Investigations of the mine dumps revealed asbestos fibres on the mine dumps located adjacent to the hospital grounds as had been noted by Dr Donohue. The dumps had been covered with soil, however, some areas had not been adequately covered resulting in the exposure of asbestos. It is assumed that secondary pollution of the site would be extensive. The mine dumps in the area were not fenced and there was animal and human access to the dumps. It was noted that the surfaces of the dumps were covered by leaf litter with limited vegetative cover.

3.6.2. Small mammal assessment

Table 2 presents data of the small mammal assessment conducted on the rehabilitated mine dumps.

Table 2: Small Mammal Assessment Results

Treatment Group	Treatment	Location (Dump number)	Species	Number	Sex	Mass (g)
Group 1	Planted by spreading manure containing *Dichrostachys cinerea* and *Acacia tortilis* seeds	Penge 1	-	-	-	-
		Penge 2	*Aethomys crysophilus* (Red veld rat)	1	Female	52
Group 2	No treatment	Penge 3	*Aethomys crysophilus*	1	Male	54
		Penge 4	-	-	-	-
		Penge 5	-	-	-	-
		Penge 6	-	-	-	-
		Penge 7	*Aethomys crysophilus*	1	Male	56
		Penge 8	-	-	-	-
Group 3	Planted with *Euphorbia tirucali*. No manure	Penge 9	*Aethomys crysophilus*	1	Male	55
		Penge 10	*Aethomys crysophilus*	1	Male	84
		Penge 11	-	-	-	-

3.6.2.1 Interpretation of results

During the investigation of small mammal occurrence on the rehabilitated mine dumps, only rodents were captured. Only a few individuals of the same species, the *Aethomys crysophilus* (Red Veld Rat) were identified in the study area. The presence of mammals on the mine dumps is a positive sign and encouraging. The occurrence of rodents appeared to be random and was not linked to the treatments on the dumps. One individual was captured in five of the eleven mine dumps namely mine dumps Penge 2,3,7,9, and Penge 10. No rodent was captured more than once. At least one rodent was captured in each of the treatment groups. The small mammal data do not lend themselves to statistical analysis because of the limited sample size.

3.6.3. Macro-elements

Table 3: Mean value (n=3) of soil analysis (Macro-elements) sampled from eleven dumps in the Penge Area. Soil sampled at 30 cm depth. All units are in millimol per litre except for P (Bray 1 ppm) and C (%).

Treatment Group	**Treatment**	**Location (Dump number)**	**Ca^{2+}**	**Mg^{2+}**	**K^{+}**	**Na^{+}**	**P-bray 1 (ppm)**	**PO$_4^-$**	**SO$_4^-$**	**NO$_3^-$**	**NH$_4^+$**	**%C**
Group 1	Planted by spreading manure containing *Dichrostachys cinerea* and *Acacia tortilis* seeds	Penge 1	0.82±0.54	0.29±0.18	1.13±0.78	0.08±0.06	7.32±5.10	<0.01	0.13±0.15	1.15±1.59	0.05±0.02	0.47±0.15
		Penge 2	0.76±0.66	0.33±0.22	0.17±0.14	0.19±0.19	7.56±3.53	<0.01	0.13±0.16	0.90±1.40	0.04±0.03	0.41±0.31
Group 2	No treatment	Penge 3	0.49±0.50	0.22±0.18	0.24±0.22	0.06±0.01	1.57±0.36	<0.01	0.16±0.18	0.32±0.32	0.05±0.01	0.73±0.08
		Penge 4	0.45±0.08	0.17±0.20	0.35±0.23	0.07±0.03	2.89±0.91	<0.01	0.07±0.05	0.41±0.20	0.06±0.01	0.72±0.12
		Penge 5	0.59±0.09	0.23±0.06	0.50±0.59	0.07±0.02	2.67±1.38	<0.01	0.08±0.06	0.46±0.38	0.05±0.01	0.74±0.15
		Penge 6	0.71±0.58	0.23±0.23	0.77±0.93	0.05±0.02	3.69±1.76	<0.01	0.10±0.14	0.93±1.48	0.02±0.02	0.58±0.18
		Penge 7	0.28±0.10	0.10±0.05	0.66±0.10	0.11±0.06	4.79±0.95	<0.01	0.04±0.01	0.32±0.09	0.02±0.01	0.52±0.04
		Penge 8	0.63±0.15	0.19±0.10	0.64±0.47	0.06±0.01	4.26±0.22	0.03±0.01	0.10±0.05	0.12±0.05	0.03±0.01	0.59±0.18
Group 3	Planted with *Euphorbia tirucali*. No manure	Penge 9	0.51±0.04	0.13±0.02	0.50±0.72	0.06±0.02	7.42±8.36	0.01±<0.01	0.04±0.04	0.32±0.19	0.03±0.01	0.46±0.02
		Penge 10	1.01±0.50	0.27±0.18	0.80±0.82	0.21±0.18	2.83±1.30	<0.01	0.21±0.19	1.51±1.97	0.03±0.01	0.70±0.26
		Penge 11	0.39±0.23	0.21±0.16	0.12±0.05	0.09±0.08	1.88±0.15	<0.01	0.05±0.04	0.20±0.06	0.04±0.01	0.47±0.07

Treatment Groups highlighted with the same colours within a column were not significantly different at $p<0.05$

3.6.3.1 Interpretation of results

The macronutrient results presented in Table 3 indicate that the highest macro-element concentration measured on the mine dumps was available phosphorus and the lowest recorded concentration was water-soluble phosphorus. There is no pattern across the three treatments with respect to the macro-elements. The soils are not sodic as the sodium levels are not significantly higher than the calcium and magnesium concentrations. Statistical analyses revealed that there were some statistically different results between the treatment groups. Bray 1 phosphorus concentrations, which is an index of available phosphorus in soils, measured in treatment Group 2 (no treatment) were significantly lower than those measured in treatment Group 1 (planted with *Dichrostachys cinerea* and *Acacia totilis*) at p=0.02. Treatment Group 1 had the highest phosphorus concentrations. The reason why the Bray 1 phosphorus values are higher than the water soluble phosphorus values is that the Bray 1 method removes the easily acid-soluble phosphorus forms, largely calcium phosphates, and a portion of the aluminium and iron phosphates. Soil carbon levels are low which indicates that organic matter should be added to the system for long term sustainability.

3.6.4. Micro-elements

Table 4: Mean value (n=3) of soil analysis (Micro-elements) sampled from eleven dumps in the Penge Area. Soil sampled at 30 cm depth. All units are in millimol per litre

Treatment Group	**Treatment**	**Location (Dump number)**	**Fe^{+}**	**Mn^{3-}**	**Cu^{2-}**	**Zn^{++}**	**B^{3+}**	**Cl^{-}**
Group 1	Planted by spreading manure containing *Dichrostachys cinerea* and *Acacia tortilis* seeds	Penge 1	19.31±13.50	0.54±0.26	0.52±0.07	0.08±0.07	1.50±0.71	0.32±0.46
		Penge 2	12.38±12.60	0.56±0.46	0.71±0.56	0.12±0.13	1.50±0.71	0.14±0.12
Group 2	No treatment	Penge 3	17.70±11.77	1.71±1.14	0.80±0.68	0.21±0.15	1.50±0.71	0.3±0.38
		Penge 4	21.39±5.08	0.44±0.23	0.65±0.67	0.06±0.07	2.00±1.00	0.14±0.01
		Penge 5	13.65±12.79	0.25±0.26	0.61±0.33	0.05±0.03	3.00±<1.00	0.09±0.04
		Penge 6	17.71±14.43	0.99±0.28	0.38±0.34	0.09±0.06	1.00±<1.00	0.23±0.34
		Penge 7	34.52±4.07	3.39±4.02	0.53±0.24	0.32±0.28	1.50±<1.00	0.06±0.01
		Penge 8	20.18±3.00	1.16±2.26	0.59±0.30	0.13±0.08	1.64±0	0.21±0.54
Group 3	Planted with *Euphorbia tirucali*. No manure	Penge 9	18.68±9.73	0.50±0.24	0.43±0.09	0.02±0.01	1.33±<1.00	0.06±0.04
		Penge 10	9.66±11.19	0.24±0.10	0.62±0.075	0.10±0.08	2.00±0	0.19±0.12
		Penge 11	16.95±13.59	1.77±2.48	0.50±0.12	0.19±0.22	1.00±<1.00	0.09±0.05
Treatment Groups highlighted with the same colours within a column were not significantly different at p<0.05								

3.6.4.1 Interpretation of results

Statistical analysis revealed that all micronutrients across the treatment groups were statistically similar. There is no pattern across the three treatments for the micro-elements measured.

3.6.5 Soil pH and electric conductivity

Table 5 presents data of the pH and EC of the soil samples from rehabilitated mine dumps.

Table 5: Mean value (n=3) of soil analysis (pH & EC) sampled from eleven dumps in the Penge Area. Soil sampled at 30 cm depth.

Treatment Group	**Treatment**	**Location (Dump number)**	**pH**	**EC (mS/cm)**
Group 1	Planted by spreading manure containing *Dichrostachys cinerea* and *Acacia tortilis* seeds	Penge 1	6.89±0.36	0.32±0.21
		Penge 2	7.45±0.16	0.26±0.18
Group 2	No treatment	Penge 3	6.87±0.52	0.18±0.16
		Penge 4	7.03±0.13	0.18±0.03
		Penge 5	7.13±0.14	0.23±0.09
		Penge 6	7.26±0.12	0.28±0.25
		Penge 7	7.25±0.12	0.16±0.02
		Penge 8	7.33±0.01	0.23±0.10
Group 3	Planted with *Euphorbia tirucali*. No manure	Penge 9	7.18±0.15	0.19±0.07
		Penge 10	7.45±0.09	0.36±0.23
		Penge 11	7.05±0.32	0.15±0.08
Treatment Groups highlighted with the same colours within a column were not significantly different at $p<0.05$				

3.6.5.1 Interpretation of results

Statistical analysis revealed that pH and EC levels across the treatment groups were statistically similar. There is no pattern across the three treatments for the pH and EC measured. The pH is neutral making the soils favourable for plant growth, it is unusual to have pH values so close to neutral as most soils in South Africa are acidic. The EC values are within the range of soils that have a relatively low base status.

3.6.6 Dehydrogenase results

Table 6 presents the dehydrogenase data from the soil samples from the rehabilitated mine dumps.

Table 6: Mean value (n=3) of soil analysis (microbial dehydrogenase activity) sampled from eleven dumps in the Penge area. Soil sampled at 10 cm below ground level

Treatment Group	**Treatment**	**Location (Dump number)**	**Dehydrogenase activity (INF $\mu g\ g^{-1}\ h^{-2}$)**
Group 1	Planted by spreading manure containing *Dichrostachys cinerea* and *Acacia tortilis* seeds	Penge 1	196.2±6.6
		Penge 2	168.4±9.3
Group 2	No treatment	Penge 3	241.3±39.9
		Penge 4	206.5±21.2
		Penge 5	295.4±29.3
		Penge 6	280.3±31.9
		Penge 7	188.7±60.5
		Penge 8	144.3±48.8
Group 3	Planted with *Euphorbia tirucali*. No manure	Penge 9	276.9±109.8
		Penge 10	355.4±25.0
		Penge 11	177.4±14.0
Treatment Groups highlighted with the same colours within a column were not significantly different at p<0.05			

3.6.6.1 Interpretation of results

Statistical analysis revealed that dehydrogenase activity across the treatment groups was statistically similar. There is no pattern across the three treatments for the dehydrogenase activity measured. The highest dehydrogenase activity was measured in treatment Group 3.

3.6.7 Soil depth results

Table 7 presents the soil depth at the rehabilitated mine dumps.

Table 7: Mean value (n=3) of soil depths measured from eleven dumps in the Penge Area.

Treatment Group	Treatment	Location (Dump number)	Soil Depth (mm)
Group 1	Planted by spreading manure containing *Dichrostachys cinerea* and *Acacia tortilis* seeds	Penge 1	360±30.0
		Penge 2	316.7±75.1
Group 2	No treatment	Penge 3	286.7±80.8
		Penge 4	243.3±210.8
		Penge 5	313.3±133.7
		Penge 6	320.0±30.0
		Penge 7	236.7±205.0
		Penge 8	90.0±55.1
Group 3	Planted with *Euphorbia tirucali*. No manure	Penge 9	243.3±98.2
		Penge 10	296.7±71.0
		Penge 11	236.7±55.1
Treatment Groups highlighted with the same colours within a column were not significantly different at $p<0.05$			

3.6.7.1 Interpretation of results

Statistical analysis revealed that soil depths across the treatment groups were statistically similar. There is no pattern across the three treatments for the soil depths measured. The deepest average soil layer between the treatment groups was measured in Group 1 followed by Group 3 and the shallowest average soil depth was measured in Group 2. The soil depth was completely determined by the addition of the topsoil to each of the dumps.

3.6.8 Vegetation results

Table 8 presents the vegetation cover and density on the rehabilitated mine dumps.

Table 8: Mean (n=3) percentage vegetation cover and vegetation density on each mine dump

Treatment Group	**Treatment**	**Location (Dump number)**	**Herbaceous crown cover (%)**	**Woody crown cover (%)**	**Basal cover (%)**	**Vegetation density (number of plants/m^2)**
Group 1	Planted by spreading manure containing *Dichrostachys cinerea* and *Acacia tortilis* seeds	Penge 1	10.1±4.4	11.9±15.7	4.5±1.8	15.3±6.0
		Penge 2	9.3±4.5	24.6±20.6	5.7±1.0	23.9±5.6
Group 2	No treatment	Penge 3	18.5±4.7	12.5±5.4	7.3±1.5	24.0±7.8
		Penge 4	5.9±1.7	12.1±11.2	3.0±0.7	19.0±0.6
		Penge 5	11.7±9.5	10.9±8.2	3.6±1.3	18.5±3.4
		Penge 6	15.8±10.8	27.9±11.6	3.9±0.4	20.4±15.7
		Penge 7	18.5±3.6	11.3±9.9	4.9±0.1	24.9±5.6
		Penge 8	6.6±6.3	40.4±26.7	3.5±0.3	12.4±11.4
Group 3	Planted with *Euphorbia tirucali*. No manure	Penge 9	8.1±3.6	15.9±9.7	3.5±0.6	20.0±2.2
		Penge 10	3.6±2.3	8.3±2.9	2.4±1.0	14.8±6.1
		Penge 11	16.7±16.2	13.4±19.9	3.7±1.9	22.2±0.5
Treatment Groups highlighted with the same colours within a column were not significantly different at $p<0.05$						

3.6.8.1 Interpretation of results

There are no apparent trends in the dominant vegetation on the dumps as a function of treatment. There is no significant difference in percentage herbaceous cover, percentage woody cover, percentage basal cover and vegetation density between treatment groups. The regrowth on the dumps is adequate and encouraging.

3.6.9 Species identification results

Table 9 presents dominate vegetation species on the rehabilitated mine dumps

Table 9: List of dominant species on each mine dump

Treatment Group	Treatment	Location (Dump number)	Dominant tree	Dominant shrub	Dominant grass	Dominant forbs
Group 1	Planted by spreading manure containing *Dichrostachys cinerea* and *Acacia tortilis* seeds	Penge 1	*Acacia tortilis*	*Acacia tortilis*	*Cenchrus ciliaris*	*Achyrantes aspera*
		Penge 2	*Acacia tortilis*	*Acacia tortilis*	*Enneapogon cenchroides*	*Achyrantes aspera*
Group 2	No treatment	Penge 3	*Dichrostachys cinerea*	*Acacia tortilis*	*Aristida congesta*	*Corchoris kirkii*
		Penge 4	*Acacia tortilis*	*Acacia tortilis*	*Enneapogon cenchroides*	*Sida cordifolia*
		Penge 5	*Acacia tortilis*	*Acacia tortilis*	*Enneapogon cenchroides*	*Corchoris kirkii*
		Penge 6	*Euphorbia tirucali*	*Euphorbia tirucali*	*Aristida congesta*	*Tephrosia rhodesica*
		Penge 7	*Acacia grandicornuta*	*Acacia tortilis*	*Enneapogon cenchroides*	*Hibiscus micranthus*
		Penge 8	*Euphorbia tirucali*	*Euphorbia tirucali*	*Cenchrus ciliaris*	*Rhynchosia minima*
Group 3	Planted with *Euphorbia tirucali*. No manure	Penge 9	*Dichrostachys cinerea*	*Dichrostachys cinerea*	*Aristida congesta*	*Abutilon angulatum*
		Penge 10	*Acacia tortilis*	*Acacia tortilis*	*Urochloa mosambicensis*	*Achyrantes aspera*
		Penge 11	*Acacia tortilis*	*Dichrostachys cinerea*	*Aristida congesta*	*Hibiscus micranthus*
Treatment Groups highlighted with the same colours within a column were not significantly different at p<0.05						

3.6.9.1 Interpretation of results

There are no apparent trends in the dominant vegetation species on the dumps as a function of treatment. The results of the species identification revealed that the *Acacia tortilis* species was the dominant tree and shrub species on the mine dumps. *Aristida congesta and Enneapogon cenchroides* species were the dominant grasses on the mine dumps with the dominant forb being *Achyrantes aspera.* Although mine dumps in treatment Group 1 were planted with *Dichrostachys cinerea* and treatment group 3 planted with *Euphorbia tirucali*, none of these species were dominant on the mine dumps within the treatment group. The results indicate that the must have been significant seed bank in the top soil used to cover the dumps. The grasses and forbs could have established from the seed bank.

3.7 Discussion of Results

Interpretation of the results for the current investigation is difficult as there is no background information on the soil, fauna and flora conditions prior to implementation of rehabilitation.

3.7.1 Site inspection

Asbestos fibres, in former mining areas, will be found in trace concentrations in the soil of the area and will also be found in larger concentrations in buried waste sites (Anderson *et al*., 2005). Results of the site inspection conducted at the site revealed that there are substantial amounts of asbestos waste buried at the site and some of the asbestos fibres have been exposed in some areas, posing a health risk. There were no visible asbestos fibres on buildings and on road surfaces, however, this does not mean that fibres are not present. Amosite asbestos has significant health impacts if inhaled and has been associated with an increase in mesothelioma infection rates in some areas (Suzuki *et al*., 2005). It is not only the fibres buried in the mine dumps that pose a health risk to communities, but also asbestos fibres in the houses. During asbestos mining, operations were known to be dusty and fibre particles were carried from the mine and milling sites towards residential properties (McCulloch, 2002). This process is expected to have occurred at Penge. Asbestos fibres from the mining operations are deposited on materials such as wood, roads and buildings until disturbed. The fibres will still be dangerous even after a long time, as asbestos fibres are known to be persistent in the environment (Pasetto *et al*, 2005; Webber *et al*., 2006). There was no systematic investigation of secondary pollution in the area but it is assumed that asbestos will still be contaminating the environment e.g. soils, water and atmosphere.

3.7.2 Small mammals

The *Aethomy chrysophilus* (Red Veld Rat) species was the only small mammal species captured on the rehabilitated mine dumps and its occurrence was not linked to the treatments on the dumps. The red veld rat is a species predominately found in east, central and southern Africa (Winton, 1987). It is endemic to Africa and is found in habitats which include woodlands and varying combinations of grass and herbaceous cover and shrubby understories (Linzey &Chimimba, 2008). The presence of fauna in a previously degraded area is an indication of recovery as was observed during studies conducted by Nichols & Nichols. (2003), Slabova *et al*. (2005) and Linzey & Chimimba, (2008) on the trends of recolonization of rehabilitated sites which revealed that generalist foraging mammals recolonised rapidly compared to predators. It is very difficult to ascertain whether these rodents had made nests in the area or were “just passing through”. Different species inhabited the spoils at different stages of recovery of the spoils.

3.7.3 Physico-chemical Assessment

The investigation of macronutrients did not identify any trends related to the treatment groups. Macronutrients are key factors for plant development and low concentrations do not support the development of sustainable vegetation (Elandor & Rolfes, 2007). It is difficult to establish whether the concentrations have increased or decreased on the rehabilitated mine dumps as there is no background information on the soil properties. Significant difference in macroelements in relation to treatments was determined in the phosphorus concentration. Water–soluble phosphate concentrations which are an essential requirement for overall plant growth were extremely low on the mine dumps. Bray 1 phosphate concentrations were much higher than the water soluble values, this is expected as the Bray 1 method removes the easily acid-soluble phosphorus forms. Information received from the contractor responsible for rehabilitation indicated that manure was added only on mine dumps in treatment group 1 during the remediation of the mine dumps. Taking this into consideration, the presence of higher concentrations of inorganic phosphorus in this treatment group is expected to be as a result of the manure application on the soil that was sourced to cap the mine dumps. In addition, the phosphate in all the treatment groups could be expected to be as a result of decomposition from decaying plant material and waste from grazing animals and scavengers. The carbon concentration levels were slightly higher in treatment Group 2 and lowest in Group 1. Soil organic carbon plays an important role in soil aggregate stability as it influences the soil porosity and thus the gas exchange reactions and water relations. In addition, it also has a significant influence on biological and chemical processes that are vital in nutrient release and availability (Johnson, 1985). The presence of carbon in soil also promotes the establishment and activity of microorganisms which play a crucial role in plant development for example through nitrogen fixation (Kuzyakov, 2006). On the whole the levels of nutrients are low especially the calcium, potassium and magnesium levels. Nitrate is the dominant nitrogen ion which usually indicates that microbial activity is taking place and that the system is ecologically functional.

No pattern or notable differences could be identified in soil micronutrients across the dumps by treatment groups. The pH across the treatment groups was neutral which is conducive for plant growth. The soil pH has a significant influence on many chemical reactions that influence nutrient availability and the most favourable soil pH for plant growth is between 6 - 7 (Aune & Lal, 1997). Macronutrient uptake is increased in soils which are slightly alkaline except for phosphorus which is most available in soils which are slightly acidic (Alam *et al.*, 1999).

The soil depth results indicated that soil depths across the treatment groups were statistically similar. Treatment Group 2 had the shallowest soil depth. The shallowest soil on the mine dumps was determined in this group. Soil depth has an influence on the amount of resources available to plants per unit area (Schoenholtz *et al.*, 2000). Deeper soils mean more resource availability compared to shallow soils. Shallow soils limit root volume and also influence microorganism activity (Hoyle, 1971). Soils with large root volumes will have higher dehydrogenase activity due to the presence of easily metabolisable root exudates and surfaces for microbial colonization (Curl & Truelove, 1986). However, in this study soil depth could not be correlated microbial activity. It would be of benefit to increase the depth of soil cover over the fibres to ensure that fibres are not exposed and to promote root development.

3.7.4 Microbiological

Dehydrogenase activity was higher in treatment Group 3, with slightly lower levels measured in treatment Group 1. Dehydrogenase activity is a good indicator of ecosystem health as dehydrogenase activity responds rapidly to changes in management and is sensitive to environmental stress (Dick, 1997; Bandick & Dick, 1999; Alkota *et al*., 2003). As a result, soil chemical processes, nutrient mineralisation rate and organic matter accumulation can be investigated effectively by assessing soil enzyme assays (Udawatta *et al*., 2008). Dick *et al*. (1996) determined that dehydrogenase activity is directly related to the oxidation of organic matter in the soil. This further confirmed the result of a study conducted by Kirchner *et al*., (1993) which indicated that, the addition of organic matter increases microbial population and diversity. The results of the study conducted by Dick *et al*., (1996) were also supported by Doran (1980) who observed that diverse and competitive microbial populations are higher in soils that are managed to enhance organic matter production. Soil with higher organic matter will most likely have higher microbial activity, which would contribute significantly to the improvement of the soil quality. In this study, however, dehydrogenase activity could not be correlated with either percentage carbon nor with vegetation density. Microorganisms are key players in the soil biochemical process (Cundell, 1977; Manitoba agriculture, food & rural initiatives, 2001). Microbial abundance and communities will vary with different plant species (Bardgett *et al*., 1998). During the site inspection it was noted that the floor of the dumps was covered with leaf litter.

3.7.5 Vegetation

No apparent trends in the dominant vegetation on the dumps as a function of treatment could be identified from the investigation results. It is interesting to note that the vegetation density was not significantly different between the treatment groups although no vegetation had been planted on treatment Group 2. The vegetation density in treatment Group 2 was determined to be the highest among the treatment groups although no treatment was implemented. In addition, although the specific species were planted on each treatment group, species not planted were identified on the mine dumps during the survey. This is significant as it indicates that seeds were either present in the soil used to cover the asbestos dumps, or seed dispersal between the groups was occurring or the combination of both. Seed dispersal across the mine dumps may have spread via animals feeding on the plants and releasing faeces containing seeds; or seeds may have attached themselves to the animals and dropped off in the next dump as the animal feeds. The droppings of these animals will also contribute nutrients to the soil (Saunders *et al*., 1991). Basal cover measured on the mine dumps was low compared to the percentage herbaceous and woody crown cover. This requires attention, as limited basal cover can lead to erosion. The low basal cover is likely to be caused by overgrazing, as it was noted during the investigation that the mine dumps were not fenced off and animals (cows and goats) were noted grazing on the dumps. Overgrazing can impact on photosynthesis of plants and reduce root growth and seed dispersal (Tainton, 1984; Lemaire & Chapman, 1996; Sharma, 1997). The woody cover on the mine dumps would be adequate to provide shade if livestock were to continue to use the dumps as a food resource. Overall, the ecosystem on the mine dumps has improved with the rehabilitation efforts implemented as can be seen by the establishment of vegetation, seed dispersal and presence of fauna, which are considered vital for a healthy ecosystem (Aronson *et al*., 1993).

There were no apparent trends in the dominant vegetation species on the dumps as a function of treatment. All the species identified on the mine dumps were indigenous. *Acacia tortilis* was the dominant species on the mine dumps. This was expected in mine dumps in treatment Group 1 as manure rich in *Acacia tortilis* was spread over the dumps. The presence of *Acacia tortilis* in the other mine dumps is expected to be as a result of the seed bank in the soil used to cap the mine dumps or from seed dispersal. *Acacia tortilis* can be used by animals for food and shelter (Milton, 1983). *Dichrostachys*, an invasive species that does not have significant negative impacts on ecological function, had also become dominant on the dumps. This species has the capacity to establish on poor soil conditions (Wright & Fabacea, 2008) and it has been noted to be prolific when established on open land (Mbuya *et al*., 1994). *Dichrostachys* and *Acacia* are both palatable, having high protein content in the leaves and the seeds. They are also prolific seeders and are mostly animal dispersed. The two dominant woody species exist for about 40-60 years and during this period sufficient seeds are introduced into the seedbed to make it a functional and sustainable system. Four grass species were dominant on the mine dumps, some being more palatable than others (Walker, 2002). *Urochloa mosambicensis* and *Cenchrus ciliaris* are both highly palatable with the other species being less palatable but crucial in binding the soil and preventing erosion.

CHAPTER 4: REVIEW OF DME TECHNICAL GUIDELINES

4 STANDARD PROTOCOL AND GUIDELINES FOR THE REHABILITATION OF DERELICT/OWNERLESS ASBESTOS MINE RESIDUE DEPOSITS IN SOUTH AFRICA

4.1. Introduction

The Department of Minerals and Energy (DME) affairs, as the lead authority on mineral and energy matters in South Africa was tasked by the National Asbestos Summit (NAS) to develop a standard protocol and guidelines for asbestos mine dump rehabilitation, in partnership with other government stakeholders and interested and affected parties (I&APs) (REDCO, 1999). The main issues to be addressed during the development of the technical guidelines were:

- The guidelines should promote transparency between government and I&APs.
- DME has to involve the local community from the onset, including the budgeting phase and during the development of rehabilitation prioritisation criteria.
- Rehabilitation activities should promote skills transfer to affected communities.
- Rehabilitation techniques should use the best available technologies and alternatives should be considered in the selection of technologies.
- The objectives of rehabilitating an area should allow for controlled grazing and job creation.
- Rehabilitation should also include monitoring of rehabilitated mine dumps. The owner/contractor should be responsible for the health and safety of workers in carrying out rehabilitation activities.

The National Asbestos Summit was convened in November 1998 to debate the use, implications and effects of asbestos in South Africa. The debate was also to explore possible rehabilitation strategies which would be suitable for implementation in South Africa. The summit noted that the success of asbestos rehabilitation in the country would require commitment from the government and other stakeholders. The relevant parties were encouraged to commit to the recommendations made during the summit.

Following the summit, the DME developed technical guidelines on rehabilitation of asbestos mine dumps in South Africa, documented as "Standard Protocol and Guidelines for the Rehabilitation of Derelict/Ownerless Asbestos Mine Residue Deposits in South Africa" (RECO, 1999). The guidelines developed by DME cover all aspects of asbestos dump rehabilitation, from issues of contractor/consultant appointment, development of a rehabilitation methodology to be used, aims and goals of rehabilitation, prioritization of rehabilitation, how to implement rehabilitation methodology, community and government participation and development of research and new methodologies.

In terms of the repealed Minerals Act of 1991 (Act 50 of 1991) and current Minerals and Petroleum Resources Development Act of 2002 (Act 28 of 2002), rehabilitation of the surface of land concerned with any prospecting or mining operations shall be carried out by the holder of the prospecting permit or mining authorization and he/she must restore the surface of the land to its natural state or predetermined land use that complies with the concepts of sustainable development. Where the mine is ownerless, the government should intervene in the interest of the community and environment by addressing the contamination subject to the availability of funds. In 1986 it became internationally accepted that asbestos fibres pose a serious health impact to humans and a need for urgent rehabilitation of the mine dumps was identified in South Africa. Asbestos contamination rehabilitation started in 1986, starting with the most critical asbestos pollution sources in and around Priska, Krugersdorp and in some areas in the Limpopo Province. Most of the department's rehabilitation efforts have focused mainly in the Northern Cape Province since 1986. The primary aims of rehabilitation are to permanently eliminate the dispersion of asbestos fibres by environmental agents; the rehabilitated area must be self-sustaining and should be the best practical environmental option. The secondary aim of rehabilitation is to return the disturbed area to an ecologically stable environment.

In 2005, the DME reported that there were approximately 50 former asbestos mining areas remaining to be rehabilitated and 60% of all derelict asbestos mine dumps had been rehabilitated between 1986 and 2004 (Venter, 2005). The department had already spent R50 million by 2005 and it was anticipated that

R100 million more was still required to complete rehabilitation of the remaining mine dumps in South Africa.

4.2 Technical Guidelines on Rehabilitation of Asbestos Mine Dumps In South Africa

The DME developed criteria which could be used to prioritise rehabilitation of the various mine dumps across the country, as the asbestos mine dumps cannot all be rehabilitated simultaneously. A prioritization of criteria was developed at the same time as the technical guidelines for rehabilitation of mine dumps and form an integral part of the guideline document. These criteria are called the rehabilitation priority index (RPI) values. The criteria include:

- Presence of residents in close proximity to the mine dumps
- Quality and quantity of asbestos fibres at the source
- Potential for dispersion of asbestos fibres
- Wind characteristics of an area
- Availability of funds for a financial year

The method for rehabilitation of asbestos mine dumps currently used by the DME is the encapsulation method, which has been determined to be the most successful proven method. The encapsulation method involves the grading, reshaping and covering of asbestos residue deposits with 300 – 500 mm of clean fertile soil. The mine dump slopes are reshaped to a maximum of 18 degrees. This is done to allow infiltration of rainwater into the soil and to lower the rate of erosion. Following encapsulation, the rehabilitated dumps are then planted with indigenous plant species. Alternatively, depending on site conditions, trenches may be excavated in an area and the excavation filled with the asbestos residue. The excavated soil can then be used to cover the asbestos residue in the excavation and indigenous plants planted over the buried fibres. Erosion prevention measures are also implemented during rehabilitation. Erosion prevention measures include construction of contours and drains to minimise erosion by limiting the speed of running water, construction of cut-off trenches to divert water flow from adjacent catchment areas, construction of a retaining wall where the toe of a dump is located below the 1:100 year flood line and by re-vegetation of the area.

The guidelines also require monitoring and maintenance of mine dumps for three to five years following establishment of vegetation. Implementation of rehabilitation efforts should be conducted in consultation with affected communities and other government organizations. The health of the contractors and communities should be taken into consideration during the rehabilitation events.

The technical guidelines encourage further research on methods of asbestos dump rehabilitation and the DME has committed to implementing suitable and successful new methodologies in rehabilitation of asbestos mine dumps.

4.3 Technical Guidelines and The Case in Penge

It appears that the guidelines and the rehabilitation at Penge were being conducted in parallel. When considering, the technical guidelines developed by DME it can be concluded that the approach used during the rehabilitation of the Penge asbestos mine dumps did meet the requirements of the standard protocol and guidelines for the rehabilitation of derelict/ownerless asbestos mine residue deposits in South Africa. Although the mine dumps in Penge were rehabilitated according to the guideline recommendations, some areas showed limited success.

The technical guidelines allow for deviation from the outlined preferred approach and encourage development of research and new methodologies for the consideration and selection of the best available technology. The methodology recommended by the guideline which was also used at Penge, yielded some results, however, it did not completely eradicate the asbestos contamination problem in the area. Based on the observation of the persistence of asbestos contamination in the area, it is evident that supplementary methods or techniques are required to eliminate the contamination problem. The encapsulation method is widely used across the world, however, there are some variations in the rehabilitation method that can be added to improve the success of rehabilitation. One of the variations would be to augment the soil cover over the mine dumps with fertilizer for example, to increase the success of plant establishment on the mine dumps (USEPA, 2006). Other additional methods that can be used at the site to limit asbestos exposure, include restriction of access to the rehabilitation area by fencing and to only allow controlled access once vegetation has established. Permanent restriction to the rehabilitation area would ensure that there is no anthropogenic disturbance of the soil cap and underlying asbestos fibres. Significant migration of asbestos fibres is caused mostly by anthropogenic or major geological activity (Otness *et al*., 2003). Another method of limiting disturbance of the fibres, especially in areas where there is activity over the rehabilitation area, would be to install an impermeable layer over the mine dumps before the fertile top soil is added and revegetated. The vegetation on the mine dumps can be improved by replanting those areas where there is limited success. The asbestos problem at the former mining site is not only limited to the mine dumps, as asbestos fibres were also found in the town which could be as a result of previous mining practice and/ or as a result of fibres being blown from the mine dumps to the town. Other areas as those around the residential buildings and roads also need to be cleaned of asbestos fibres to ensure that these areas do not become the source of asbestos contamination in the area.

The success of rehabilitation can only be ascertained by monitoring the work undertaken as promoted by the technical guidelines, which recommend monitoring and maintenance of rehabilitated mine dumps over three to five growing seasons following establishment of vegetation. Following reshaping and vegetation of the mine dumps, monitoring should be conducted on a seasonal basis to ensure that shortfalls are identified early and where there are problems, rehabilitation measures are re-implemented. However, due to limitation of available funds, maintenance and monitoring of the rehabilitation at Penge were not conducted as per the DME recommendations, therefore, any additional work to be conducted at the site would need to be monitored to ensure success and early detection of any further problems.

CHAPTER 5: GENERAL DISCUSSION

5. GENERAL DISCUSSION

Case studies reviewed as part of this research highlighted that asbestos mining was extensively undertaken across the world leaving behind a legacy of environmental contamination and health impacts on communities living in the vicinity of mines and other asbestos handling areas. In some countries rehabilitation of asbestos contamination has been extensively practiced whereas in other countries limited rehabilitation efforts were implemented. Different rehabilitation strategies have been implemented in different areas depending on environmental conditions and presence of humans within contaminated areas. The common rehabilitation measures involved placing a cap over the asbestos mine dumps to prevent asbestos dust emissions and to provide a suitable substrate on which indigenous plant species are planted. Communities living in the vicinity of contaminated areas are either temporarily relocated during rehabilitation and communities brought back following cleanup or the residents are permanently relocated to promote sustainable rehabilitation. In most of the cases, the contaminated areas are fenced to restrict human and animal access. Monitoring of rehabilitation efforts were conducted on all the reviewed case studies, which was a major difference to the Penge case where no monitoring was conducted for 12 years following rehabilitation. It is evident from the case studies that, although rehabilitation of the mine dumps may be considered successful, the asbestos fibres stay in the environment long after a functional ecology has been developed on the mine dumps.

Research on the rehabilitation measures implemented at Penge indicates that the asbestos fibre encapsulation method commonly used across the world was implemented and indigenous vegetation planted. The database kept by REDCO indicates that detailed planning for the rehabilitation had been documented but these documents were not available. There are no records of what volume of soil was moved to the area, and there are also no data on the chemical, physical and microbiological properties of the soil used in the rehabilitation of the dumps. No initial samples were collected from the rehabilitated dumps in 1996 (to act as the baseline data), therefore it makes it very difficult to discuss the impacts over the last 12 years. This study highlighted that there was poor project management by DME of rehabilitation measures implemented.

Sampling of soils, fauna and vegetation, by REDCO on behalf of the DME was conducted in September and October 2007. A site inspection was conducted by myself over a one day period on 10 October 2008 to physically view the site area and to become familiar with the area and its current environmental conditions. The results of the study, which revealed that vegetation is growing on the dumps and maintaining a fairly high density, are encouraging. It was also noted that the nutrient levels were generally low at the site. Taking this observation into consideration, it is expected that vegetation establishment and growth on the dumps would be improved significantly with the application of supplementary nutrients and replanting of areas that failed to establish growth. Erosion control would also need to be implemented. The vegetation on the dumps does not only appear to be affected by nutrient availability, but also the negative impact of grazing of domestic animals. All dumps have livestock grazing on them. These animals are attracted by the presence of the palatable species. Obviously, complete restriction preventing the soil cover from being disturbed would ensure a more stable and effective vegetation cover but this would limit addition of nutrients and seed dispersal by animals.

In terms of the health impacts posed by the current environmental contamination status of the site, it is not possible to give conclusive assessments of the human health risk created by former mining activities, as the scope of this study was limited specifically to the assessment of soil, flora and fauna conditions of the rehabilitated mine dumps. No fibre content of the air for example was taken. This assessment would be critical in determining the fibre concentration in the environment and comparing it with health requirements. Nevertheless, exposed asbestos fibres were observed in some waste burial areas, posing a significant health risk as only minimal wind disturbance is required to lift fibres into the air (Van der Walt *et al*., 1996). In addition, the fibres possibly lodged in site buildings and other infrastructures around the former mining area, pose a significant risk as these can be blown around or can be disturbed by humans when they clean their houses and sweep their yards. Occupation of the mining area by people is dangerous as this increases the chance of asbestos fibre exposure from their daily activities and through expansion into areas where material containing fibres may be located (Otness *et al*., 2003). Restriction of disturbance of contaminated areas will limit the quantity of dust fibres in the air. There is no significant migration of asbestos fibres through soil other than through disturbance by anthropogenic activity (Van der Walt *et al*., 1996). From this observation it is clear that asbestos contaminated areas are not suitable for human occupation unless extensive asbestos rehabilitation is conducted. Rehabilitation needs to encompass residential infrastructure similar to the efforts implemented in the Wittenoom and Mountainview mobile home estate where residents had to be temporarily relocated while contaminated structures were either destroyed or cleaned out. This would be a huge task and most likely extremely costly. In my opinion the best solution in a case such as Penge, is to completely close off the site and relocate the residents permanently to another area. This option would be similar to the final recommendations implemented at Wittenoom and Mountainview mobile home estate after it was identified that even after extensive rehabilitation, asbestos fibres continued to pose health impacts to residents.

The Department of Minerals and Energy (DME) formulated guidelines for the rehabilitation of asbestos mine dumps in South Africa and although these guidelines had not been formulated at the time of rehabilitation of the mine dumps in Penge, available information indicates that rehabilitation of the Penge mine dumps did meet common practice. Best practices from the case studies pointed towards: encapsulation, fencing, permanent resettlement of people and monitoring. These practices could have been carried out at the Penge site. However, the guideline requirement of monitoring rehabilitation efforts was not followed up at Penge, with monitoring being conducted after 12 years following rehabilitation contrary to the guideline which recommends a three to five year period. It should be acknowledged that the DME may have had financial constrains which prevented adequate monitoring of the rehabilitation efforts. The nature of the financial constraints is not clear, it appears that there are adequate funds for rehabilitation but there is difficulty in the allocation and spreading of the funds. In order to reduce the cost of monitoring, individuals within the communities should be trained to monitor and report on the progress of rehabilitation. In addition, these individuals should be trained to be in a position to conduct rehabilitation in identified areas. This would greatly reduce the cost of hiring professional consultants to continuously monitor the asbestos mine dumps and at the same time this would provide local contractors with employment opportunities. Although, the guidelines were not completely followed through, this study identified positive outcomes of a re-establishing ecosystem on the mine dumps. The results presented in this project should be utilized as a baseline for future studies in order to determine the success or failure of rehabilitation efforts.

CHAPTER 6: REFERENCES

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