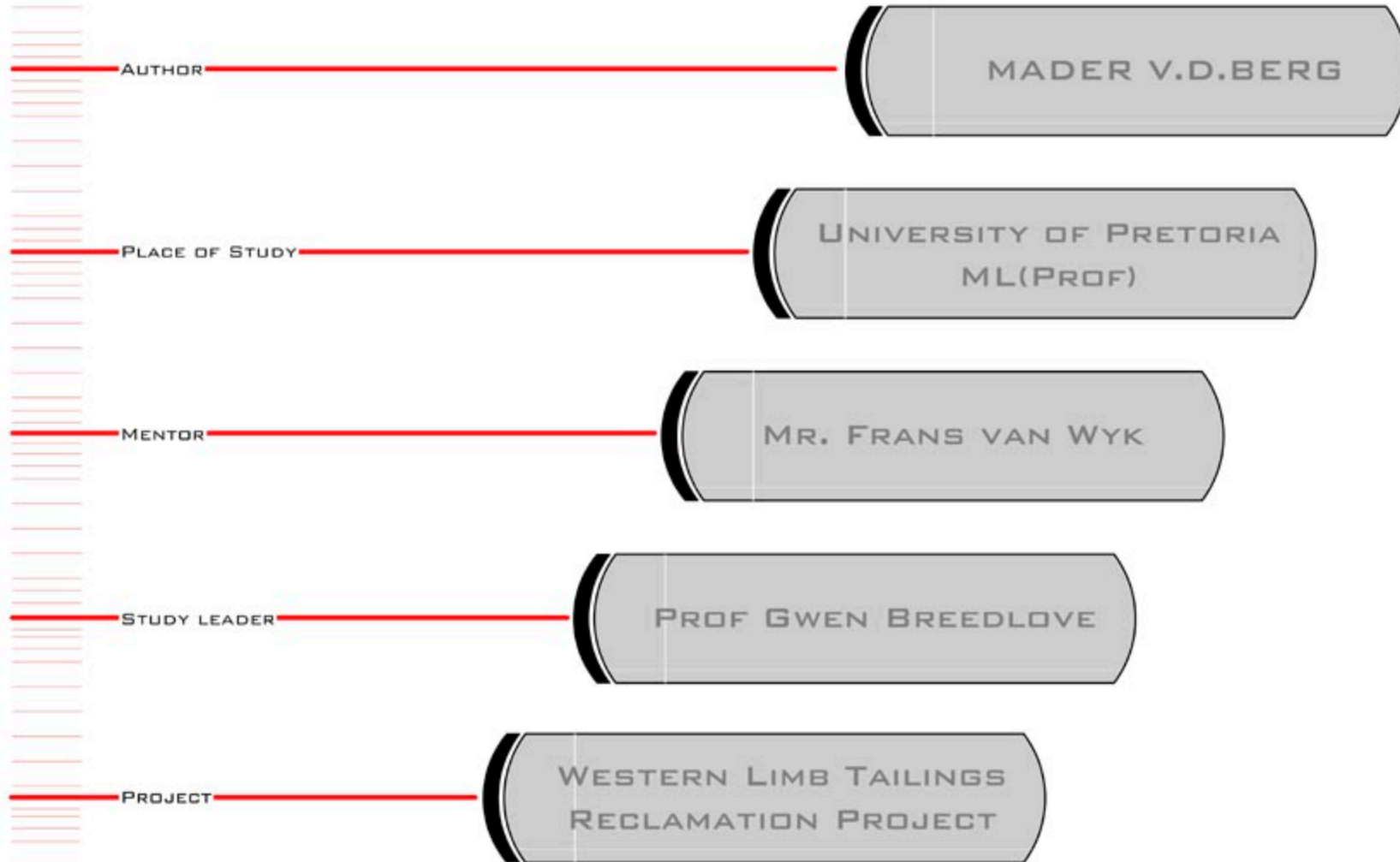


University of Pretoria etd - v.d. Berg M (2004)

Submitted as part of the requirements for the degree of Magister in
Landscape Architecture (Professional), ML(Prof), in the Faculty of
Engineering , Built Environment and Information Technology.



ACKNOWLEDGEMENTS

AL DIE DANK AAN GOD, ONS SKEPPER EN BRON VAN ALLE KENNIS

My ouers

Thania le Roux

Brain Rademeyer

Frans van Wyk

Anglo Platinum

Department of Bio-systems and Civil Engineering

Abstract

A new approach towards waste management in a mining environment is developed and applied. This dissertation specifically studies the storage and management of tailings in the platinum industry as well as the associated environmental impacts. The product is an alteration of conventional tailings storage methodologies, to a sustainable design strategy in order to minimise environmental impact and optimise social and natural conditions. Factors influencing Tailings Disposal Facility design is: geo-technical stability, public safety, economic considerations, visual impact, water, soil and air pollution, local social context and end land use goals. Each are discussed from an environmental and social impact point of view in order to arrive at a sustainable landform (Tailings Disposal Facility) design.

Keywords

Tailings Disposal Facility

Tailings

Platinum

Waste management

Dust outfall

Visual impact

Impoundment

Landform design

Table of contents	I
Glossary	II
Briefing	
Introduction	p1
Life-of-mine	p2
Environmental impacts	p3
Applicable legislation	p4
Formulating a new approach	p5
Integrated Planning Approach	p6
Context	
Site location	p8
Bio-physical environment	p9
Dust outfall	p16
Socio-Economics	p17
Aesthetics	p18
Baseline	
Typical system elements	p20
Slope and profile analysis	p21
Deposition methods	p24
Tailings characteristics	p26
Water balance	p29
Visual perception	p34
Technical	
Impoundment stability	p36
Erosion control practices	p37
Hydrological cycle	p40
Watercourse and wetland design	p42
Land-uses associated with certain slopes	p44
Concept development	
Conceptual phasing	p45
Site assessment	p47
Concept development	p48
Final landform	p51
Profile development	p54
Addendum 1	p59
Addendum 2	p60
Addendum 3	p61
References	

Decommissioning: "...the transitional period between cessation of operations and final." (Mudder & Harvey 1998)

Deposit: "A dump, heap, pile or filling which usually projects above the natural ground surface, but may occupy the space of a pre-existing excavation." (Chamber of Mines of South Africa 1996:1)

Impoundment: "...a system of one or more barriers which intercepts all potential routes for the transfer of material and which results in an acceptably low rate of transfer of contained materials to the environment." (Chamber Mines of South Africa 1996:2))

Reclamation: "...the site should be habitable to organisms originally present in approximately the same composition and density after the reclamation process." (Box 1978:4)

Rehabilitation: "...the disturbed site should be returned to a form of productivity in conformity with a prior use plan." (Box 1978:4)

Residue: "...any waste rock, slimes or tailings derived from any mining operation or processing to extract those constituents or parts which is profitable to extract at the time." (Mudder & Harvey 1998)

Restoration: "...the exact conditions and density after the reclamation process." (Box 1978:3)

Tailings: "...crushed rock particles that are either produced or deposited in slurry form. This encompasses the vast majority of finely ground mill or mineral processing wastes remaining after extraction of mineral values." (Vick 1983:1)

Wetland: Rogers (1995) defines a wetland as a "open-ended system, which occur adjacent to river and stream channels where plant species distribution and growth is determined by at least intermittent soil, (root zone) saturated or inundation as a consequence of fluctuations in flow."

BRIEFING

University of Pretoria etd - v.d. Berg M (2004)

PAGE 1

INTRODUCTION

PAGE 2

LIFE-OF-MINE

PAGE 3

ENVIRONMENTAL
IMPACTS

PAGE 4

APPLICABLE
LEGISLATION

PAGE 5

FORMULATING A
NEW APPROACH

PAGE 6-7

INTEGRATED
PLANNING APPROACH

WASTE GENERATION AND MANAGEMENT

INTRODUCTION

LIFE-OF-MINE

ENVIRONMENTAL IMPACTS

APPLICABLE LEGISLATION

FORMULATING A NEW APPROACH

INTEGRATED PLANNING APPROACH

Introduction

The **Western Limb Tailings Reclamation Project (WLTRP)** is a new initiative pursued by Anglo-Platinum. The project is concerned with the re-extraction of platinum from existing tailings impoundments at the Rustenburg Platinum Mines Limited - Rustenburg section (RPMR).

This project requires a terrain that will occupy approximately 850ha. The project is in its second year of operation and the necessary infrastructure to accommodate all operations has been erected. The infrastructure consist of the following:

- Tailings Disposal Facility (TDF)
- Associated topsoil stockpiles
- Return water dam
- Rock stockpile (fig 1-1)
- Concentrator complex (fig 1-2) and pipelines
- Roads, power lines etc.

Ultimately, the plant and associated components will be dismantled and removed after operation ceases. The TDF and waste rock dumps will remain and rehabilitation will be implemented to reduce further pollution of the environment. Current practice aims at re-vegetating TDF's in order to maintain stability and comply with environmental legislative frameworks.

The TDF needs to be stabilised to ensure safety for the public as well as to reduce adverse environmental impacts to an acceptable level before a closure certificate can be issued by the Department of Mineral and Energy Affairs. Only when this level of closure is achieved, is it possible to transfer ownership of the site and will the liability rest upon the new owner.

The "Closure concept"

The objectives for the successful closure of a mining facility as stipulated in the November 1998 edition of *Mining Environmental Management*, is as follows:

"Minimising long-term environmental liability, attaining regulatory compliance and maintaining geo-technical stability, while closing as quick and cost effectively as possible. All this should materialise within the general goal of returning the land to a safe and stable condition for the purpose of post-mining alternative functions. A successful closure procedure is a combination of innovative concepts, long-term commitment and multiparty cooperation." (Mudder & Harvey 1998:1)

These criteria are often not achieved. The lack of proper and updated closure plans has resulted in severe detrimental environmental, social and economic consequences in the past. Figure 1-4 is a diagrammatic example of a holistic approach. The emphasis is on the pre-defined closure and land use plan resulting in a long-term sustainable and productive land-use activity.

Waste generation and management (fig 1-3)

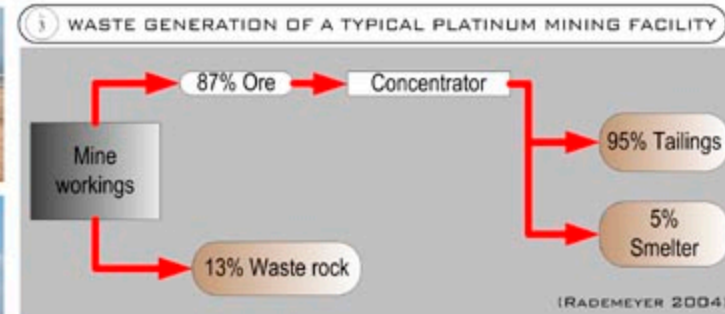
Tailings

The depositing of tailings occurs through various methods and in various forms depending on the characteristics of the tailings as well as the terrain where it will be deposited. It is common practice to deposit tailings of gold and platinum in a TDF. For the purpose of this study, one can define a TDF as being a permanent detention structure of mining waste above natural ground level.

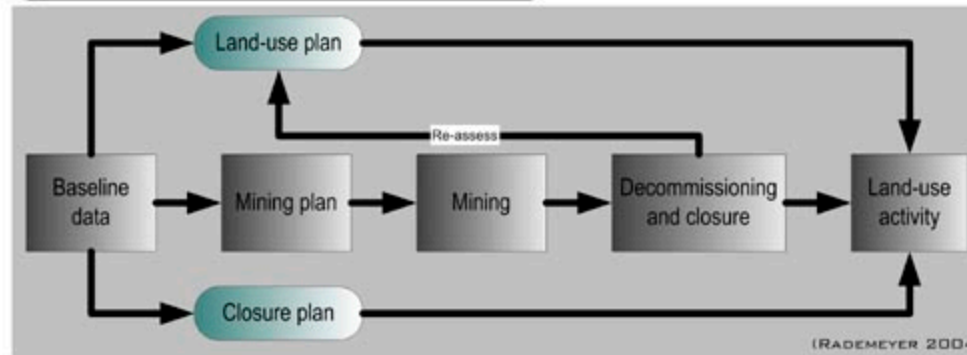
Tailings are defined "...as crushed rock particles that are either produced or deposited in slurry form. This encompasses the vast majority of finely ground mill or mineral processing wastes remaining after extraction of mineral values." (Vick 1983:1)

Waste rock (fig 1-1)

Waste rock often occurs in stockpiles near the plant and is occasionally applied in rehabilitation as a capping on the TDF to reduce the erosive effects of water and wind. If that is not the case, rehabilitation also needs to be applied on the stockpiles.

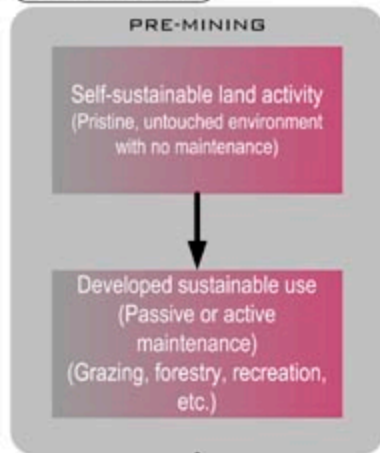


HOLISTIC APPROACH TO MINE PLANNING



GENERAL ENVIRONMENTAL LEGISLATION CRITIC

LIFE-OF-MINE



Pre-mining

The pre-mining environment entails either a green- or brown field site. The current land-use is often dictated by the surface conditions. Mining activity will often proceed regardless of existing conditions and to the detriment of environmental and social environments. It is often a scenario of which land activity will yield the greatest economic affluence. Mining is more often than not triumphant over any other land activity.

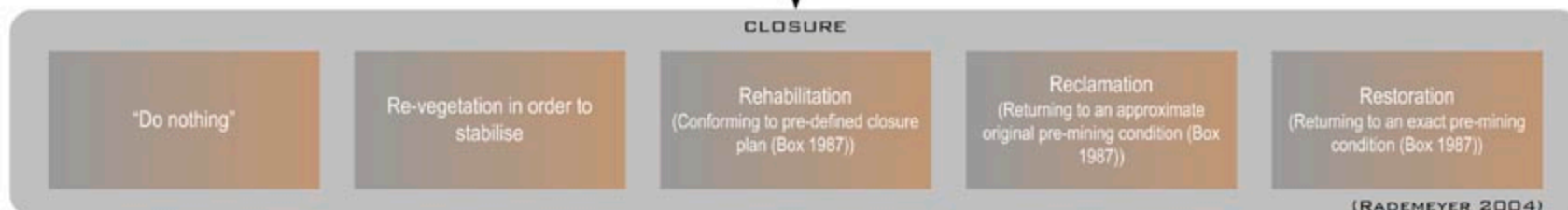
Exploitation

Exploitation will proceed for a determinate period of time. It is not uncommon for a single shaft to be mined for 50 years or longer. Waste production for a typical platinum mine shaft is approximately 98% of the total ore extracted (fig 1-3). The exploitation process requires an enormous amount of energy and water. Both are expensive and scarce commodities. The need for a frugal approach is essential in a sustainable and environmental responsible practice.



Closure

In entering the closure phase, the mining company is faced with a series of options. All are concerned with the management of waste and the exercising of the companies environmental liability and moral obligation. The mining industry is constantly criticised regarding environmental conservation. Government and influenced-and-affected parties are applying constant pressure on mining companies to comply with increasing stringent environmental standards and policies. An approach of environmental sensitive mining as well as the engagement on a social-responsible level is at least appropriate from a sustainable development point of view.



General environmental legislation critic

Considering the Constitution of South Africa, Act 108 of 1996, mining companies are responsible for maintaining a healthy environment for the benefit of all users. Environmental legislation aims at specifying statutory standards and regulations pertaining to mining activity. The broad descriptions of these standards and regulations are often vague. Phrases such as:

- "...mining will not result in **unacceptable** pollution, **ecological degradation** or damage to the environment." (MPRDA Act 28 of 2002)
- "...the holder of mineral rights must **as far as it is reasonably practicable**, rehabilitate the environment affected by mining operation." (*ibid*)

allows for much disparity. Guidelines for rehabilitation are available from the Chamber of Mines of South Africa, but are often left at that and not actively implemented. It is often left to the judgment of the environmental officer to decide what is **unacceptable** and **reasonably practicable**.

(See page 4 for detail description of the legislation environment)

- INTRODUCTION
- LIFE-OF-MINE**
- ENVIRONMENTAL IMPACTS
- APPLICABLE LEGISLATION
- FORMULATING A NEW APPROACH
- INTEGRATED PLANNING APPROACH

INTRODUCTION

LIFE-OF-MINE

ENVIRONMENTAL IMPACTS

APPLICABLE LEGISLATION

FORMULATING A NEW APPROACH

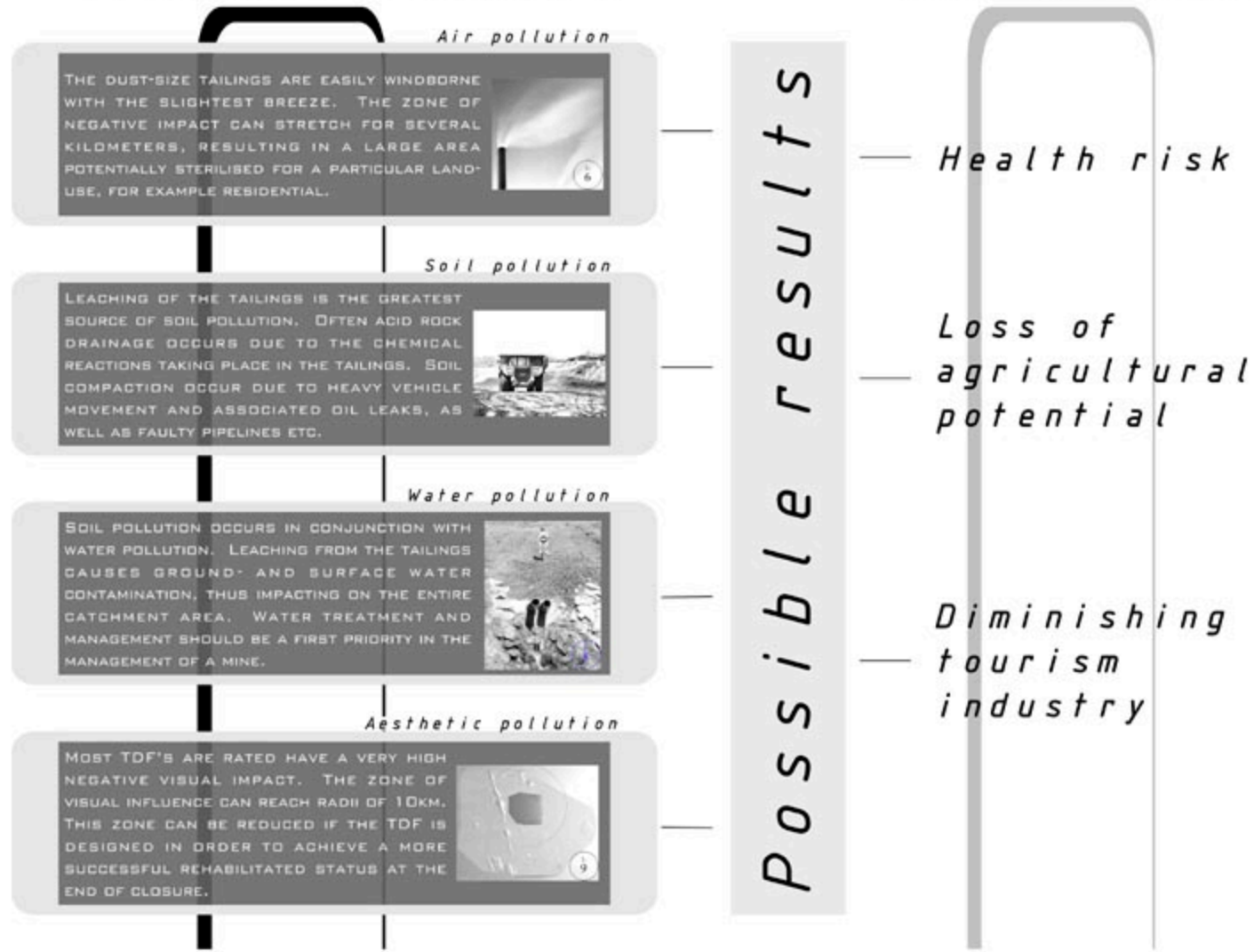
INTEGRATED PLANNING APPROACH

Introduction

Potential negative environmental and associated economic impacts are always present in an industry of this nature. In the past, the main challenge was to balance capital spent with capital earned in order to generate a profit from the business venture, in spite of the negative impact on the social and natural environments. Updated environmental legislation force mining companies to reconsider the potential environmental and subsequent economic impacts prior to exploitation. This has to go hand in hand with a realistic, yet creative end-land use plan on a regional as well as a local scale.

Environmental impacts

Economic impacts



LEGISLATION (Boswell 2004)

Introduction

Prior to 1994, environmental monitoring in the South Africa's mining industry was governed under separate legislation. Current legislation focuses on issues concerning social impact and sustainable development and is dictated by the requirements of the new constitution as well as an increasingly environmental aware public. The promulgation of the National Environmental Management Act 107 of 1998 (NEMA) is seen as a progressive step towards stringent but practicable environmental legislation to the benefit of all South Africans presently and in the future.

National Environmental Management Second Amendment Bill

- Published for comment in 2003
- Aims at amending the section on integrated environmental management (IEM) in NEMA and to regulate environmental impact assessment (EIA) and other management tools
- EIA's are currently regulated in terms of section 21, 22 and 26 of the Environment Conservation Act 73 of 1989 (ECA) and the associated Regulations 1182 and 1183. As soon as the Second Amendment Bill is accepted, EIA's will be regulated completely in terms of NEMA.
- The amendments to the Bill will also enable the Minister or MEC to request a particular company to compile an impact assessment report at any time. The minister has the authorisation to instruct the company to cease the operation activity either completely or partly and to rehabilitate the site. Alternatively, an environmental authorisation may be issued for that activity (s 24G).
- The Bill furthermore stipulates that associations of environmental assessment practitioners need to be registered in order to ensure that proper standards are maintained. The Bill aims at enhancing the quality of reports submitted for approval (s 24H).

National Environmental Management: Air Quality Bill

- Substituting the outdated Atmospheric Pollution Prevention Act 45 of 1965 (APPA)
- The overall objective of the bill is to reform the law regulating air quality in order to protect, restore and enhance the quality of air in South Africa
- Key features of the bill pertaining to mining operation include the following:
 - The bill embraces an ambient air quality management approach and introduces ambient air quality standards into the law.
 - The instituting of air quality officers at national, provincial and local levels to enforce the requirements of the act.
 - An air quality officer or authorising entity may require any person or company to submit an atmospheric impact report at any time.
 - The amended bill also provides for the control of dust by way of regulations.
 - The Minister or MEC may publish a 'list of activities' that may result in atmospheric emissions which have or are declared as significantly detrimental to the natural, social or economic environment, that poses a health risk or negatively impacts on cultural heritage.
 - The Minister or MEC may declare 'priority pollutants' and are authorised to publish a notice in the gazette requiring any blameworthy entity to prepare and implement a pollution prevention plan concerning the declared priority pollutants (s 24). The requirements for the pollution prevention plan will be prescribed by regulation.
 - Recognition programmes are provided for to recognise significant achievements in the area of pollution prevention (s 26)
- In order to meet the proposed clean air standards, it is required from business entities to upgrade outdated plant and equipment components on their own expense.

Environment Conservation Act Amendment Bill

Section 20 of the Environment Conservation Act 73 of 1989 deals with waste management. The current Act stipulates that the Minister of Water Affairs and Forestry should administer the operation of waste landfill sites and related control measures. This amendment transfers the administration from the Minister of Water Affairs and Forestry to the DEAT Minister to encourage and allow for a more integrated approach to the management of waste management facilities.

National Waste Management Strategies and Action Plans

- The objective of the National Waste Management Strategy (NWMS) is to deal with the full cycle of waste, from generation to final disposal.
- The goal is to reduce environmental impact in order to facilitate the country's socio-economic development and to improve healthy conditions and the quality of the environmental resources.
- The NWMS will require:
 1. The classification of the mining waste
 2. Consideration of waste- and site-specific issues
 3. Acceptable facility design, operation and closure plan for mining
 4. A detailed and continual review of the closure plan
- Mines will be required to implement cleaner technologies and to advance to new approaches considering the treatment and reduction of waste

National Water Act 36 of 1998

The Department of Water Affairs and Forestry (DWAf) is the public trustee of the country's water resources and has the mandate to manage these in a sustainable manner. Important strategies that originated from the transformation in water resource management are:

1. National Water Recourses Strategy (NWRS)
 2. Water Pricing Strategy
 3. Waste Discharge Charge System (WDCS)
1. The NWRS focuses on the protection of ground and surface water resources via the implementation of two approaches entitled Resource-Directed Measures and Source-Directed Controls. This strategy has not yet been finalised
 2. The National Water Pricing Strategy deals specifically with the pricing of first tier water (i.e. water obtained from the actual source), rather than second and third tier water (i.e. water supplied in bulk and distributed through water boards or municipalities)
 3. The WDCS is based on the 'polluter pays' principle as supported by NEMA. It is a strategy relating to waste discharge and costs associated with disposing of waste that holds the potential to detrimentally impact on a water resource

Minerals Act 50 of 1991





Introduction

Considering the previous discussions on mining activities as well as waste generation and the potential impacts associated with it, it is clear that mining companies need to effectively exercise their environmental liability and moral obligation as dictated by legislative frameworks. It also becomes apparent that an adoption of a new approach towards waste management, rehabilitation programs and closure achievement, is essential.

The minimum satisfaction of laws and regulations are not alone sufficient, as the advancement of sustainable development relies upon creative problem-solving and the acknowledgement of possible opportunities.

Formulating a new approach

When a particular company enters the endeavour of mining, an approximate volume of waste is pre-determined and the appropriate procedure for deposition and accommodation is decided on. A rate of waste deposition is required in order to maintain a profitable rate of mineral extraction. According to this study an expectation concerning rate-of-deposition exists in order to attain the goal of viable economic return.

Once this is finalised and an appropriate site is allocated, different TDF designs are evaluated according to economic parameters and subsequently to environmental and possible social implications. The chosen TDF is accompanied by a rehabilitation plan intended for implementation after decommissioning (fig 1-10).

The newly formulated approach is founded on the following argument: It is evident that a TDF is designed to contain tailings/waste within the parameters of satisfying safety and stability standards. However, this can be defined as a short-term function concluding as the mine enters the closure phase. Following decommissioning the TDF undergo an alteration in function. It is no longer a tailings storage facility per se, but a permanent, hazardous landform in the landscape. Rehabilitation is often applied as what seems as an after-thought, thus explaining the poor success.

It can be hypothesised that if the TDF is designed with the aim of both storing tailings and functioning as a natural landform in its context, it will potentially increase the rehabilitation success, support a future alternative land-use and shorten the closure-certificate application period.

This hypothesis entails that major alterations concerning the geometry is required, but still satisfying safety and stability.

Research on this topic indicates that it is possible to construct a TDF with varying slope gradients, slope lengths, bench widths, etc. Final rehabilitation can result in a profile similar to adjacent landforms with a diverse slope configuration, varying microclimate conditions necessary to establish a diversity of floral species.

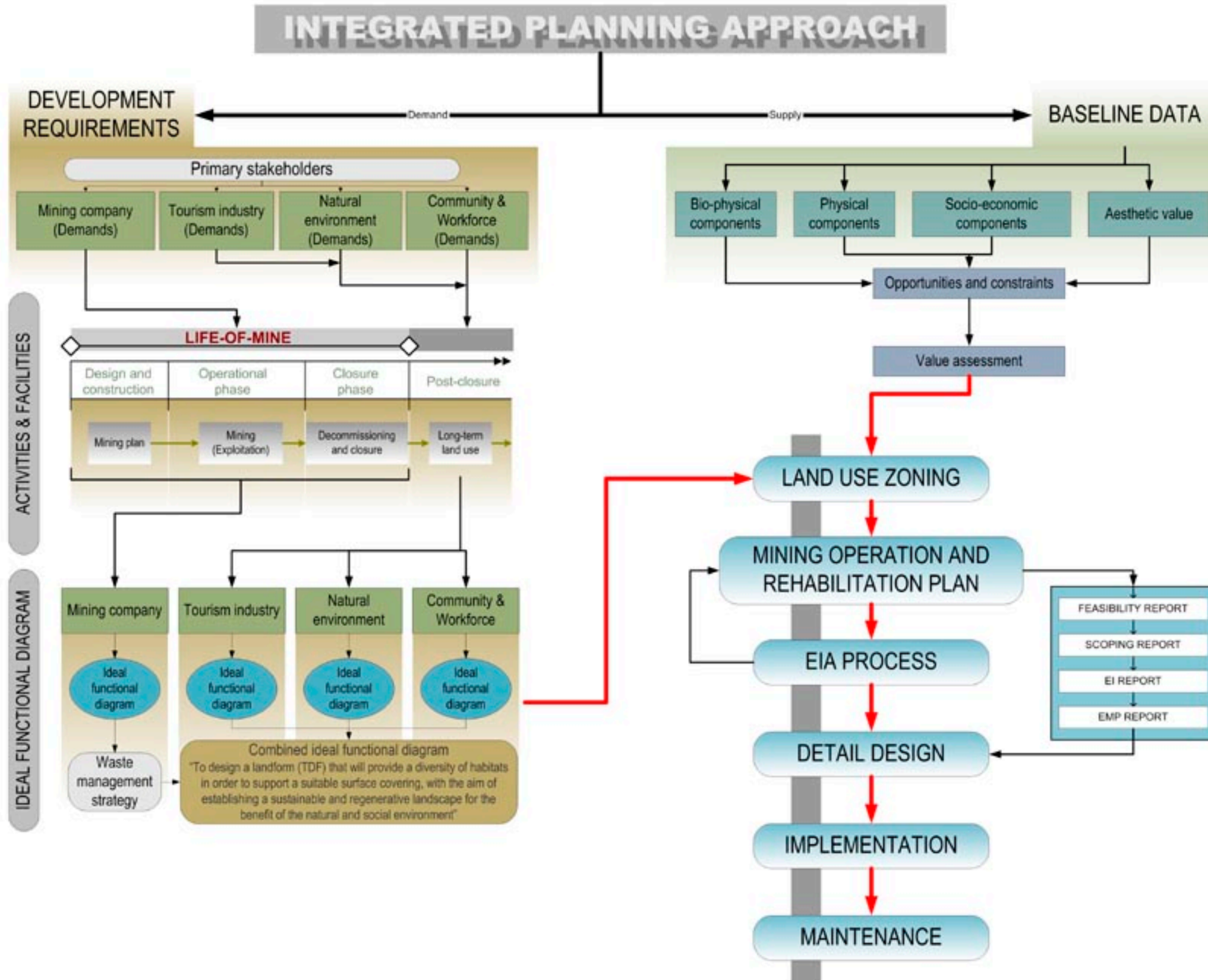
Project goal

*This project is concerned with the design of a **landform (TDF)** that will provide a diversity of **habitats** in order to support a suitable **surface covering**, with the aim of establishing a sustainable and regenerative **landscape** for the benefit of the **natural and social environment**. This should be a long-term goal determined prior to **construction**, re-assessed periodically during **operation** and accurately implemented **post-closure**, with the appropriate maintenance, until stability of the system is achieved.*

10 DESIGN AND ASSOCIATED REHABILITATION OPTIONS



(Adapted from Van Riet & Louw Landscape Architects 2002)



- INTRODUCTION
- LIFE-OF-MINE
- ENVIRONMENTAL IMPACTS
- APPLICABLE LEGISLATION
- FORMULATING A NEW APPROACH
- INTEGRATED PLANNING APPROACH**

INTRODUCTION

Integrated planning approach

The integrated planning approach acknowledges both development requirements (demands) as well as environmental components (supply) as key objects in reaching a suitable compromise for the benefit of both aspects.

Primary stakeholders

Identification of primary stakeholders is proof of a holistic and integrative planning approach. It is necessary to identify each stakeholder's requirements in terms of the activities performed and facilities erected by the company endeavouring in mining.

Activities & facilities

The requirements of activities and facilities are determined for the life-of-mine. Each stakeholder is connected to a phase or phases over the life-of-mine where it finds most concern.

It is apparent that the mining company's greatest concern lies with the first three stages during mineral extraction and optimum operation of the associated infrastructure. Although the other stakeholders are influenced over the full cycle of the mine, this study focuses on the post-closure phase and the requirements of the concerned parties in order to implement a successful long-term land use.

Ideal functional diagram

The concerned mining company anticipates a waste management strategy that is in the best interest of its economical status.

Each of the other stakeholders has different requirements to be satisfied:

- The tourism industry relies on an aesthetic pleasing environment with recreational potential.
- The natural environment requires a pollution free condition in order to function aptly and to support the existing land-use of the terrain.
- The community is dependent on a healthy and safe environment that satisfies its basic needs such as security, food and employment.

It is evident that the tourism industry, natural environment, community and workforce share common interests. This is often in contrast with the objectives of the mining company and a compromise is necessary.

In order to conclude with an integrative ideal functional diagram, an assimilation of each stakeholder's requirements should dictate the formulation of a combined ideal functional diagram.

Baseline data

Baseline data assembly should be as comprehensive as possible. This enables the recognition of thoroughly researched opportunities and constraints present in the context of the proposed mining activity.

Value assessment

The value assessment aims at quantifying or providing a qualitative value to a subject. Each subject's value will be discussed in terms of the interest concerning all stakeholders.

Land use zoning

Land-use zoning is the convergence of development requirements and baseline data in an attempt to satisfy all stakeholders' needs. The result is an allocation of development zones as well as the identification of areas-of-concern with appropriate mitigation measures.

Mining operation and rehabilitation plan

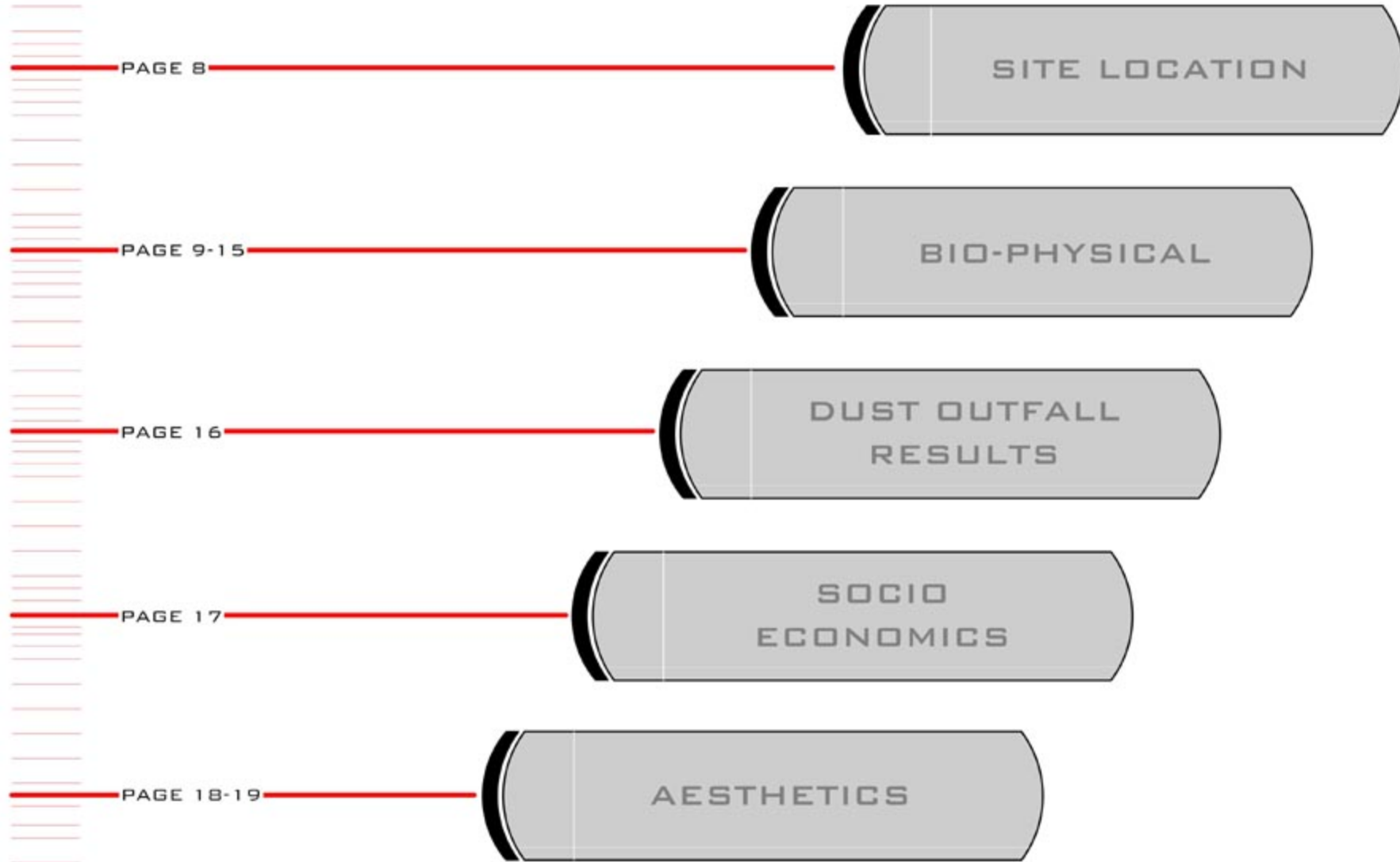
Mining operation and rehabilitation programs should result in an iterative procedure with the EIA process. This process will continue until a satisfactory product is achieved, resulting in a strategy of least environmental impact.

Detail design, implementation and maintenance

Detail design results in the execution of the proposed development. Implementation should comply with on going monitoring of activities as well as periodic re-assessment of rehabilitation plans. A maintenance component and long-term commitment from the mining company is essential to ensure the success of rehabilitation.

INTEGRATED
PLANNING
APPROACH

CONTEXT



SITE LOCATION

BIO-PHYSICAL ENVIRONMENT

DUST OUTFALL RESULTS

SOCIO ECONOMICS

AESTHETICS



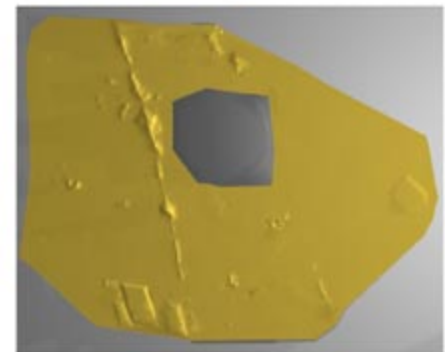
NORTH-WEST PROVINCE



RUSTENBURG DISTRICT

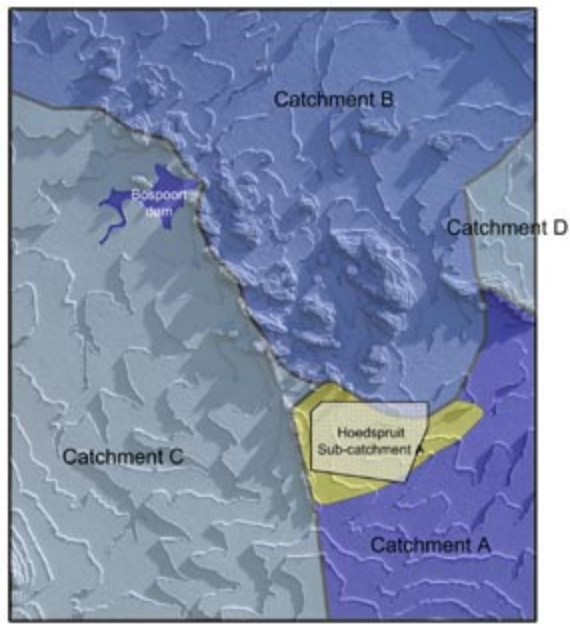


SITE LOCATION

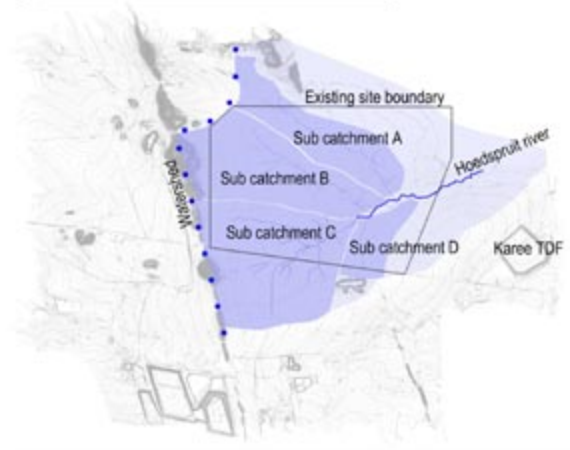


- SITE LOCATION
- BIO-PHYSICAL ENVIRONMENT
- DUST OUTFALL RESULTS
- SOCIO ECONOMICS
- AESTHETICS

WATERSHED ANALYSIS - REGIONAL



WATERSHED ANALYSIS - SITE



Surface Water

Surface water use

- The following informal water users, downstream from the study area were identified:
- Domestic use by residents of the informal communities in the vicinity,
 - Livestock watering of animals owned by residents of the informal communities,
 - Aquatic users
 - Recreational users of the Bospoort and Vaalkop dams (Botha *et al* 2002)

Water Authority

The North West Regional office of the Department of Water Affairs and Forestry (DWAf) in Hartebeespoort is the responsible water authority (*ibid*).

Wetlands

According to the studies conducted by Envirolink for Anglo Platinum, no wetlands occur in the study area. The definition for wetlands compiled by Rogers (1995), was adopted in that report (*ibid*).

Groundwater

Depth of water table

The water table level average at a depth of 10.5m below ground level for the study area. (*ibid*)

Ground water quality

The ground water quality was compared to and classified in accordance with the Quality of Domestic Supplies, Volume 1, Assessment Guide published by DWAf (1999).

All the tests have shown that the ground water quality is poor and unacceptable for domestic use. (*ibid*)

Ground water use

Surveys have showed that ground water is not used as a resource within a 1km radius of the study area. The surrounding communities utilise municipal water only. (*ibid*)

Catchment size

Hoedspruit sub-catchment A = 18.3km²
 Site area = 15km² (*ibid*)

Mean annual runoff

Hoedspruit catchment	0.26 mill m ³ /ha	
Flood peaks and volumes	1:20 year flood - 39.2 m ³ /s	0.54 mill m ³
	1:50 year flood - 59.6 m ³ /s	0.8 mill m ³
	1:100 year flood - 79.2 m ³ /s	1.03 mill m ³ (<i>ibid</i>)

SITE LOCATION

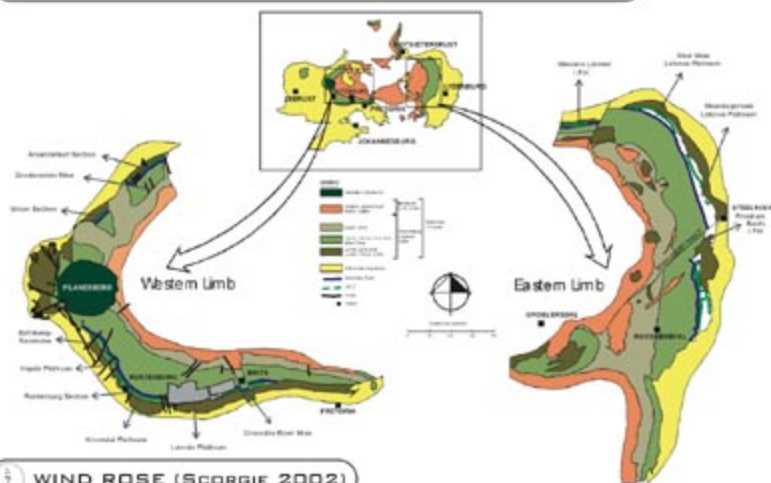
BIO-PHYSICAL ENVIRONMENT

DUST OUTFALL RESULTS

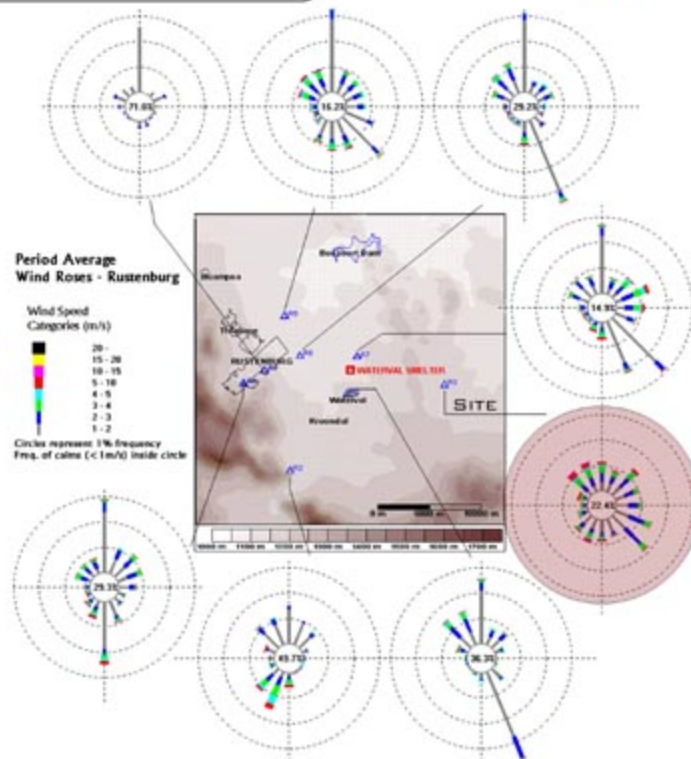
SOCIO ECONOMICS

AESTHETICS

6 GEOLOGY - BUSHVELD COMPLEX (RADEMEYER 2004)



7 WIND ROSE (SCORGIE 2002)



Geology (fig 2-6)

The Bushveld Complex is rich in a variety of minerals due to its specific geological formation. Potentially, the entire Bushveld Complex is a source for future mineral extraction. Currently, mining is restricted to the mining-belt that is located on the fringes of the Bushveld Complex. Platinum is nearest to the surface in these areas and thus making extraction less expensive. South Africa has the richest platinum bearing geology in the world, with the greatest concentration in the Bushveld Complex.

Climate on meso-scale

Ambient temperature

Summer: 16°C-31°C

Winter: 3°C-24°C

Average daily max and min (Rustenburg)

January	30.6°C	16.9°C
April	26.2°C	10.6°C
July	20.6°C	1.8°C
October	30.0°C	13.4°C

(Carruthers 2000)

Precipitation and evaporation

The study area occurs in a summer rainfall area. Approximately 70% of annual rainfall occurs during October to February.

Average rainfall: 630mm-740mm

Average seasonal distribution of rain:

January - March	44%	300mm
April - June	11%	75mm
July - September	5%	34mm
October - December	40%	272mm

(Ibid)

Average number of rainy days per annum: 80

Average nr of thunderstorms per annum: 75

Average incidence of hail per annum: 4

Surface winds (fig 2-7)

Prevailing wind direction:

Summer mornings	East to north-east
Summer afternoons	North to north-east
Winter mornings	South-east to north-east
Winter afternoons	North-west

(Ibid)

- SITE LOCATION
- BIO-PHYSICAL ENVIRONMENT
- DUST OUTFALL RESULTS
- SOCIO ECONOMICS
- AESTHETICS

Soil (fig 2-8)

Regional soil is typically shallow soils on rocky ridges and gentle to flat mid slopes where Arcadia and Hutton soils are found. (Botha *et al* 2002)

Soil analysis

pH levels: 6.3-8.5

Electrical conductivity (indicator of salinity): 21-68 mS/m indicating that soils are not saline

Sodium levels: Low, meaning that no risk of erosion due to dispersion of clay particles by sodium ions will occur

Nitrogen and phosphorus: Fairly low

Potassium, calcium & magnesium: Sufficient to sustain normal plant growth

Hutton soils have a low buffer capacity, high porosity and high infiltration capacity. Arcadia soils have a high buffer capacity, low porosity and low infiltration capacity (*ibid*).

Suitability of soils for mining operations

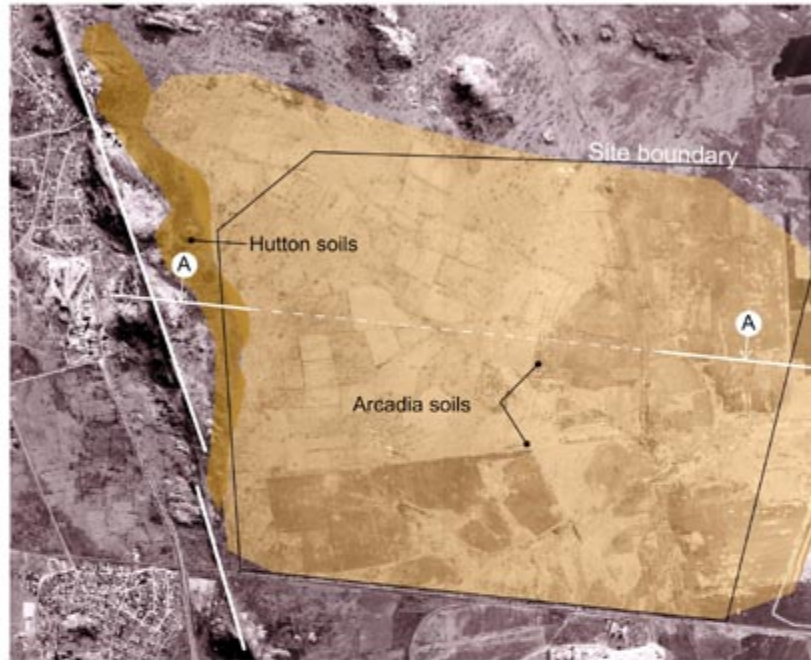
Both Hutton and Arcadia soils are chemically and physically suitable for use in rehabilitation (*ibid*). Hutton soils are particularly suitable for rehabilitation. Arcadia soils provide a valuable natural liner to reduce seepage of contaminated water to the groundwater. Caution should be taken when topsoil is collected from the surface for subsequent capping of the TDF, not to destroy the buffer layer i.e. natural liner.

Refer to Addendum 1 for soil stripping and stockpiling techniques as well as placement during rehabilitation.

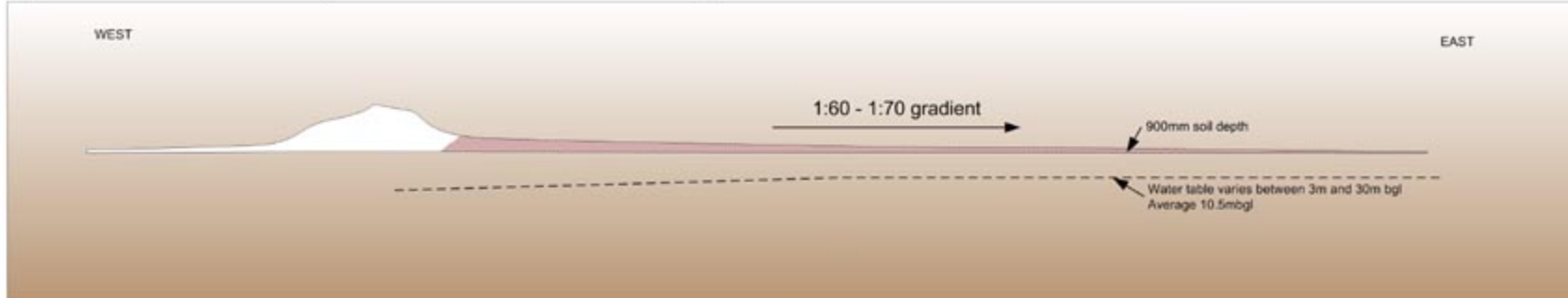
Pre-mining land use

The pre-mining land use was dominated by grazing and cropping although most fields were found fallow (*ibid*).

SOIL DISTRIBUTION



SECTION A-A: SOIL DEPTH



SITE LOCATION

BIO-PHYSICAL ENVIRONMENT

DUST OUTFALL RESULTS

SOCIO ECONOMICS

AESTHETICS

Flora status

Flora of pre-mining environment

The proposed project area is situated in the Savannah Biome. 25 vegetation types occur in the Savannah biome from which the Clay Thorn Bushveld and Mixed Bushveld are relevant. (Botha et al 2002)

Clay Thorn Bushveld

This vegetation type is determined mainly due to the extremely clayey soils. The economic uses are primarily for cultivating crops such as wheat, maize and sunflower.

Dominating plant sp. in the Clay Thorn Bushveld region:

- *Acacia karoo*
- *Acacia nilotica*
- *Ziziphus mucronata*
- *Dichrostachys cinerea*
- *Grewia flava*
- *Ischaemum afrum*
- *Sehima galpinii*
- *Setaria incrassate*
- *Panicum coloratum (ibid)*

Mixed Bushveld

A great variety of plant communities occur in this vegetation type ranging from dense, short bushveld to rather open tree savannah. *Mixed Bushveld* is characterised by coarse, sandy and shallow soil, overlying granite, quartzite sandstone or shale.

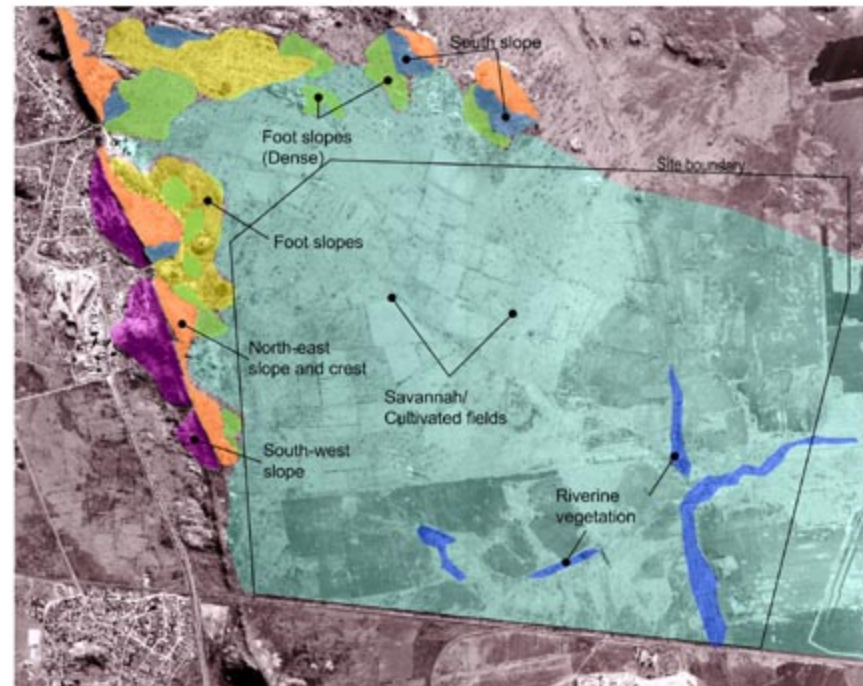
Dominating plant sp. in the Mixed Bushveld region:

- *Combretum apiculatum*
- *Acacia caffra*
- *Lannea discolour*
- *Sclerocarya birrea*
- *Terminalia sericea*
- *Ochna pulcra*
- *Burkea africana*
- *Digitaria eriantha*
- *Schmidtia pappopharoides*
- *Antheophora pubescens*
- *Eragrostis pallens*
- *Perotis patens (ibid)*

10 RIVERINE VEGETATION (SOURCE: SEF DATE UNKNOWN)

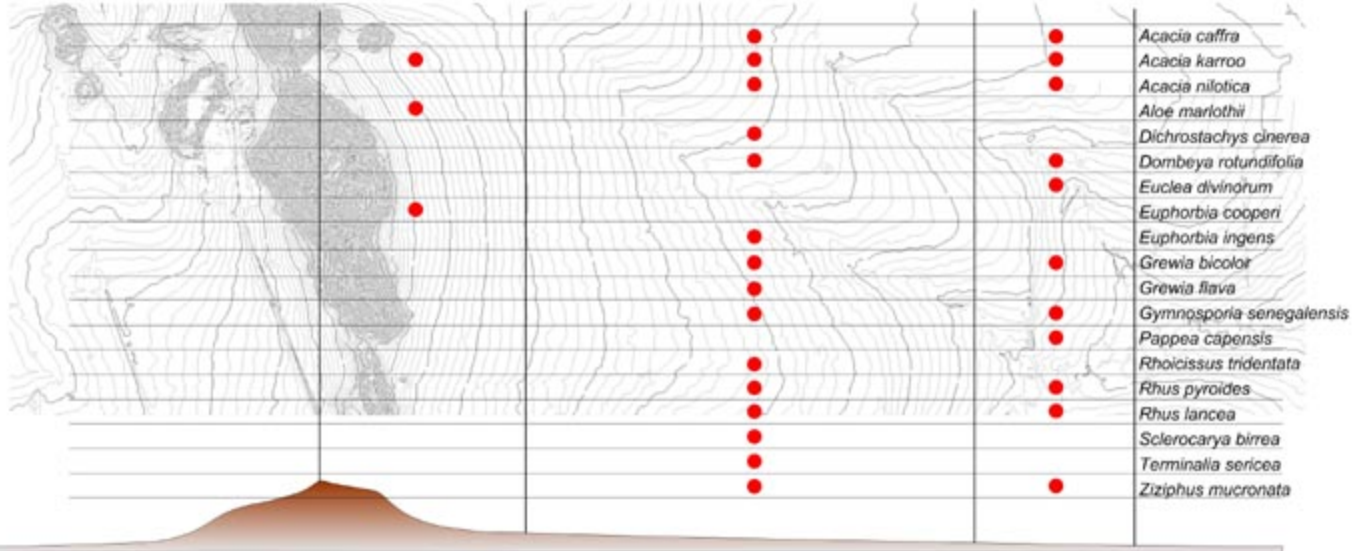
Vegetation Zone A	Vegetation Zone B	Vegetation Zone C
<p>Rushes</p> <ul style="list-style-type: none"> <i>Juncus effusus</i> <i>Juncus krausii</i> <p>Sedges</p> <ul style="list-style-type: none"> <i>Cyrcium tubulosum</i> <i>Cyperus esculentus</i> <i>Plantago longissima</i> <i>Schoenoplectus corymbosus</i> <p>Bulrushes</p> <ul style="list-style-type: none"> <i>Typha capensis</i> Grass & Grass like <i>Phragmites australis</i> 	<p>Grass & Grass like</p> <ul style="list-style-type: none"> <i>Pennisetum macroumum</i> <p>Sedges</p> <ul style="list-style-type: none"> <i>Cyrcium tubulosum</i> <i>Cyperus esculentus</i> <i>Plantago longissima</i> <i>Schoenoplectus corymbosus</i> <p>Grass & Grass like</p> <ul style="list-style-type: none"> <i>Phragmites australis</i> 	<p>Trees</p> <ul style="list-style-type: none"> <i>Acacia karoo</i> <i>Combretum erythrophyllum</i> <i>Rhus lancea</i> <i>Salix mucronata</i> subs. <i>Woodii</i> <p>Shrubs</p> <ul style="list-style-type: none"> <i>Calpurnea aurea</i> <i>Halleria lucida</i> "orange" <i>Mellianthus major</i> <i>Rhamnus prinoides</i> <i>Tetradenia riparia</i> <p>Grass & Grass like</p> <ul style="list-style-type: none"> <i>Eragrostis plana</i> <i>Hyparrhenia tamba</i> <i>Imperata cylindrical</i> <i>Setaria sphacelata</i> var. <i>sercea</i> <i>Sporobolus africanus</i>

11 TOPOGRAPHIC DIVISIONS



DISTRIBUTION ON SITE

12 TYPICAL TREE AND SHRUB DISTRIBUTION ACROSS SITE



13 TYPICAL GRASS DISTRIBUTION ACROSS SITE



SITE LOCATION

BIO-PHYSICAL ENVIRONMENT

DUST OUTFALL RESULTS

SOCIO ECONOMICS

AESTHETICS

SITE LOCATION

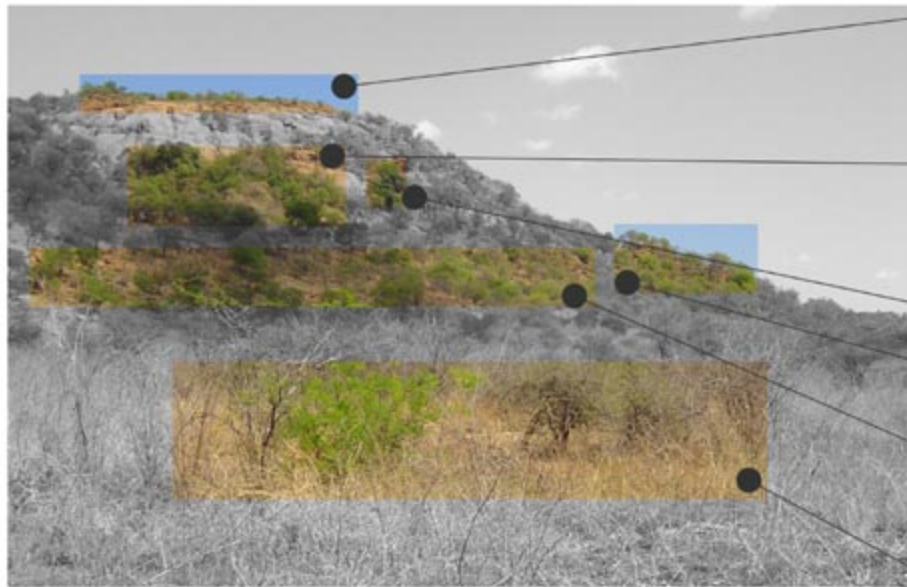
BIO-PHYSICAL ENVIRONMENT

DUST OUTFALL RESULTS

SOCIO ECONOMICS

AESTHETICS

14 EAST SLOPE VEGETATION AND CONDITIONS 1

**East slope 1** (fig 2-14)

The crest usually consists of a rocky, granite outcrop. Conditions is dry and very hot. In addition to the aridness is the high solar gain capability of the exposed rock. Roots find their way into cracks in search of moisture. Vegetation is limited to succulent (*Euphorbia cooperi*) and drought resistant trees and shrubs. Grass distribution is sparse.

A characteristic element of adjacent hills, are cliffs. Vegetation is usually dense directly underneath the cliff, probably due to deeper soil, higher moisture availability and protection from wind and fire. Rock debris and a well established leave canopy, protect soil from heavy erosion. Steep slopes are present directly underneath the cliffs, but are stable.

Ficus ingens (Red-leaved rock fig) is characteristic of cliff vegetation in this region.

Another rocky outcrop is often present halfway down the slope. In most cases it is boulders from a previous unstable cliff scenario. Vegetation is similar than directly underneath the cliff.

The slope slowly grades out in a concave manner to the foot of the hill. A combination of trees and grass species dominate the middle slope. Trees are less dense and enough light penetrates to the grassy surface. Periodic fires is a natural process limiting bush encroachment.

The foot of the hills are characterised by the dense thorny shrubbery. Deep, fertile soils and high moisture content stimulates vigorous growth. *Dichrostachys cinerea* is dominant and indicates possible disturbance of the soil.

15 EAST SLOPE VEGETATION AND CONDITIONS 2

**East slope 2** (fig 2-15)

This example of a crest, shows a more fragmented condition. Drought tolerant species find it easier to establish. A denser grass cover ensures a more readily occurrence of veldfire.

The middle slope resembles the previous example. A savannah type grass/tree relationship is clearly present.

Clusters of *Aloe marlothii* (Mountain aloe) make its appearance near the foot of the slope. Individual specimens are identifiable in other locations.

The plains are often characterised by dense bushveld vegetation. The availability of fertile, clayey soils with high moisture retention capability, sustain these vegetation communities.

ANALYSIS 2

(i) WEST SLOPE VEGETATION AND CONDITIONS



(ii) SOUTH-SLOPE VEGETATION AND CONDITIONS



- Acacia caffra*
- Diospyros lyciodes*
- Ficus ingens*
- Ziziphus mucronata*
- Papea capensis*
- Rhus pyroides*
- Rhus lancea*

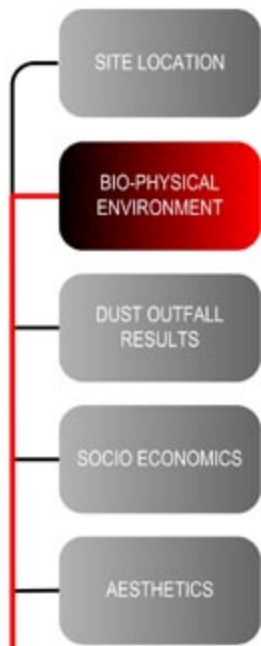
West slope (fig 2-16)

A large colony of *Euphorbia cooperi* is present on the west slope of this hill. Overall, the hill is densely vegetated apart from the odd grassy patches on the bottom left and right. Some vegetation is very specific in terms of its growing conditions. Soil type, water availability and slope aspect is in most cases the determinant factors.

Conclusion

One can conclude the following:

- The distribution of species on the north, east, west and south slope is in most cases very similar.
- The distribution of vegetation is rather determined by micro-condition variations than macro climatic factors.
- Soil type, soil depth and moisture availability dictates vegetation distribution.
- Vegetation on the crest is drought resistant shrubs and small trees interspersed with succulent species.
- It is clear that larger trees require protection from fire and wind. These conditions are available on or adjacent rocky outcrops down the side of the slope.
- Grass dominated areas occur mostly near the foot of a hill.
- The plains can either be savannah vegetation type, or dense low growing shrubbery, resembling a bushveld vegetation type.



SITE LOCATION

BIO-PHYSICAL ENVIRONMENT

DUST OUTFALL RESULTS

SOCIO ECONOMICS

AESTHETICS

Introduction

Following the information concerning wind speed and predominant direction, it is possible to arrive at isopleth plots illustrating highest daily average PM₁₀⁽¹⁾ concentrations and maximum daily dust fall rates, based on results from simulations on a 850 ha and 750 ha tailings dam area scenario.

Air quality guidelines

New air quality target guidelines for PM₁₀ are stipulated by the provincial air pollution control officer. The target guidelines are specified as 50 µg/m³ for a 24 hour averaging period with compliance by 2005. It is also required that modelling be performed for a regular grid covering the impact area with approximate distance of 75 m between receptors.

In the air impact assessment report specific reference is made to the predicted level of pollution to occur at the closest exiting residential settlement. When analysing incremental concentrations due to the proposed TDF with 50 µg/m³ and 35 µg/m³ thresholds, the following is noted:

- These thresholds are likely to be exceeded given the 850 ha TDF, regardless of effective controls implemented and the restriction of the TDF to a height of 45m.
- With effective mitigation⁽²⁾ in place, the 45 m high 750 ha TDF is not expected to exceed the 35 µg/m³ threshold. The increase of the TDF to 120 m is likely to result in exceeding this threshold, although maximum concentrations is still lower than the 50 µg/m³ level.

Significance of impact

The significance of the impact is specified as follows:

- Very high - 850 ha, no mitigation
- High - 850 ha, effective mitigation
- Medium-high - 750 ha, effective mitigation

Social concern

The greatest concern lies with the high impact zone on the north-west and south-west areas adjacent to the TDF (fig 2-18 -21). Coincidentally, these are the areas where settlements occur. The establishment of an effective mitigation practice is essential and a subject that will receive attention during the design process.

⁽¹⁾ Inhalable particulate fraction or PM₁₀, particulate matter with an aerodynamic diameter of, 10µm

⁽²⁾ Refers to maintenance of a wet beach over 70% to 80% of the tailings surface, and 80% vegetation density on the side walls up until at least 1 m from the top of the tailings.

18 850 HA TAILINGS IMPOUNDMENT PREDICTED MAXIMUM 'TOTAL DAILY' DUSTFALL (mg/m²/day) DUE TO THE WESTERN LIMB TAILINGS PROJECT (NO MITIGATION)



19 850 HA TAILINGS IMPOUNDMENT PREDICTED MAXIMUM 'TOTAL DAILY' DUSTFALL (mg/m²/day) DUE TO THE WESTERN LIMB TAILINGS PROJECT (WITH MITIGATION)



20 750 HA TAILINGS IMPOUNDMENT PREDICTED MAXIMUM 'TOTAL DAILY' DUSTFALL (mg/m²/day) DUE TO THE WESTERN LIMB TAILINGS PROJECT (NO MITIGATION)



21 750 HA TAILINGS IMPOUNDMENT PREDICTED MAXIMUM 'TOTAL DAILY' DUSTFALL (mg/m²/day) DUE TO THE WESTERN LIMB TAILINGS PROJECT (WITH MITIGATION)





Socio-Economic Environment

Provincial and District Overview

Population size, age and gender distribution
(Source: RSA Population Census, Statistics South Africa, 1996)

North West Province population: 3.3 million

Density: 25 persons per square km

Population in urban centres: 1.17 million

Non-urban population: 2.18 million

Racial composition:

Black	91.2%
White	6.6%
Coloured	0.3%
Indian/Asian	0.3%

Gender distribution:

Female	1.7 million (50.8%)
Male	1.6 million (49.2%)

Unemployment issues

In Southern Africa, each mineworker is responsible for an average of 9-11 dependants, whereas in developed countries, this figure varies between 3 and 6. The problem multiplies when one considers the labour intensive practices currently undertaken by mining companies. The closure of a single mineshaft could result in between 1500-3000 jobless individuals resulting in enormous economic and social impacts. (Knoll 2001)

From the RSA population census, one can conclude that the bulk of the population in the Bojala Platinum District Municipality (BPDM) is of a labour-able age (Addendum 2). This is a reason for concern due to the extensive mining activity in the region. This could be cumbersome if the statistics given in the Nov/Dec Urban Green File (2001) issue are correct. This will only become a problem if the area is depleted of its minerals and mining activity is located elsewhere.

It is a common occurrence in a mineshaft closure event that the employees are left unemployed with little or no education or skills. The conventional approach for dealing with large-scale retrenchment subsequent to mine closure, is the establishment of dedicated funds in order to retrain employees for alternative occupations or to support potential entrepreneurial prospect among retrenched workers. The success has been erratic. (Knoll 2001)

The responsibility of sustainable design rests heavily on mining companies, especially concerning the subject of waste management. In the event of waste deposition and rehabilitation thereof, it is important to realise the requirements of the natural and social components and how it will form an integrative, synergistic system in the future to come.

SITE LOCATION

BIO-PHYSICAL ENVIRONMENT

DUST OUTFALL RESULTS

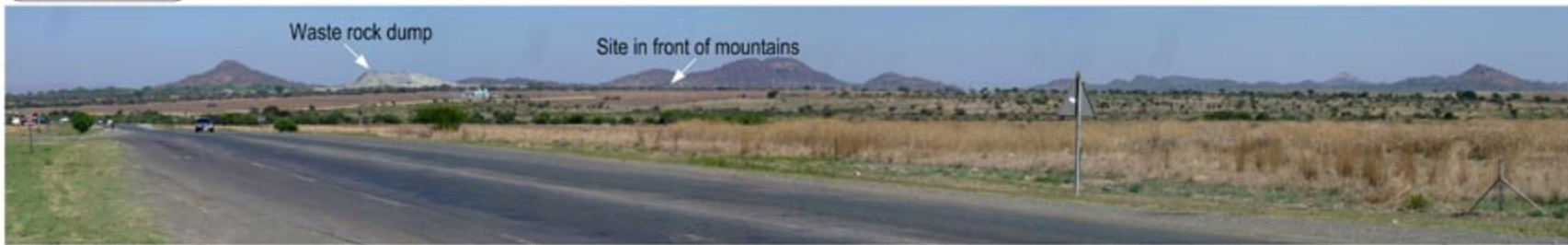
SOCIO ECONOMICS

AESTHETICS

29 10 KM TO SITE



30 5 KM TO SITE



31 TYPICAL LANDFORM ADJACENT TO SITE

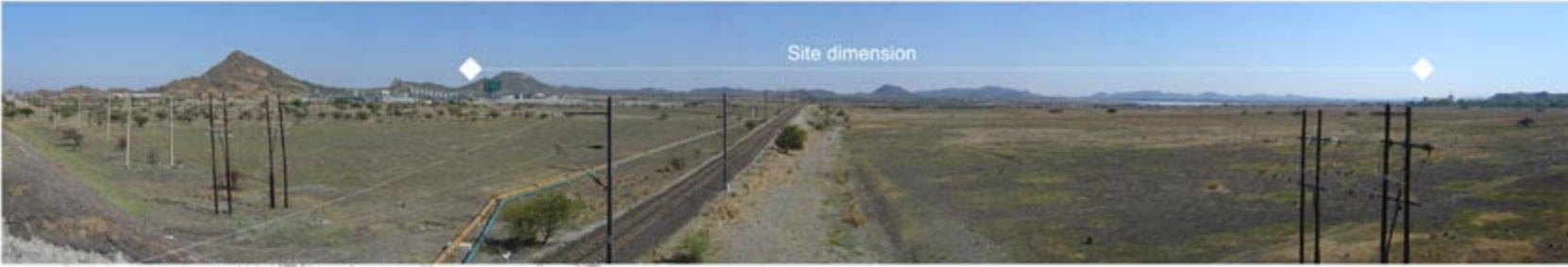


32 TYPICAL LANDFORM ADJACENT TO SITE

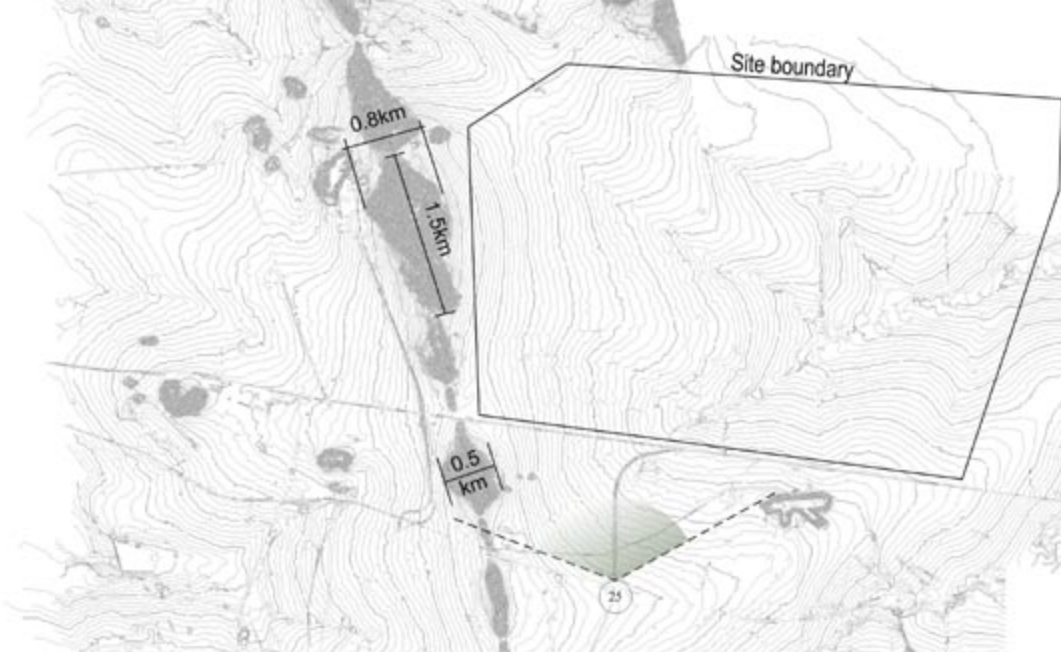


- SITE LOCATION
- BIO-PHYSICAL ENVIRONMENT
- DUST OUTFALL RESULTS
- SOCIO ECONOMICS
- AESTHETICS**

13 PHOTOGRAPH OF SITE FROM MAIN TRANSPORT ROUTE



14 CONTOUR MAP OF SITE INDICATING HORIZONTAL DIMENSIONS OF ADJACENT LANDFORMS



Local landforms and landscape character

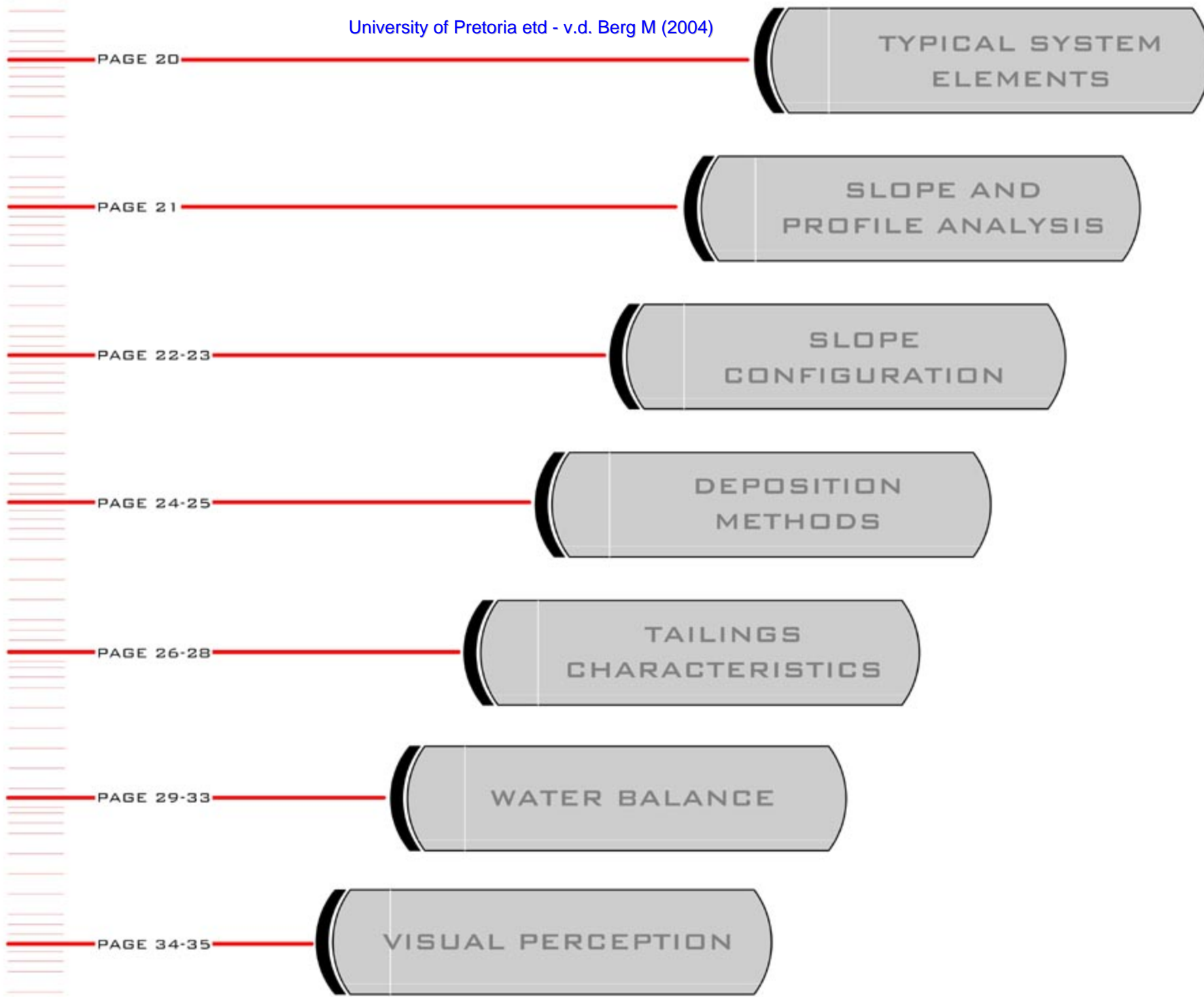
This section attempts to determine the visual absorption capability of the site in terms of the scale and proportion of the proposed TDF. The TDF, proposed by SRK, is compared to the adjacent landforms. A clear contrast is noticeable (fig 2-34). From a visual point of view, it is necessary that the existing landforms act as guidelines for the design of a TDF. The scale of the TDF becomes most important, followed by the geometry as well as the surface texture and colour. Each of these elements should be designed/applied with the appropriate complexity, harmony, intensity, etc.

The maximum dimensions for the proposed TDF should be within an acceptable range, considering the adjacent landforms' dimensions. A tolerance of approximately 10% is found to be acceptable.

15 ELEVATION FIGURE-GROUND INDICATING VERTICAL DIMENSIONS AND CONTRASTING PROFILES



BASELINE



ELEMENTS OF A TAILINGS DISPOSAL FACILITY

TYPICAL SYSTEM ELEMENTS

SLOPE AND PROFILE ANALYSIS

SLOPE CONFIGURATION

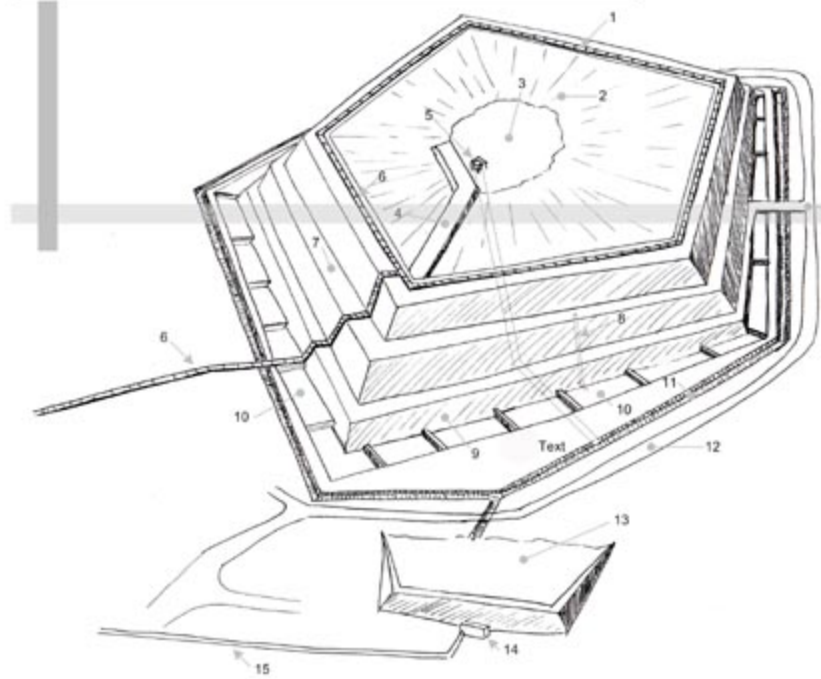
DEPOSITION METHODS

TAILINGS CHARACTERISTICS

WATER BALANCE

VISUAL PERCEPTION

1 DIAGRAMMATIC REPRESENTATION OF A TYPICAL TDF (CHAMBER OF MINES OF SOUTH AFRICA 1996)



- 1 Daywall
- 2 Beach
- 3 Pool
- 4 Catwalk
- 5 Penstock
- 6 Delivery pipe
- 7 Bench
- 8 Bench penstock
- 9 Starter wall
- 10 Catchment paddock
- 11 Toe drain/solution trench
- 12 Access road
- 13 Return water dam
- 14 Pump station
- 15 Return water pipeline

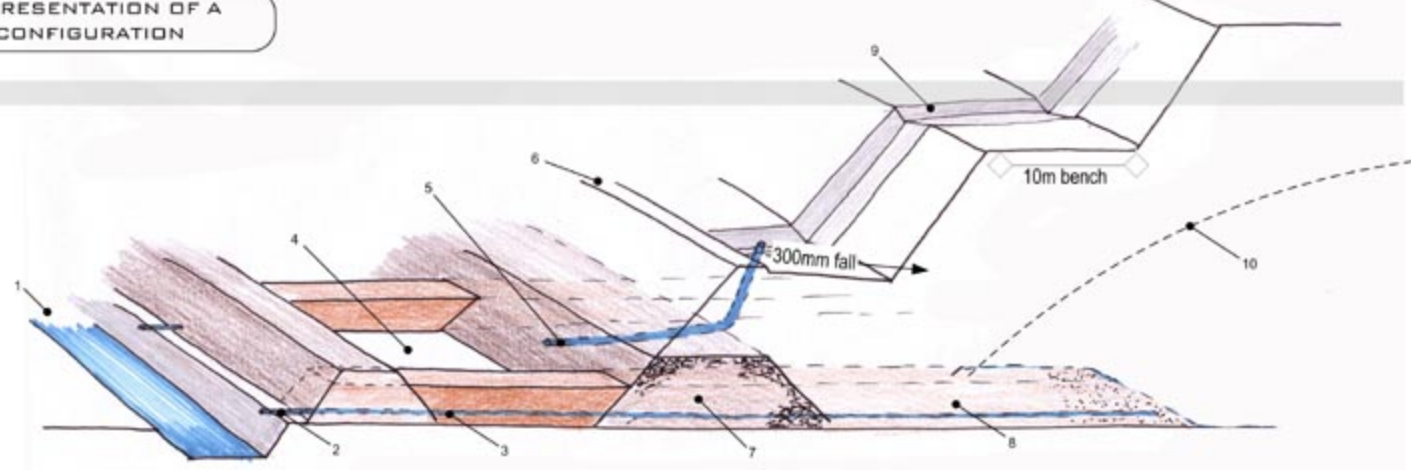


4 BLANKET DRAIN OUTLET

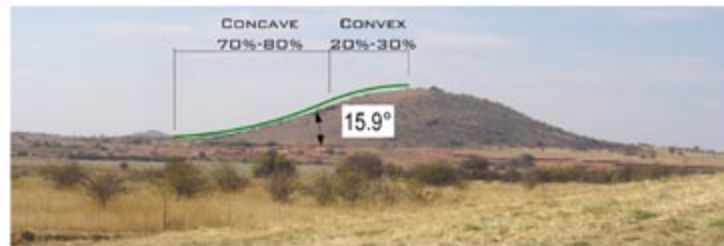
5 SOLUTION TRENCH

2 DIAGRAMMATIC REPRESENTATION OF A TYPICAL SLOPE CONFIGURATION

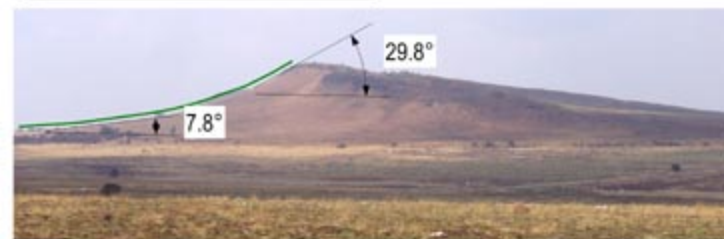
- 1 Solution trench
- 2 Blanket drain outlet
- 3 Geo-pipe
- 4 Paddock
- 5 Bench penstock outlet
- 6 0.5 m bund wall
- 7 Starter wall
- 8 Blanket drain
- 9 Surface channel
- 10 Phreatic surface



NATURAL SLOPE PROFILE 1



NATURAL SLOPE PROFILE 2



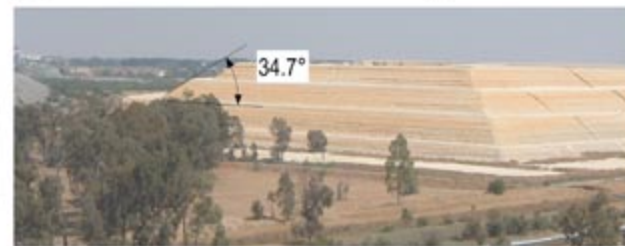
Natural slope profile

An analysis of natural slopes reveals that four basic slope forms are identifiable; straight, convex, concave and s-shaped slopes. Smooth S-shaped slopes usually indicates long-term stability and a state of equilibrium among slope forces. Such slopes rarely exceed 45° inclination and are usually secured against heavy erosion by a substantial plant cover (Marsh 1991). A natural slope is usually a complex combination of these four slope forms.

A principle applied in coal mine overburden rehabilitation is to create a S-shaped profile with the upper 20%-30% being convex and the lower 70%-80%, concave, thus simulating a natural, stable profile (fig 3-6). This shape is a result of erosion and deposition until stability is achieved (fig 3-13). The catchment area at any point on the slope is a function of the slope length above it. As one progresses down the slope, the catchment area increases as well as the volume of runoff derived from a rainfall event (Hannan 1984).

"Over geological time the forces of erosion and deposition have acted upon natural slopes until an angle is reached which, for a given soil type, is in equilibrium with the effects of *catchment area, runoff volume and vegetative cover*. This results in a slope which becomes progressively flatter towards the bottom so that flow velocity is maintained at a roughly constant, non-erosive value." (Hannan 1984:22) (fig 3-7)

TDF SLOPE PROFILE-OPERATION



TDF SLOPE PROFILE-REHABILITATED



Constructed slope profile

Side slopes of TDFs are generally constructed at 33°. However, 33° angle is about the optimum angle for erosion (Chamber of Mines of South Africa 1996), thus resulting in severe erosion problems and rehabilitation difficulty as well as with ongoing maintenance and repair (Blight & Amponsah-Dacosta 1999).

Benches are introduced to break a continuous slope length. This reduces the overall slope angle and improves erosion control.

During the rehabilitation phase, slopes are often flattened to a 18°-25° gradient (fig 3-9). Slopes are vegetated for the purpose of erosion control and to satisfy visual requirements. A common problem is that vegetation cover is often unsatisfactory due to the draughty nature of the growth medium (tailings). Water retention is poor and most water is either lost through infiltration or runoff, causing erosion.

In conclusion, it seems that rehabilitation must aim at simulating a slope profile that represents the tailings material's natural erosion resistant gradient. This optimum slope angle has not been determined yet by associated research. A comparison to sand dune profiles reveals that 9° slopes exist on windward slopes and 33° on leeward slopes (Blight & Amponsah-Dacosta 1999).

Angles steeper than 18° will not be adopted for this project as field surveys has proven steeper gradients unsuccessful.

TYPICAL SYSTEM ELEMENTS

SLOPE AND PROFILE ANALYSIS

SLOPE CONFIGURATION

DEPOSITION METHODS

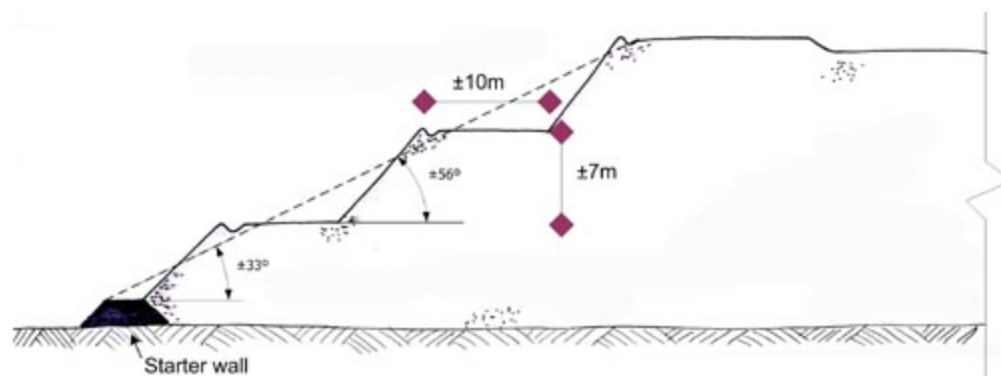
TAILINGS CHARACTERISTICS

WATER BALANCE

VISUAL PERCEPTION

- TYPICAL SYSTEM ELEMENTS
- SLOPE AND PROFILE ANALYSIS
- SLOPE CONFIGURATION**
- DEPOSITION METHODS
- TAILINGS CHARACTERISTICS
- WATER BALANCE
- VISUAL PERCEPTION

10 CONVENTIONAL SLOPE CONFIGURATION

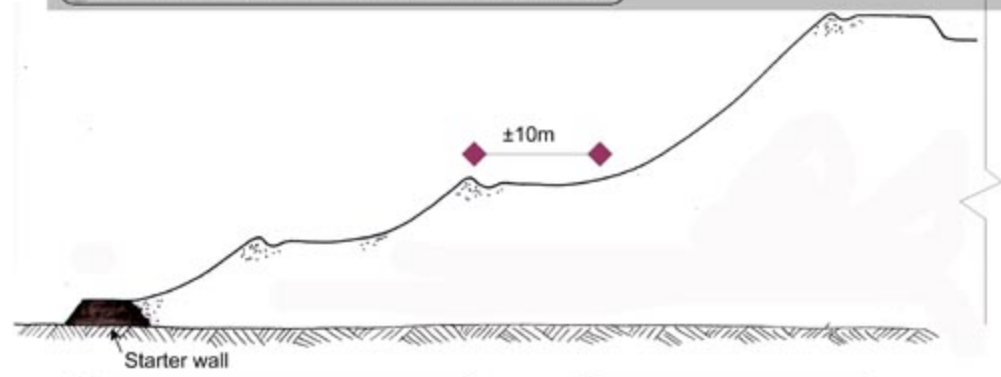


Conventional slope configuration

A conventional slope configuration is presented in figure 3-10. A uniform rise and tread (bench) is consistent from toe to crest. Benches provide access and assist in run-off and erosion control. Sediment from erosion accumulates on the benches, thus reducing the loss of material off the site. The slope length corresponds with the volume of runoff that can occur during a specific frequency rain event. Runoff is conveyed via surface channels to selected drop-points on the benches.

The distribution of light on a slope with this configuration, creates sharp shadows and contribute negatively to the visual impact of the TDF as a whole (fig 3-12).

11 PROPOSED REHABILITATED CONFIGURATION

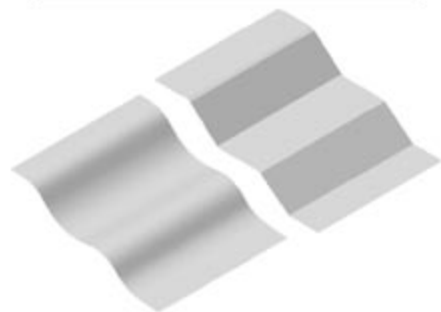


Proposed rehabilitated configuration (fig 3-11)

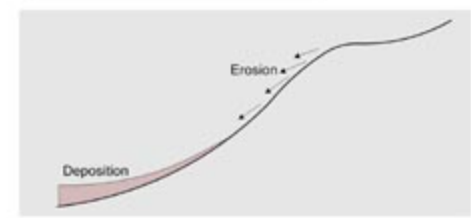
An S-shaped profile is noticeable of a stable slope (Hannan 1984). Erosion of top sections are deposited at the bottom until a stable scenario is achieved (fig 3-13). One can pursue the argument that less erosion will occur on a slope with this profile and an increase in stability is possible.

A concave/convex slope distributes light evenly over the length of the slope. It is softer on the eye and it could be argued that visual impact is reduced (fig 3-12).

12 LIGHT DISTRIBUTION OVER VARIOUS SLOPE CONFIGURATIONS



13 EROSION AND DEPOSITION EQUILIBRIUM



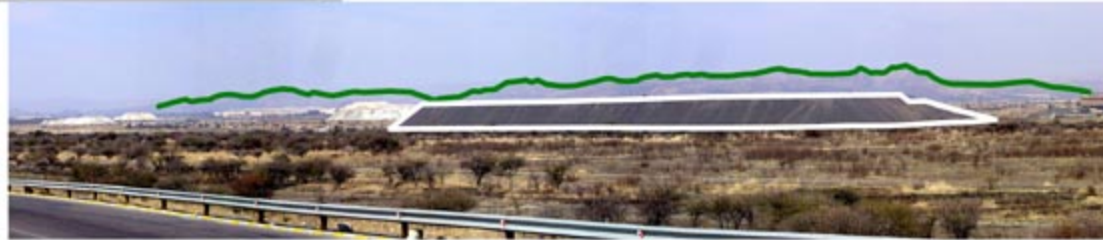
- TYPICAL SYSTEM ELEMENTS
- SLOPE AND PROFILE ANALYSIS
- SLOPE CONFIGURATION**
- DEPOSITION METHODS
- TAILINGS CHARACTERISTICS
- WATER BALANCE
- VISUAL PERCEPTION

Profile comparison

14 PROFILE COMPARISON

- Profile of mountains in the background
- Profile of typical Mine Residue Deposit

The stark contrast in form, line, colour and texture, confirms the high visual impact. The flat top, steep uniform side angles and sharp corners, are elements of concern.



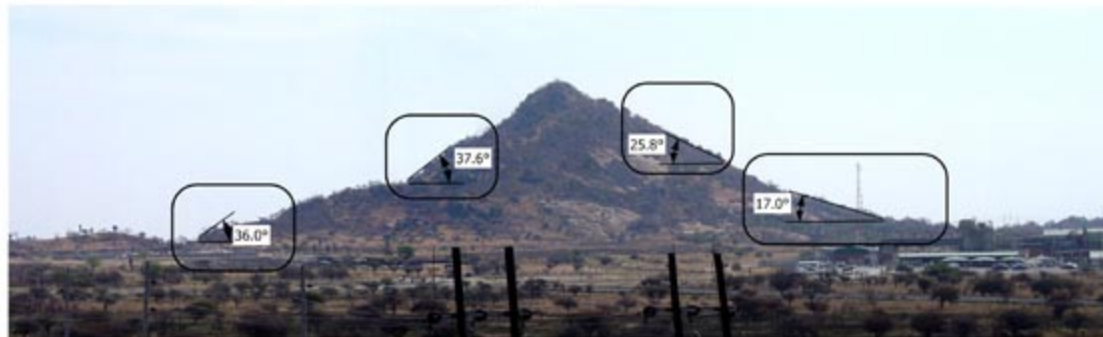
Natural landform slope analysis

15 NATURAL LANDFORM SLOPE ANALYSIS

A slope analysis of one of the prominent natural landforms in the region, indicates the variety in slope angles of this particular slope configuration.

The diversity of slope gradients correlates with a diversity in habitat conditions, water availability, plant distribution and soil depths.

The focus is on plant distribution and the associated conditions.



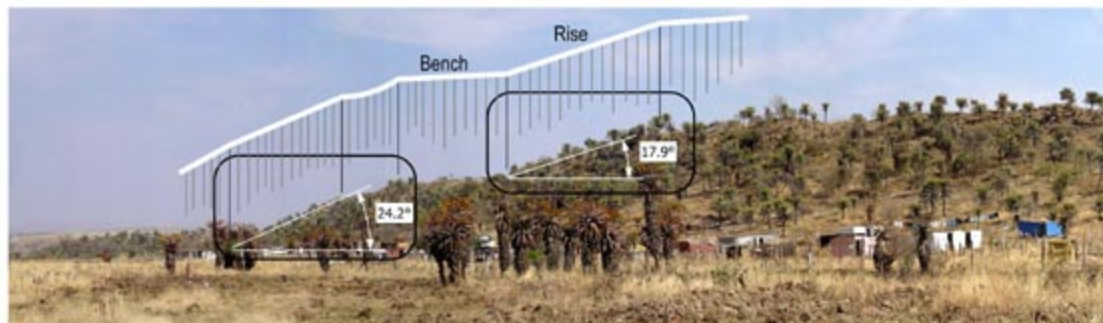
Natural landform profile analysis

16 NATURAL LANDFORM PROFILE ANALYSIS

This is a profile analysis of a relative small landform in the region. The variation in side slope configuration is the focus of this analysis.

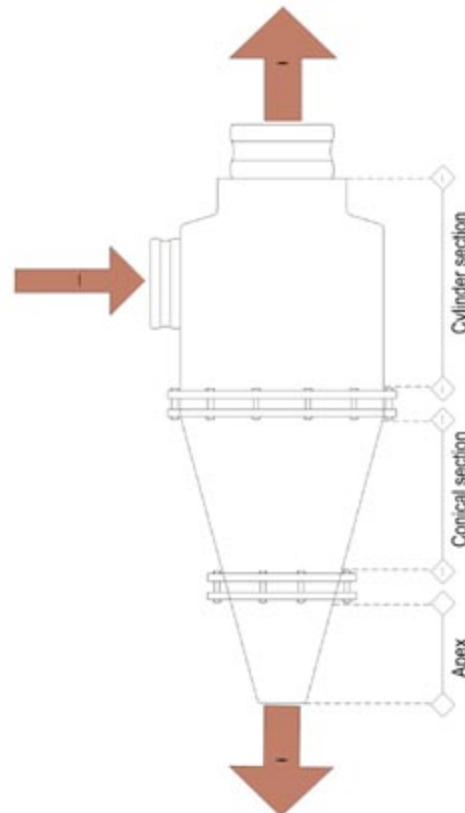
The white line is a simplified profile resembling similarities of TDF side slopes. The bench and rise are clearly identified in the profile.

- 1:2 = 50% = 26.5°
- 1:3 = 33% = 18.5°
- 1:6 = 17% = 9.5°
- 1:9 = 11% = 6°

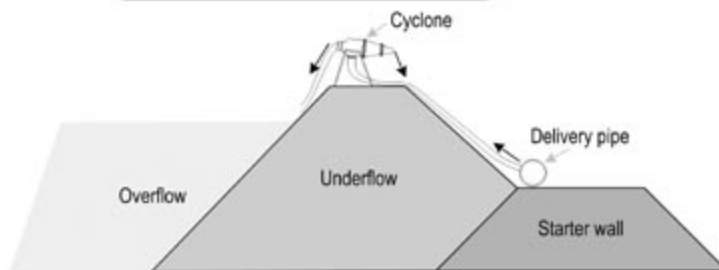


- TYPICAL SYSTEM ELEMENTS
- SLOPE AND PROFILE ANALYSIS
- SLOPE CONFIGURATION
- DEPOSITION METHODS**
- TAILINGS CHARACTERISTICS
- WATER BALANCE
- VISUAL PERCEPTION

17 CYCLONE DEVICE (Vick 1983)



18 EMBANKMENT CONSTRUCTION VIA CYCLONE DEPOSITION



Introduction

Alternative tailings deposition methods exist in the mining industry. The two main methods, commonly used in South Africa is cyclone and spigot deposition. Cyclone deposition requires a relatively high initial capital cost but is justified by the quick rate-of-rise. A safe rate-of-rise of approximately 9 m per year is possible compared to a 2.5 m resulting from spigot deposition (Chamber of Mines of South Africa 1996).

Cycloned tailings

The use of cycloned tailings in embankment construction presents an attractive alternative design option when other suitable soils or quantities are unavailable. A significant cost advantage may occur if it is considered to substitute imported soils with the sand fraction of the tailings. The sand fraction is easily separated from the bulk with little added cost. The resulting cycloned sand has a high effective strength and permeability, making it an ideal material to construct embankments and facilitate the necessary drainage to control the phreatic surface (Vick 1983).

Another advantage is the reduction of 10%-30% of the bulk of tailings discharged, depending on impoundment configuration and embankment type. Due to the separation and the deposition of only the fine material, the total permeability of the discharge is less, thus reducing vertical seepage through the impoundment and subsequent contamination of groundwater (*ibid*).

Cyclones are simple devices that function on a centrifugal separation principle. The pressurised tailings slurry from the plant enters a cylindrical feed chamber. The coarse particles in the slurry spiral downward through the conical apex at the bottom (*underflow*) and the finer fraction along with most of the water rise to the outlet as *overflow* (*ibid*). (fig 3-17)

On-dam cycloning (fig 3-18)

On-dam cycloning is probably the most preferred cycloning method. Generally, many small cyclone devices are arranged on the embankment crest on small towers or scaffolds. Underflow from each cyclone is discharged towards the embankment face and overflow slimes is deposited to the inside of the impoundment. The cyclones are periodically raised as the embankment height increases.

The overflow is allowed to flow as a thick slurry, consisting of approximately 70%-75% solids, directly onto the embankment. At this pulp density, the sands assume a natural angle of repose of 1:3 (18.5°) to 1:4 (14°). (*ibid*)

Stationary cycloning

This method entails that the coarse and fine fraction is separated at a single high-capacity cyclone station, often near the location of deposition. The embankment is mechanically constructed by conventional earth-moving equipment and the overflow is conveyed to the impoundment via a separate slimes delivery line (*ibid*).

Embankment construction (fig 3-19 to 3-22)

The conical shape deposited of each cyclone requires periodical movement of cyclones in order to ensure an even distribution of tailings over the embankment. A daily management of the delivery and deposition is necessary to keep the rise of the embankment balanced with the deposition rate.

Water in the coarse fraction is allowed to seep down to the catchment paddocks situated at the toe of the TDF or on the benches. Water is encouraged to evaporate from the paddocks.

As previously mentioned, the slurry (coarse fraction) accepts a natural angle of repose of 1:3 to 1:4. Research indicates that erosion of the tailings at this angle is very high and rates of soil loss in the region of 500 tons per hectare per year on gold residue dams was recorded (Chamber of Mines of South Africa 1996).

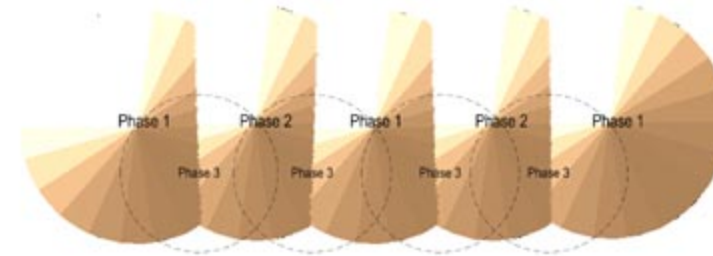
Flattened side slopes as an erosion control measure

A logical approach is to flatten the side slope angles in order to reduce erosion. It has to be noted that flattened slope angles require greater land acquisition costs in order to deposit the same volume of tailings at the same rate during the life-of-mine and still maintain safety and stability. Due to the increase in footprint size, an enlarged zone of pollution is possible.

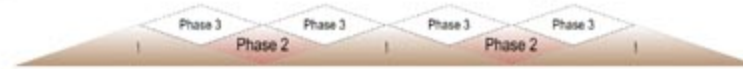
It is possible to maintain the same footprint area and still retain safety and stability by reducing the deposition rate approaching the end of the life-of-mine. This will be an economic-influenced decision due to the fact that the rate of mineral extraction also need to diminish near the end of the operational phase.

Advantages associated with the reduction of side slope angles is the instant increase in stability as well as the reduction of erosion. Water infiltration encourage successful vegetation establishment.

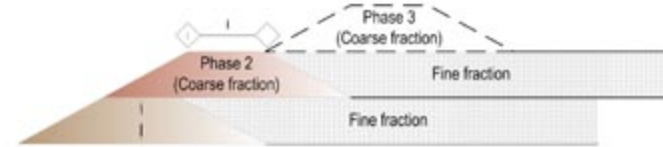
19 CYCLONE DEPOSITION PHASING - PLAN



20 CYCLONE DEPOSITION PHASING - ELEVATION



21 CYCLONE DEPOSITION PHASING - SECTION



22 CYCLONE DEVICES IN OPERATION



TYPICAL SYSTEM ELEMENTS

SLOPE AND PROFILE ANALYSIS

SLOPE CONFIGURATION

DEPOSITION METHODS

TAILINGS CHARACTERISTICS

WATER BALANCE

VISUAL PERCEPTION

TYPICAL SYSTEM ELEMENTS

SLOPE AND PROFILE ANALYSIS

SLOPE CONFIGURATION

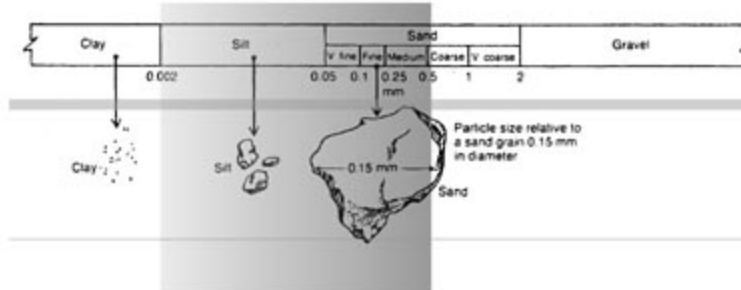
DEPOSITION METHODS

TAILINGS CHARACTERISTICS

WATER BALANCE

VISUAL PERCEPTION

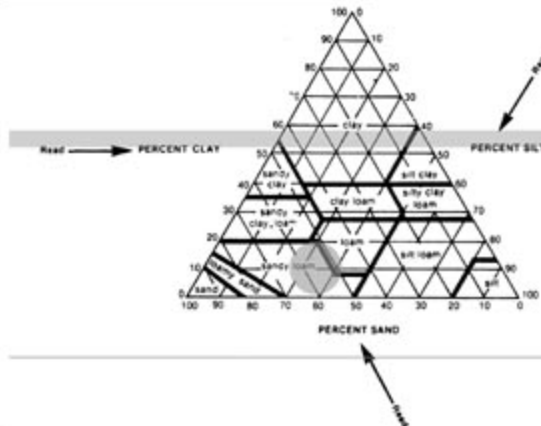
23 PARTICLE SIZE (MARSH 1991)



PARTICLE SIZE

The particle size for platinum tailings typically vary between 0.002mm - 0.6mm. The coarse fraction commonly used to construct the embankments occur in the upper range of the distribution (sand fraction). The silt and clay size particles with most of the water is discharged inside the impoundment.

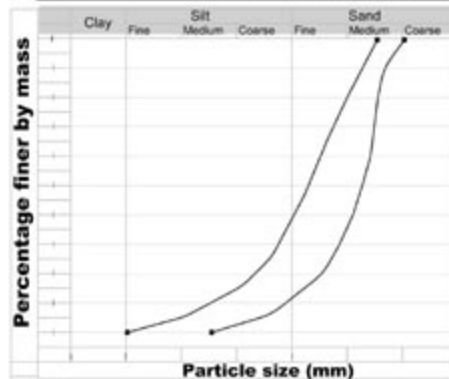
24 SOIL TEXTURE (MARSH 1991)



SOIL TEXTURE

On the soil textural triangle, platinum tailings bear characteristics of a sandy loam textured soil. If analyzed the tailings consist of 10%-40% silt fraction, 60%-90% sand fraction and a negligible clay fraction. Natural soils with similar characteristics, are colluvium deposits at the toe of slopes formed by slides and runoff (Marsh 1991:72). These soils usually drain very well and have a low slope gradient due the relative high erosion potential.

25 PARTICLE SIZE ENVELOPS FOR PLATINUM RESIDUES (CHAMBER OF MINES OF SOUTH AFRICA 1996)



Natural soil generally comprises of four components:

- Mineral particles (50%-80%)
- Organic matter
- Water
- Air (Marsh 1991)

SOIL COMPOSITION

Tailings are deprived of organic matter confirming the lack in moisture absorption and retention capability as well as microbial activity. To improve and ameliorate the tailings, a topsoil capping of 300mm to 500mm is often applied. This implies stripping of topsoil prior to construction, or massive amounts of topsoil need to be imported for the re-vegetation phase. Both these practices require high mechanical energy and are detrimental to the environment in some respect.

The aim is to enhance water retention, reduce evaporation and encourage a sufficient, self-sustaining nutrient cycle by the establishment of both pioneer and climax vegetation species.

PARTICLE DISTRIBUTION

26 TYPICAL PARTICLE DISTRIBUTION THROUGH A TDF (ADOPTED FROM CHAMBER OF MINES OF SOUTH AFRICA 1996)



ERODIBILITY

The Universal Soil Loss Equation and supporting studies have indicated that a steeper slope gradient and long slope lengths increase water erosion considerably (Dorren & Blight 1986). Arising from this research, the construction of benches on the slopes was implemented thus reducing slope lengths as well as vegetating of side slopes. To increase the erosion resistance of the side slopes, it is necessary to reduce the slope gradient as well as amend the surface conditions to increase vegetation establishment and reduce the erosive effect of both water and wind.

The following factors influence soil erosion:

- Vegetation density
- Soil type
- Slope length
- Slope gradient
- Frequency and intensity of rainfall events (Marsh 1991)

Current practice circumstances

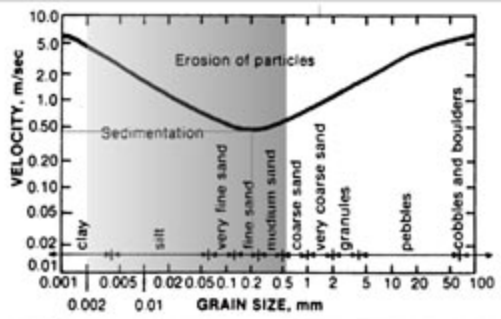
- Negligible vegetation cover
- Sandy loam
- Approximately 12m
- 1:1,5 (33°) to 1:3 (18,5°)
- Dependent on region (Chamber of Mines of South Africa 1996)

EROSIVE POTENTIAL

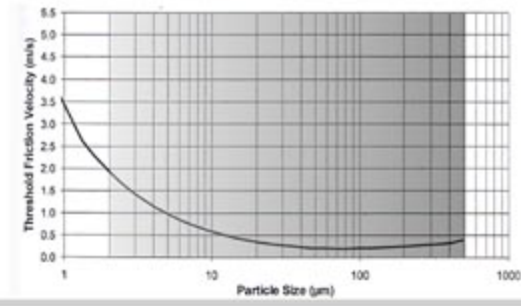
Losses from unprotected slopes of gold tailings in South Africa of over 500 tons/ha/year are quite common, while vegetated slopes can reduce erosion rates to 200 tons/ha/year. These results are due to both wind and water forces.

It is apparent that the sand fraction's erosion threshold gives away at the lowest flow velocities (water erosion), giving it the highest erosion potential. This is of great concern as the outer slopes consist mostly of the sand fraction and is also the material most exposed to the erosive forces of water. Due to a higher resistance to dislodgement as a result of water movement, waste rock is often placed on outer slopes to reduce erosion.

The threshold wind friction velocity is defined as "...the minimum friction velocity required to initiate particle motion" (Scorgie & Randell 2001). Particles with a diameter of <60µm requires an increasingly high threshold friction velocity to be dislodged due to the increasingly strong cohesion forces connecting the particles. Consequently, the outer slopes are subject to high wind erosion due the low threshold level of the particles.



27 WATER EROSION THRESHOLD VELOCITIES (MARSH 1991)



28 WIND EROSION THRESHOLD VELOCITIES (SCORGIE & RANDELL 2001)

- TYPICAL SYSTEM ELEMENTS
- SLOPE AND PROFILE ANALYSIS
- SLOPE CONFIGURATION
- DEPOSITION METHODS
- TAILINGS CHARACTERISTICS**
- WATER BALANCE
- VISUAL PERCEPTION

TYPICAL SYSTEM ELEMENTS

SLOPE AND PROFILE ANALYSIS

SLOPE CONFIGURATION

DEPOSITION METHODS

TAILINGS CHARACTERISTICS

WATER BALANCE

VISUAL PERCEPTION

Toxic leaching potential

A composite sample of the tailings was tested at Lakefield Research in Johannesburg for the following analysis:

- Acid Base Accounting (ABA)
- South African Acid Rain Test (SAAR)
- Toxicity Characteristic Leaching Procedure (TCLP)
- Total Digest
- 10% aqueous solution (Hudson 2002)

The results indicates that the material is likely to be non-acid generating. It must be noted that a risk factor does exist as a single sample laboratory test would not be sufficient and comprehensive enough to assess the potential of ARD over a longer time period. The potential is likely to be of a low level but appropriate measures should be implemented to monitor and treat if necessary (*ibid*).

The TCLP results indicates that some of the metals present in the tailings could be released into the environment in mildly acidic conditions. Of particular note is chrome III, chrome VI, manganese and zirconium, copper and iron.

29 SOLUTION TRENCH CONVEYING CONTAMINATED WATER



30 SULPHATE PRECIPITATION FROM TAILINGS

The formation of Acid Rock Drainage (ARD)

The formation of ARD is primarily a function of the geology, hydrology and mining technology employed for the mine site. AMD is formed by a series of complex geo-chemical and microbial reactions that occur when water comes in contact with pyrite (iron disulfide minerals) in the overburden of a mine operation. The resulting water is usually high in acidity and dissolved metals. The metals stay dissolved in solution until the pH raises to a level where precipitation occurs. (DEP 1996)

Treatment of AMD**Chemical treatment / Active treatment**

Acidity is buffered by the addition of alkaline chemicals such as calcium carbonate, sodium hydroxide, sodium bicarbonate or anhydrous ammonia. These chemicals raise the pH to acceptable levels and decrease the solubility of dissolved metals. These chemicals are expensive and the treatment system requires additional costs associated with operation and maintenance as well as the disposal of metal-laden sludge (*ibid*).

Passive treatment

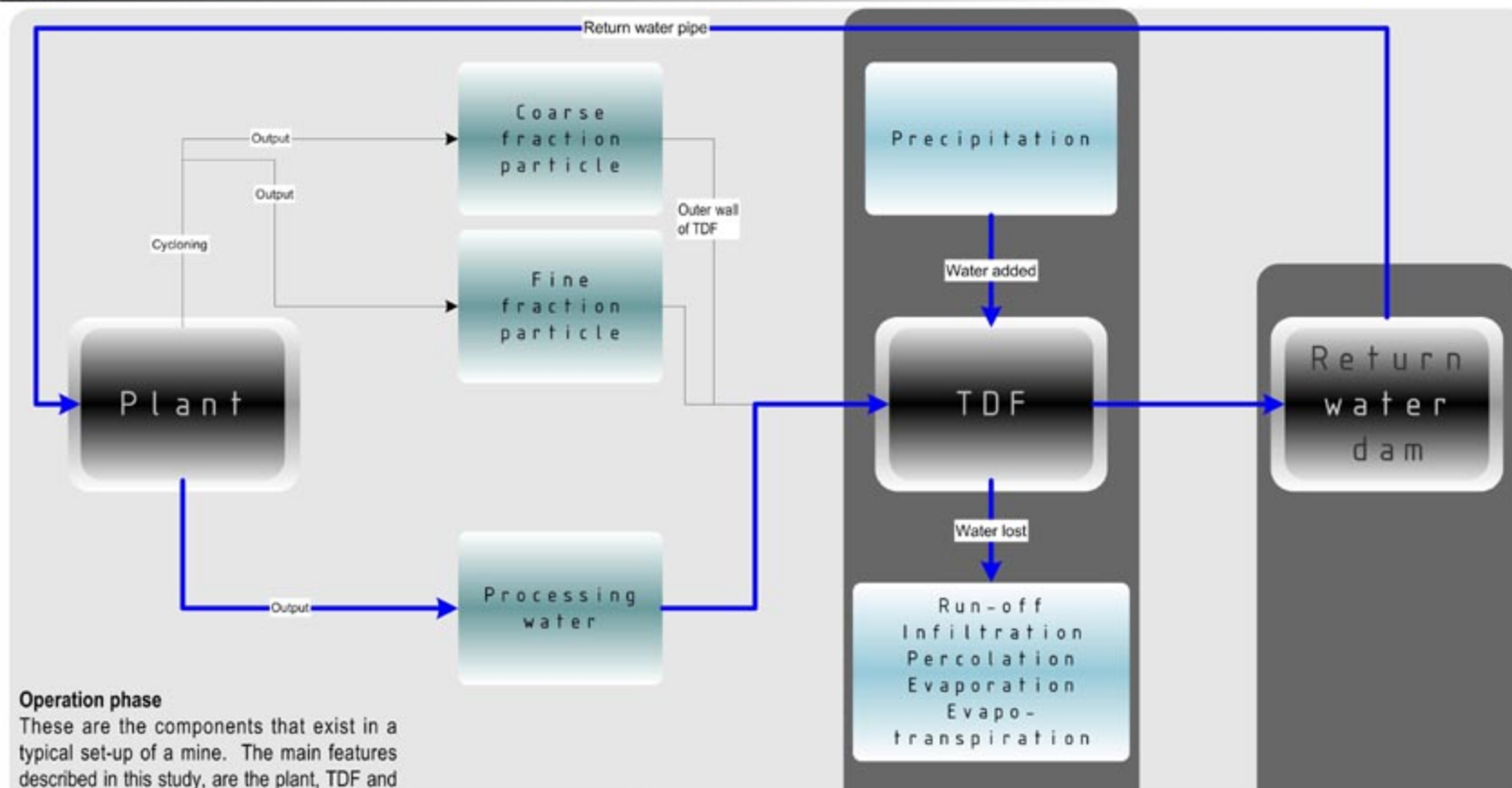
The concept behind passive treatment is to allow the natural occurring chemical and biological reactions that aid in AMD treatment to occur in a controlled and managed environment, and not releasing it in the receiving environment before satisfactory results is achieved. Passive treatment offers many advantages over active treatment systems. Virtually no chemical additions and energy consuming treatment processes is needed, thus reducing cost. Also, operation and maintenance requirements is considerably less than for active treatment systems (*ibid*).

Passive treatment alternatives include the following systems:

- Aerobic wetlands
- Compost and anaerobic wetlands
- Open limestone channels
- Diversion wells
- Anoxic limestone drain
- Vertical flow reactors
- Pyrolusite[®] process (*ibid*)

In many cases a combination of a few of the above alternatives can be applied, depending on the significance of pollution.

(fig 3.31)



- TYPICAL SYSTEM ELEMENTS
- SLOPE AND PROFILE ANALYSIS
- SLOPE CONFIGURATION
- DEPOSITION METHODS
- TAILINGS CHARACTERISTICS
- WATER BALANCE
- VISUAL PERCEPTION

Operation phase
 These are the components that exist in a typical set-up of a mine. The main features described in this study, are the plant, TDF and return water dam. The plant and any other associated infrastructure are disassembled subsequent to decommissioning and removed off the site. The TDF and return water dam are the only elements that are permanent and are subject to rehabilitation according to legislation.

A normal ring-dyke impoundment construction makes use of the coarse fraction of the tailings to build the impoundment wall. The fine fraction and water are deposited within these constructed envelopes. The separation of the fractions occur via cycloning.

Post-closure phase
 The TDF and associated waste rock dumps are all that's left of the original system, after decommissioning of the plant. The TDF should now function as a safe and stable, independent and self-sustaining landform, free of long-term maintenance. The TDF should be able to uphold an ecology that is regenerative in its nature and support life.

 The rehabilitated system should be able to operate following the withdrawal of water from the plant. The only water supplementing the system is from precipitation.

Post-closure phase
 The return water dam can either be demolished or function as an integrated element in the normal hydrological cycle of the site. If the decision requires it to fulfill a long-term role, it should be designed appropriately, prior to the operational phase.

D&C

OPERATIONAL
PHASE

CLOSURE
PHASE

POST-CLOSURE
PHASE

DESIGN AND CONSTRUCTION

Water addition:

Plant - Water from the operation plant is the greatest percentage of water added to the system. The volume is dependent on the rate of deposition and the water concentration in the tailings.

Precipitation - In the Rustenburg area, average rainfall ranges from 630mm - 740mm annually.

Water loss:

Runoff - The system is designed to dispose of surface water off the TDF as quick as possible. Surface water can potentially cause erosion gullies as well as increase the phreatic surface to hazardous levels

Infiltration - Infiltration is usually discouraged to reduce the risk of instability or subsequent failure due to a raised phreatic surface

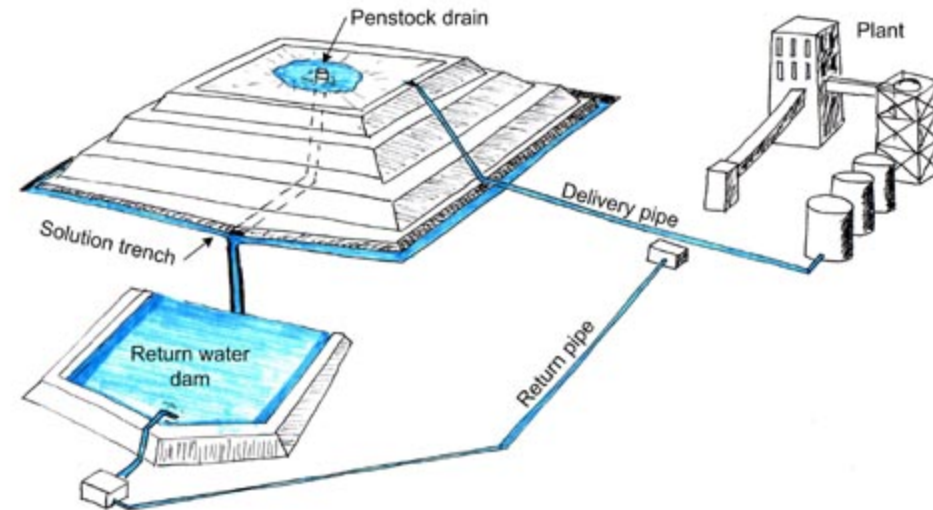
Evaporation - Mean evaporation rates in the Rustenburg area is approximately 5.6mm per day resulting in higher evaporation rates than precipitation rates. Evaporation results in a loss of recyclable operation water thus increasing the demand for additional water. Surface water is encouraged to evaporate by the use of a paddock system.

Percolation - Contaminated water is lost to the natural groundwater aquifer. The presence of a natural or synthetic liner reduces percolation.

Evapo-transpiration - Evapo-transpiration from a TDF is negligible due to the absence of vegetation

Internal drainage - Penstock drains decant water from the top surface and blanket drains drain internal seepage water. Water is conveyed via a solution trench to the return water dam

32 ILLUSTRATION OF AN OPERATIONAL DISPOSAL SYSTEM



TYPICAL SYSTEM ELEMENTS

SLOPE AND PROFILE ANALYSIS

SLOPE CONFIGURATION

DEPOSITION METHODS

TAILINGS CHARACTERISTICS

WATER BALANCE

VISUAL PERCEPTION



DESIGN AND CONSTRUCTION

Water addition:

Plant - Water addition from the plant has ceased due the decommissioning of the mine

Precipitation - Precipitation stays constant in the 630mm - 740mm per year range with isolated hazardous storm events

Water loss:

Runoff - Water retention should occur in the root zone to improve vegetation establishment. Runoff is encouraged to be absorbed and retained in the top layer instead of causing possible erosion gullies

Infiltration - Infiltration should only occur in the top layer. Too much infiltration will raise the phreatic surface and jeopardise safety and stability of the TDF. This principle is a store- and-release approach

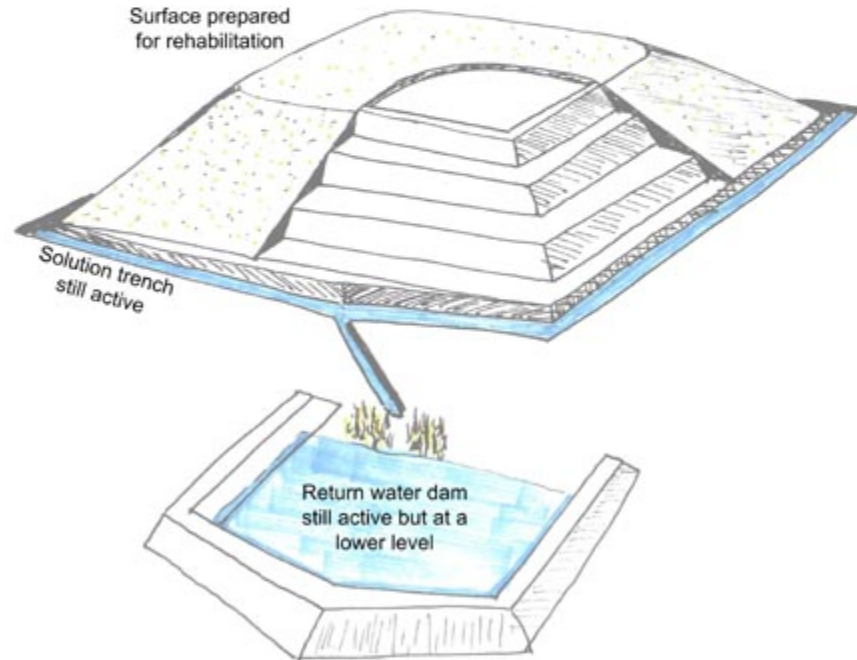
Evaporation - Evaporation stays high and the aim is to establish a cover as fast as possible to reduce evaporation to an acceptable level and stabilise the surface

Percolation - Percolation decreases due to the decline of water addition to the whole system after decommissioning

Evapo-transpiration - Evapo-transpiration becomes significant when the whole surface is vegetated. Too little water in the system will cause stress on the vegetation and subsequent poor surface stabilisation

Internal drainage - Internal drainage is still active in order to lower the phreatic surface to a safe level. Rates at which a phreatic surface in a dam subsides have been observed to be as low as 0.3m per year (Chamber of Mines of South Africa 1996)

ILLUSTRATION OF A REHABILITATED TDF



- TYPICAL SYSTEM ELEMENTS
- SLOPE AND PROFILE ANALYSIS
- SLOPE CONFIGURATION
- DEPOSITION METHODS
- TAILINGS CHARACTERISTICS
- WATER BALANCE
- VISUAL PERCEPTION

TYPICAL SYSTEM ELEMENTS

SLOPE AND PROFILE ANALYSIS

SLOPE CONFIGURATION

DEPOSITION METHODS

TAILINGS CHARACTERISTICS

WATER BALANCE

VISUAL PERCEPTION

D&C

OPERATIONAL
PHASECLOSURE
PHASEPOST-CLOSURE
PHASE

DESIGN AND CONSTRUCTION

Water addition:

Precipitation - Precipitation stays constant in the 630mm - 740mm per year range. Maximum recorded annual rainfall - 1206mm. Abnormal rain events can cause severe damage to the surface especially when vegetation cover is still immature and drainage systems are insufficient.

Water loss:

Runoff - Runoff is often still high due to steep side slopes and poor vegetation cover, causing erosion gullies. The sediment that is lost during erosion, collects in the solution trenches and subsequently silts up the return water dam. In most cases gullies also occur adjacent to the TDF and return water dam

Infiltration - Infiltration is dependent on the absorption capability of the surface material. Steep slopes impede infiltration and increase runoff. A rough surface cover and dense vegetation cover encourages infiltration

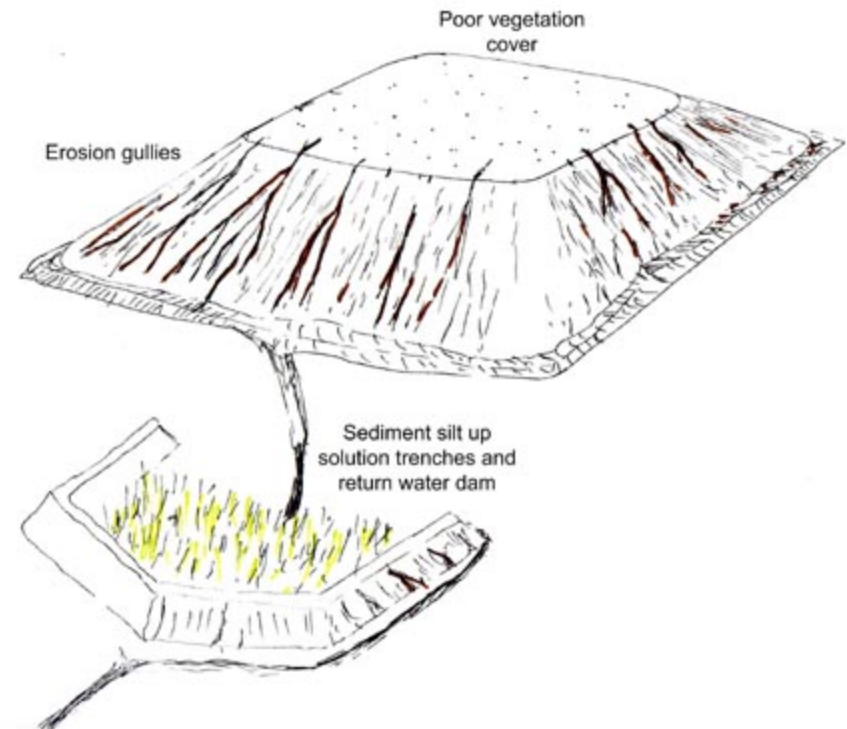
Evaporation - A bare surface has a great evaporation rate. A mulch layer or vegetation cover reduces evaporation

Percolation - Percolation will stabilise at some point when the water table has stabilised

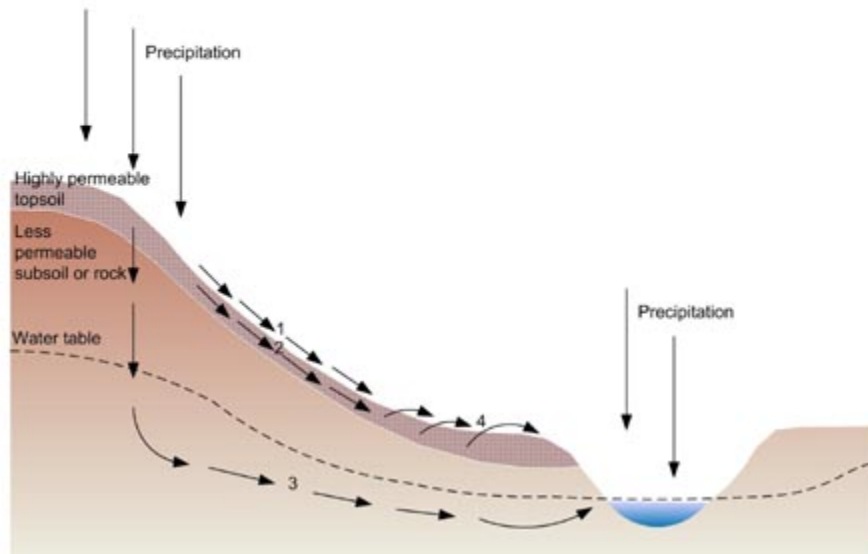
Evapo-transpiration - Evapo-transpiration directly correlates with vegetation cover. Water that is not taken up by plants, either evaporates, infiltrates or are disposed via runoff

Internal drainage - The internal drainage system will stay active until it is sealed or when it automatically clogs up

34 ILLUSTRATION OF POST-CLOSURE SCENARIO



35 POSSIBLE PATHWAYS OF WATER MOVING DOWNHILL (ADOPTED FROM DUNNE & LEOPOLD 1978)

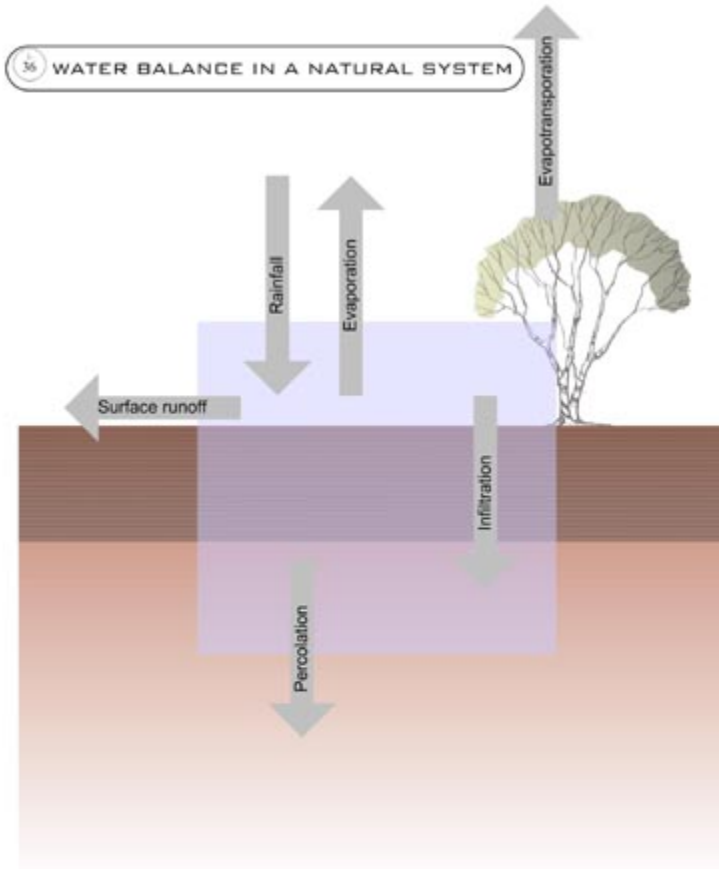


Possible pathways of water moving downhill (fig 3-35)

- Path 1: Overland flow
- Path 2: Shallow sub-surface storm flow
- Path 3: Ground water flow
- Path 4: Saturated overland flow composed of direct precipitation in the saturated area plus infiltrated water that returns to the ground surface (From Dunne & Leopold 1978)

The obvious aim is to reduce as much runoff as possible and subsequent loss to the system as well as increase infiltration in the topsoil layer. This can be achieved by applying a cover to increase surface roughness. This cover can be a stone mulch, vegetation or any organic mulch.

36 WATER BALANCE IN A NATURAL SYSTEM



Water balance in the Rustenburg Region (fig 3-36)

- Average annual rainfall: 630-740mm
- Maximum annual rainfall recorded: 1206mm
- Evaporation rate: 7mm per day
- infiltration rate: sandy loam = 25 mm/hr
- Surface runoff: $Q=A \cdot C \cdot I$
- Percolation: k-factor for material
- Evapo-transpiration rate: dependent on vegetation cover & species

In a stable natural system, an equilibrium is achieved between water received and water lost. This equilibrium is essential for sustaining healthy vegetation growth, an equilibrium not often achieved on re-vegetated TDFs. The challenge lie in providing a topsoil layer capable of absorbing water, releasing it as the demand increase.

TYPICAL SYSTEM ELEMENTS

SLOPE AND PROFILE ANALYSIS

SLOPE CONFIGURATION

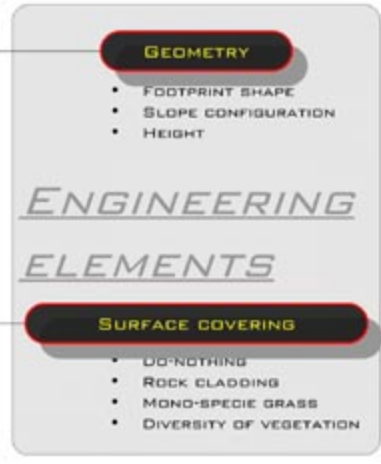
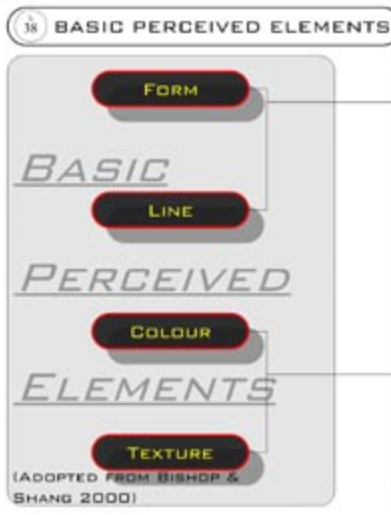
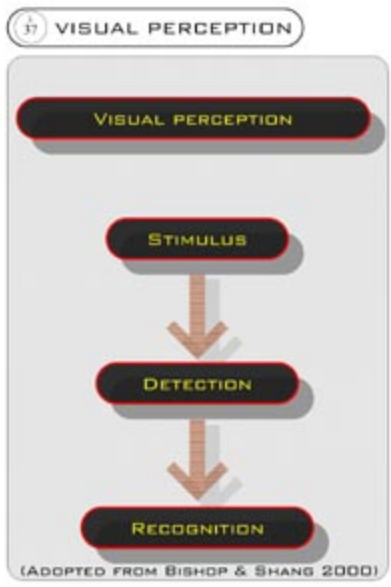
DEPOSITION METHODS

TAILINGS CHARACTERISTICS

WATER BALANCE

VISUAL PERCEPTION

- TYPICAL SYSTEM ELEMENTS
- SLOPE AND PROFILE ANALYSIS
- SLOPE CONFIGURATION
- DEPOSITION METHODS
- TAILINGS CHARACTERISTICS
- WATER BALANCE
- VISUAL PERCEPTION



Introduction

The author was involved in a study concerning the visual perception of TDF's in the South African context. It forms part of a PhD degree study currently undertaken by Mr. Brain Rademeyer under endorsement of the University of Pretoria, Department of Bio-systems and Civil Engineering in collaboration with the Department of Architecture, Landscape Architecture and Interior Architecture.

The study is concerned with the visual perception of tailings impoundments as landforms. This research is aimed at the determination of critical threshold distances where a tailings impoundment landform is visually perceived as a natural landform after applying mitigation. The effectiveness of mitigation will be evaluated according to its capability to merge the landform with its environment and to reduce the viewer-distance of *recognition* as a tailings impoundment within the landscape.

Once this is established it could be argued that the zones of *recognition* will also be the outer limit of the zone of influence, i.e. the negative visual impact zone. The inclosing zone of negative visual impact could potentially sterilise the land of uses such as tourism, residential or agriculture. It is further postulated that the assessment of the change in land-use will disclose a quantitative monetary value of the visual impact.

Visual perception

Humans are dependent on senses to attain awareness from their environment. The smell, taste and tactile senses are utilised in conjunction with the others to familiarise ourselves with our immediate surroundings. Our visual and auditory senses are much more developed and are capable of perceiving both immediate and distant environments.

Our senses are rarely used in isolation, but in some cases we deliberately rely on our visual sense to make reason of what is perceived (Bell 1999), due to the fact that the other senses are incapable of adding clarity to the perceived element/s. This usually happens when distance between the observer and the observed element/s is so great that information gained by the other senses become redundant due to their lack of competence in this particular instance. In this case we rely purely on our visual sense to acquire the necessary information needed to recognise the element/s.

The sub-conscious mind progress through a series of stages when a scene is visually perceived (Bishop & Shang 2000)(fig 3-37). A scene consists of different elements, each with its own character in terms of shape, colour and texture (fig 3-38). If one focus specifically on one of the elements, for example a tree, the tree would be the stimulus in the scene.

The first stage of perception is the detection of the stimulus in its environment. It could be that the tree is undetectable due to the distance between the observer and the tree, or merely due to the lack of contrast with its environment. This is not to say that there is no stimulus, it is just not detectable.

The second stage is the recognition of the detected stimulus. If the stimulus is a familiar object, like a tree, recognition is effortlessly obtained and the sensory experience was successful. The detected stimulus was compared and matched with a similar object in the human memory.

If it was an unusual stimulus for this specific scene, it could be unrecognisable or misinterpreted. This often happens when distance becomes greater than the ability to accurately perceive a specific

MITIGATION

element for what it truly is. Also, the contrast-factor could be insufficient to distinguish the element from its environment. Camouflage is nothing else as the reduction in contrast to such a level that recognition and even detection is disabled. If distance is added, the effectiveness of camouflage increases, hence making the stimulus either undetectable or unrecognisable.

The quantity of information and knowledge we receive depends on the diversity and degree of contrast of the sensory data we obtain and the ability to differentiate between them (Bell 1999). If the information is too little and our curiosity is stirred, we tend to want to move closer in order to increase the level of detail, thus enhancing the probability of accurate recognition.

Conclusion

One can assume that by altering certain design features of a TDF, it could be possible that the TDF will be unrecognisable and thus the zone of visual influence can be reduced. If the perception is of that of a natural landform, there is no detection or recognition of the TDF for what it truly is (fig 3-39). This is only possible if the TDF is designed to look and function as a natural landform. The design aspects that can be altered are the overall geometry and surface covering.

Mitigation

It is often relied on mitigation to reduce impacts to an acceptable standard. It is also a common miss-conception that mitigation is a remediative endeavour attempting to resolve negative impacts succeeding its detection. The true value of mitigation can only be appreciated when it is part of an iterative process during the project planning and design phases.

"The purpose of mitigation is to *avoid, reduce* and where possible *remedy or offset* any significant adverse effects on the environment arising from the proposed development." (Landscape Institute 2002:43)

Any development should be seen as an addition the landscape and should respect the environment in which it is placed. As it is common practice to amend negative impacts after its occurrence, it is necessary to critically assess the lifecycle of a mine and focus specifically on the planning and design phase in an attempt to avoid or reduce predicted impacts prior to occurrence.

39 VISUAL SIMULATIONS WITH DIFFERENT TEXTURES



Existing scenario
At 2km distance



Rock cover
At 2km distance



Vegetated - Mono specie grass
At 2km distance



Vegetated - Diversity of species
At 2km distance

TYPICAL SYSTEM ELEMENTS

SLOPE AND PROFILE ANALYSIS

SLOPE CONFIGURATION

DEPOSITION METHODS

TAILINGS CHARACTERISTICS

WATER BALANCE

VISUAL PERCEPTION

TECHNICAL

PAGE 36

IMPOUNDMENT
STABILITY

PAGE 37-39

EROSION CONTROL
PRACTICES

PAGE 40-41

HYDROLOGICAL
CYCLE

PAGE 42-43

WATERCOURSE AND
WETLAND DESIGN

PAGE 44

LAND-USES ASSOCIATED
WITH CERTAIN SLOPES

IMPOUNDMENT STABILITY

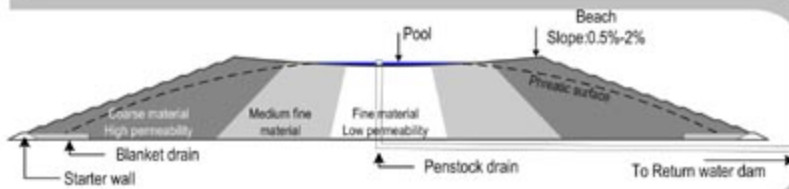
EROSION CONTROL PRACTICES

HYDROLOGICAL CYCLE

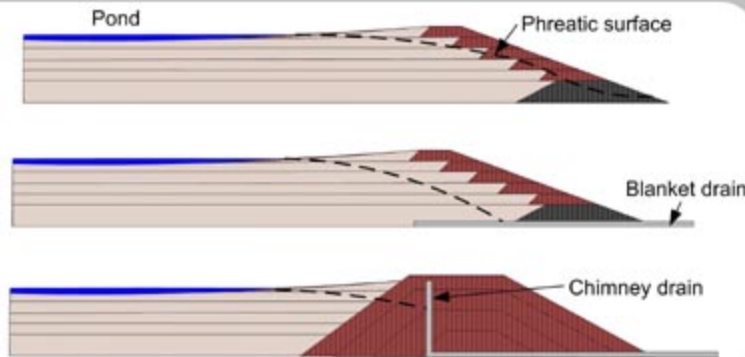
WATERCOURSE AND WETLAND DESIGN

LAND-USES ASSOCIATED WITH CERTAIN SLOPES

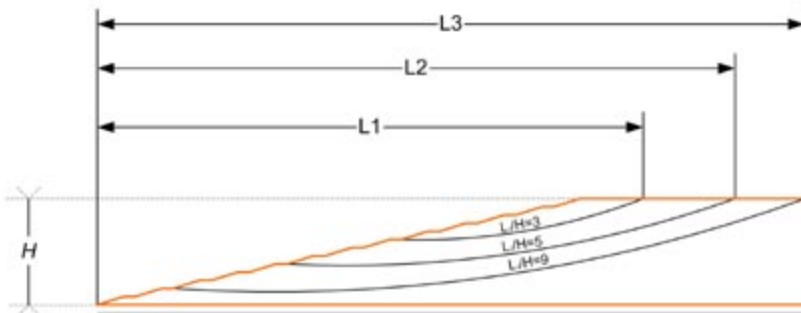
SECTION THROUGH A TDF ILLUSTRATING INTERNAL ELEMENTS



INTERNAL DRAINAGE SYSTEMS AND EFFECT ON PHREATIC SURFACE (FROM CHAMBER OF MINES OF SOUTH AFRICA 1996)



RELATIONSHIP BETWEEN POOL LOCATION AND PHREATIC SURFACE (FROM VICK 1983)



Introduction

The first goal of any impoundment design should be to accommodate the deposit within the parameters of safety and stability. The breaching of stability will have considerable environmental and economic impacts as well as potential loss of life.

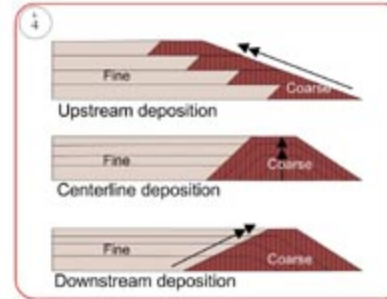
Factors influencing stability

The most important factor influencing stability is the position of the phreatic surface (similar to a water table) in the impoundment (fig 4-1). The phreatic surface is determined by the position of the pool in the center of the impoundment. If the the pool is allowed too close to the outer edge, an increased phreatic surface could jeopardise the stability of the embankment. In order to control the phreatic surface, blanket drains and chimney drains are installed. The penstock is responsible for controlling the pool size (fig 4-2).

The determination of the phreatic surface location for an upstream impoundment (fig 4-4) is in many cases more complex than for other impoundments. Some important factors influencing the phreatic surface location is the following:

- Pond location
- Lateral and vertical permeability variations of the tailings
- Anisotropic permeability of tailings
- Boundary conditions (Vick 1983:177)

A common principle for determining the phreatic surface is illustrated in figure 4-3. A L/H value greater than 9 is desired. Values of 5 and smaller pose serious stability problems.



L = Distance from toe of impoundment to pool location
H = Height of impoundment

$kh/kv=10$
Anisotropy =
Horizontal permeability(kh) > Vertical permeability(kv)
kh is always greater than kv and is a value between 2-10

- IMPOUNDMENT STABILITY
- EROSION CONTROL PRACTICES**
- HYDROLOGICAL CYCLE
- WATERCOURSE AND WETLAND DESIGN
- LAND-USES ASSOCIATED WITH CERTAIN SLOPES

Artificial wind breaks

In order to reduce wind velocity and in effect reduce erosion, a number of artificial wind break options can be implemented.

- Reed fences
- Stone mulching

Ridge ploughing of the surface (Scorgie & Randell 2001) (fig 4-5)

Ridge ploughing is considered an effective short-term measure to control dust at the top of the impoundment. Particles lifted from the crest by a slight increase of wind velocity, is immediately deposited in the adjacent valley (*ibid*) (fig 4-7).

To be most effective, barriers should always be perpendicular to the angle of the predominant wind (*ibid*).

The presence of a barrier results in an increase in wind speed over the crest and a reduction in velocity on the leeward side of the barrier. Observations confirmed that the maximum reduction in wind velocity occurs within 10H of the downwind leeward side. The flow of air becomes fairly normal again at about 30H from the barrier (H being the height of the barrier) (*ibid*) (fig 4-6).

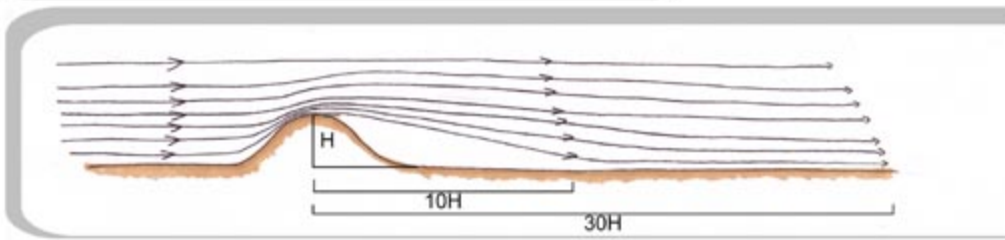
Vegetation as wind erosion control practise

A dense vegetation cover is the most sustainable and long-term solution. In order to establish an effective vegetation cover on a TDF, a suitable growth medium and adequate moisture is required. This criteria is often not met, thus implying a combination of wind erosion control practices.

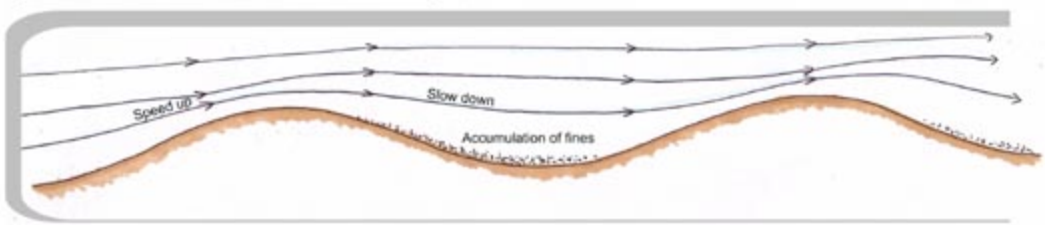
5 RIDGE PLOUGHING



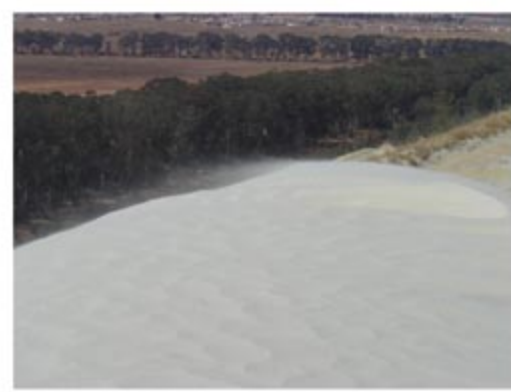
6 THE EFFECT OF WIND BARRIERS ON WIND VELOCITY



7 DEPOSITION OF FINES IN VALLEY



8 WIND BLOWN PARTICLES



IMPOUNDMENT
STABILITYEROSION CONTROL
PRACTICESHYDROLOGICAL
CYCLEWATERCOURSE AND
WETLAND DESIGNLAND-USES
ASSOCIATED WITH
CERTAIN SLOPES**Rock cladding****Fine rock**

The placement of rock on the surface of side slopes, have proven very successful in the reduction of wind and water erosion. Research indicates that the placement of a 300 mm layer of fine rock (< 150 mm diameter) onto the in-situ, unprepared side slopes, reduces water erosion by $\pm 60\%$, when compared to erosion from an untreated slope. A significant improvement in performance occurs when the surface is appropriately leveled and compacted before application. A reduction of $\pm 90\%$ is possible if the surface is prepared (Smith 2004) (fig 4-10).

A 300 mm layer of rock virtually eliminates wind erosion from the side slopes (*ibid*). Protection from wind erosion arises by destroying the kinetic energy of the wind by forming vortices in the lee of each stone chip or pebble (Chamber of Mines of South Africa 1996).

Coarse rock

A coarse rock (average 150 mm diameter) layer of 300 mm resulted in reducing water erosion by 50%-60%. An increase to 90% is possible if the surface is prepared with the placement of a geofabric and the filling of voids between the coarse rock with smaller particles. The cost of surface preparation is significantly higher and could become an uneconomical practice (Smith 2004).

These tests were conducted on the status quo slope profile scenario of 33°. One can assume that the effectiveness of rock cladding will increase with the reduction in slope angle. The implication might be that a layer of less than 300 mm is needed to achieve the same results. This will have significant cost benefits if that is the case. For the purpose of this thesis, a minimum of 300 mm rock layer is proposed.

Planting in a rock layer

Smith (2004:13) proposes a 'vegetation pocket' (fig 4-9) to establish vegetation on a side slope capped with rock. The installation is relatively expensive, but is necessary to penetrate through the compacted surface.

Topsoil

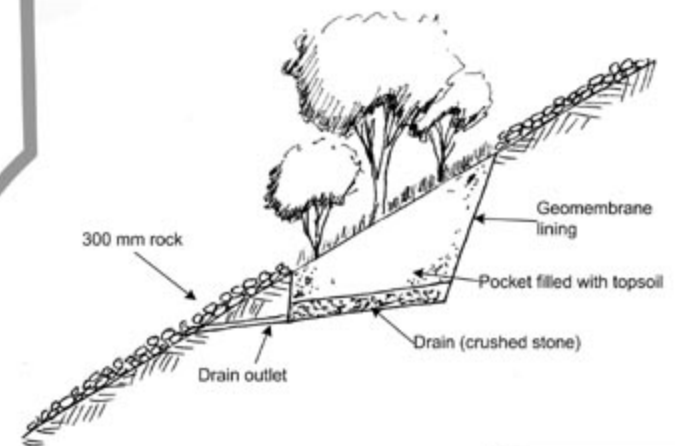
To overcome the installation of vegetation pockets, it is recommended to cap the side slope with a layer of topsoil. The topsoil should either be scarped off the construction surface before construction and stored as stockpiles, or it should be imported from elsewhere. Both options are relatively expensive and classified as energy intensive and unsustainable practices.

A mixture of topsoil and waste rock was applied on the Daggafontein Ergo TDF near Springs and proves reasonably effective in terms of erosion prevention. A layer of 500 mm is spread over the 18° inclined slope. Fertiliser and grass seeds are applied in situ. The layer aims at providing a suitable growth medium that will retain enough moisture to sustain a healthy and dense vegetation cover. Success is yet to be proven.

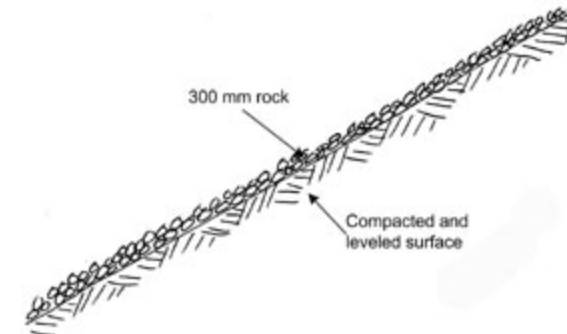
The required topsoil thickness according to proposed end-land use objectives are as following:

- Arable - 750 mm
- Grazing - 350 mm
- Wilderness - 250 mm (Chamber of Mines of South Africa 1996)

9 VEGETATION POCKET IN ROCK CLADDING
(FROM SMITH 2004)



10 ROCK CLADDING



11 IN SITU VEGETATION (KNOLL 2004)



12 RIDGE PLOUGHING AND VEGETATION



13 ARID CONDITIONS ON TDF



In situ planting of tailings

The re-vegetation of side slopes pursues a resolution for long-term instability and erosion issues.

Traditional practices involve the *in situ* propagation of indigenous grass species. Some specialists believe that grassing is an effective but short-term solution to dust control but will not contain seepage or achieve TDF closure (Knoll 2004) (fig 4-11).

Apparently only 50% cover remains three years after irrigation and fertilisation have ceased. It is difficult to obtain indigenous grass seeds to create the level of diversity needed to establish a preferable pasture grass. Large quantities of water and fertiliser are needed to establish pasture grass and irrigation promotes further leaching of pollutants (*ibid*).

Isabel Weiersbye of the School of Animal, Plant and Enviroscience at Wits states: "...the nutrient cycle necessary to get the whole ecosystem functioning and to ensure that cover is retained cannot be kick-started with grasses, as it can with woody species, because grasses produce less organic litter and this is low in nitrogen and phosphorus. In the event of fire further nutrient loss is experienced (*ibid* p25)." Weiersbye also states that the only way to maintain grassed slopes in peak condition is to make continual inputs of compost and fertilisers and to intersperse with a healthy population of legumes (*ibid*).

Weiersbye is the programme leader of an initiative to test the performance of woody, semi-woody and the containment of pollution from gold slimes dams, their effectiveness as windbreaks and in dust and hydrological control on TDFs.

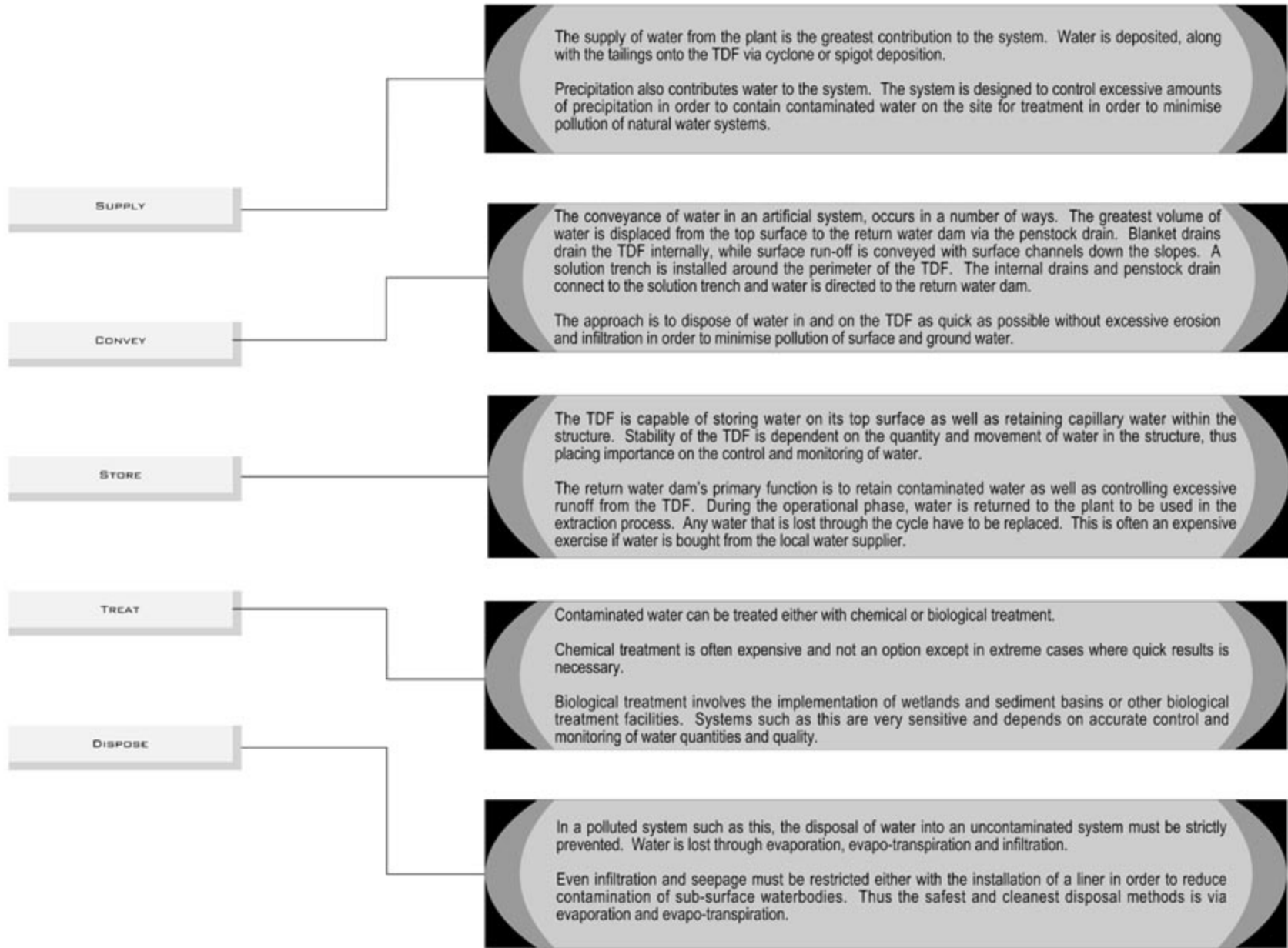
This study will increase the success of rehabilitation on TDFs in South Africa and will probably reduce associated costs. This knowledge can also be applied to the rehabilitation of platinum overburden. Tailings of platinum mines are less toxic than gold mines residue due to the difference in processing techniques and the absence of cyanide in platinum tailings.

In situ planting requires little preparation in terms of soil amelioration and earthworks. Any supplementing amendments can improve success. One such practice is ridge ploughing (fig 4-12). Ridge ploughing breaks up the surface and improves water infiltration, so-called 'micro-catchments' occur between the ploughed ridges and wind erosion is reduced by a certain percentage.

Conclusion

A combination of the discussed surface coverings is recommended to achieve a diverse surface cover, capable of withstanding local erosion forces as well as establishing a regenerative, self-sustaining ecosystem. It is important to note that each cover is particularly effective in a specific scenario. The application should follow a strategically planned design that responds to the opportunities and constraints of the environment and associated elements in order to achieve the required end-land use.

- IMPOUNDMENT STABILITY
- EROSION CONTROL PRACTICES
- HYDROLOGICAL CYCLE**
- WATERCOURSE AND WETLAND DESIGN
- LAND-USES ASSOCIATED WITH CERTAIN SLOPES



A natural system is dependent on precipitation and purged water tables for water supply. Subsequent to decommissioning, the whole system is dependent on precipitation only. As the system was designed to accumulate and dispose water as quick as possible, the rehabilitated system has difficulty to retain water in order to sustain vegetation growth. Thus the new system should be designed to make the most of the available water. The system should be altered from a concentrate-and-disposal-strategy to a retain-and-absorb-strategy. Evaporation and run-off should be reduced to a minimum and infiltration for plant-uptake encouraged to a maximum.

The systems that was used for artificial conveyance can be adopted as natural watercourses with minor alterations. Access routes and roads can also be used as watercourses, thus emphasising the importance of proper planning and locating of access routes prior to rehabilitation.

The construction of conveyance systems should encourage vegetation growth on its banks as well as being erosion resistant under the force of flowing water. Channel dimensions, lengths and gradients are factors that should be constructed appropriately to the system as a whole.

Water storage should occur in the root zone in order to present water for plant utilisation. To achieve containment of water in the top strata, it is necessary to apply suitable amelioration, enhancing absorption capacity to sustain plant growth.

If stability is ensured, water can be stored on top of the TDF. It is possible to establish a wetland system if sufficient water can be retained.

The return water dam can continue its function as an open water body presenting the opportunities for recreation and faunal habitat.

The only treatment that exist in a natural system is biological treatment. Biological treatment occurs in systems that are rich in life. The aim of a treatment facility is to trap heavy metals and extract excessive nutrients in order to increase water quality. It should be a priority to aerate water before it enters the storage facility to satisfy the Biological Oxygen Demand (BOD). Fringe vegetation need to be harvested and discarded periodically in order to dispose of the heavy metals taken up by the vegetation.

The disposal of water into the natural system should only be considered if water quality is similar to the quality of the adjacent, natural system. For this to happen the following parameters should be monitored:

- pH level
- Nutrient content
- Heavy metal concentration
- Oxygen concentration
- Organisms

SUPPLY

CONVEY

STORE

TREAT

DISPOSE

IMPOUNDMENT
STABILITY

EROSION CONTROL
PRACTICES

HYDROLOGICAL
CYCLE

WATERCOURSE AND
WETLAND DESIGN

LAND-USES
ASSOCIATED WITH
CERTAIN SLOPES

IMPOUNDMENT STABILITY

EROSION CONTROL PRACTICES

HYDROLOGICAL CYCLE

WATERCOURSE AND WETLAND DESIGN

LAND-USES ASSOCIATED WITH CERTAIN SLOPES

Introduction

Following the discussion on artificial water cycles and conversion to a natural, self-sustaining system, it necessary to set guidelines for the design of a pseudo-natural hydrological system.

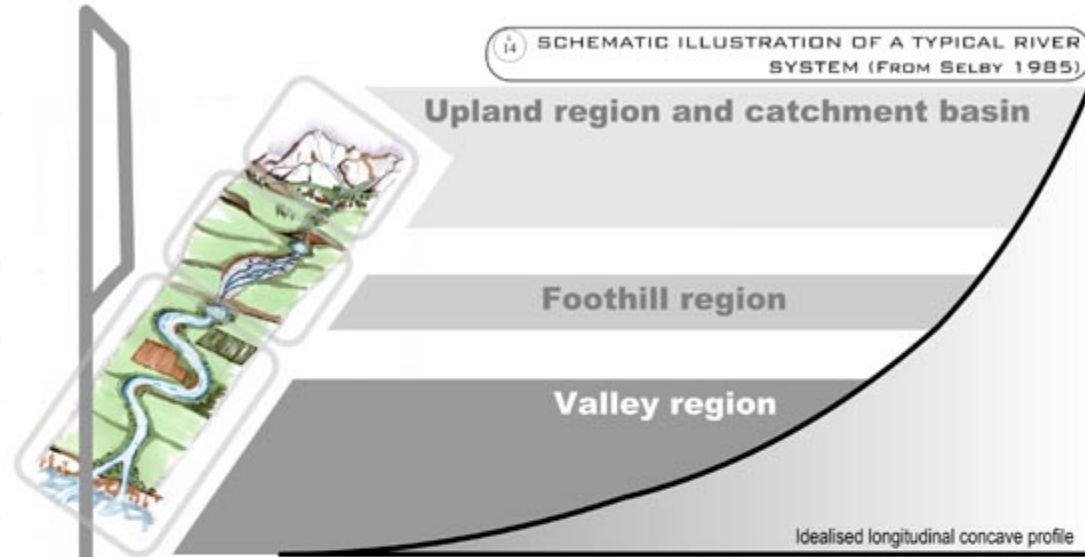
Longitudinal profiles

Longitudinal profiles represent the stream's gradient throughout its length. A simplistic portrayal indicates that channels adhere to a general concave profile with steep slopes in the headwaters and gentler slopes in lower regions with increasingly flat sections towards the mouth (fig 4-14). However, natural channels are seldom, if ever smooth and involves a degree of irregularity depending on certain influences.

Channel profiles

"As soon as water becomes confined in a channel it starts to modify the shape of that channel, both in cross-section and in gradient" (Selby 1985:260).

Cross-valley profiles are just as irregular and diverse as longitudinal profiles. Cross-valley profiles resemble longitudinal profiles in upland regions with similar steep, rock or talus slopes contributing coarse material to the channel bed. The foothill region transforms to a reduced slope scenario and subsequent deposition takes place. The valley opens in floodplains and widened channels.



Natural water courses are unique in plan and cross-section. Their form are dictated by the following elements:

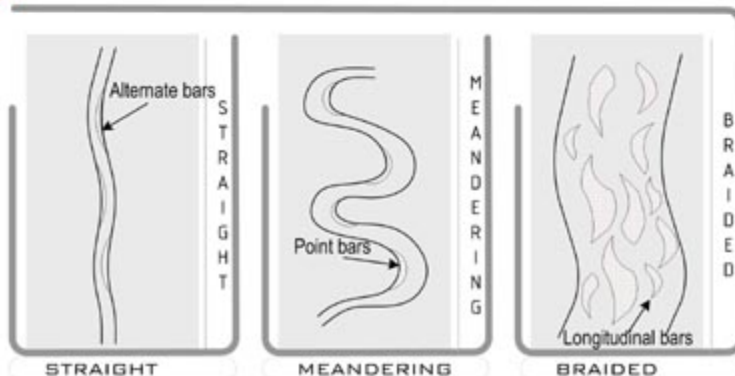
- Gradient
- Flow velocities
- Flow volumes
- Peak flood scenarios
- Riverbed material
- Terrain morphology
- Sedimentation
- Vegetation

Each portion of each water course consist of a diverse combination of these elements which gives rise to a morphologically varied system.

During the design or upgrade of a water course, one should consider the following design guidelines:

- Sinuosity
Meandering, braided and straight segments, strategically placed (fig 4-15)
- Morphological diversity in plan and section
Islands, variable bank profiles and river depths
- Biological diversity
A variation in river depth and bank profile will create micro habitats for fauna and flora
- Presence of a flood plain
Zones where flooding can occur is essential for runoff control in peak flood situations

15 GENERAL FORMS OF ALLUVIAL CHANNELS (FROM SELBY 1985)



Introduction

The design of a wetland in a waste management system is essential due to the large amounts of water present and the possible contamination that can occur. The primary objective is the treatment of water in order to improve water quality. Other objectives are secondary but just as important as it is synonym with wetlands. Wetland design guidelines is stipulated in Addendum 3.

Wetland objectives

1. Water quality enhancement

It aims at restoring the self-purification capacity and regenerative potential of the existing hydrological ecosystem. Treatment efficiency depends on:

- Water residence time
- Temperature
- Received concentration of pollutants
- Depth
- Vegetation distribution
- Hydraulic efficiency
- Light availability

2. Water storage and flood control

It aims at being a storage facility and act as an energy dissipater and detention structure in peak flood events. The hydrological engineering practices should be of the highest standard to act as a high flow buffer zone.

3. Food web support

It aims at being a source of organic matter as the basis of a food web. The system design and operational control becomes critical when food production should correspond with the quantities needed to support current and future ecological systems. High net primary production correlates with:

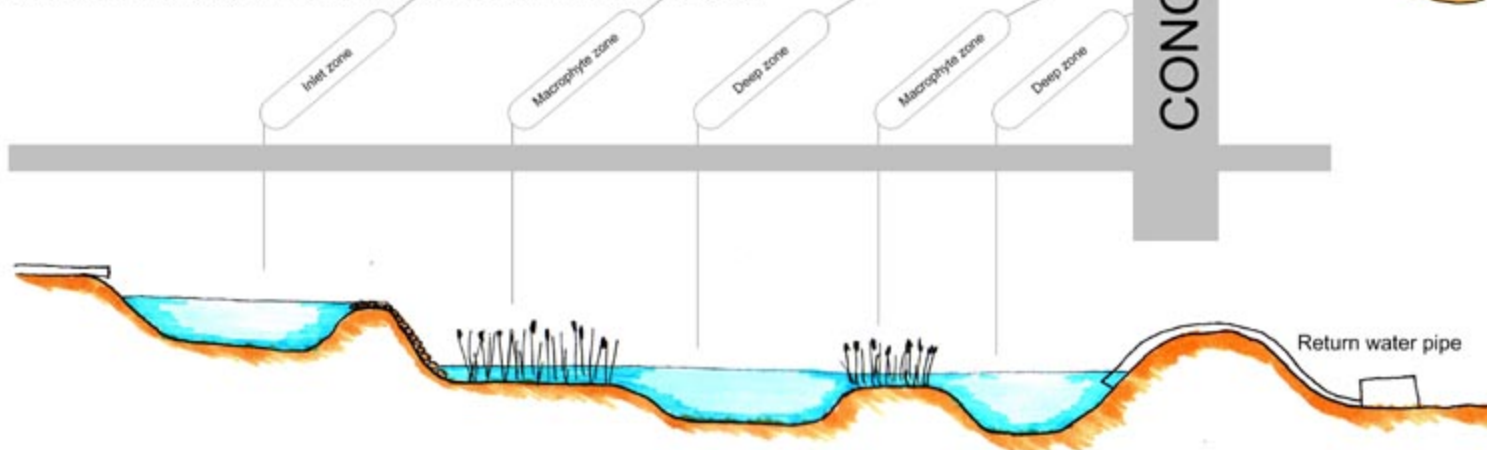
- Constant water availability combined with
- high sediment dissolved oxygen and
- light availability.

Fluctuating flood levels generally result in lower net primary production as the system is in stress during dry cycles.

4. Energy exchange with adjacent ecosystems

It aims to stabilise and function as a self-sustaining ecosystem supported and supporting adjacent ecosystems. As a potential food source, it is automatically linked with the adjacent ecosystems via faunal movement and migration routes. Wind blown or water transported seeds, carrying DNA information will be dispersed from and to this system.

CONCEPTUAL DESIGN



- IMPOUNDMENT STABILITY
- EROSION CONTROL PRACTICES
- HYDROLOGICAL CYCLE
- WATERCOURSE AND WETLAND DESIGN**
- LAND-USES ASSOCIATED WITH CERTAIN SLOPES

IMPOUNDMENT
STABILITYEROSION CONTROL
PRACTICESHYDROLOGICAL
CYCLEWATERCOURSE AND
WETLAND DESIGNLAND-USES
ASSOCIATED WITH
CERTAIN SLOPES

16 APPROPRIATE LAND-USES ON DIFFERING SLOPES
(FROM HANNAN 1984 & MARSH 1991)

Degrees	Slope		Maximum slope for land-use
	%	1 in	
45	100	1	
42	90		
38.7	80		Forestry
35	70		
30.9	60		
27	50	2	Public stairs, Hill grazing
21.8	40		Some cultivation with specialised machinery
16.7	30		Pasture, cultivation with normal machinery, lawns
11.2	20	5	Exceptional buildings
8.5	15		Septic drains, secondary tar roads and dirt roads
5.8	10	10	Arable farming, Main tar roads, Sidewalks
2.8	5	20	Industrial development, residential development
1.3	2	50	Sport fields, Parking lots
0	0		

L
A
N
D
U
S
E

O
P
T
I
O
N
S

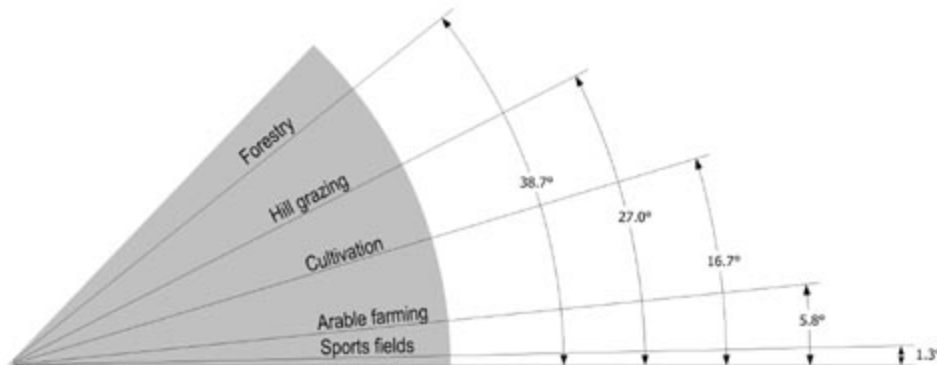
Introduction

Considering future use of a rehabilitated TDF, one need to understand the relationship between opportunities and constraints offered by the TDF and desired land-use options. It is in most cases impractical to assign a specific land-use option to a rehabilitated TDF if operation is active for a life time of 50 years or more. Projections this far into the future is likely to be inaccurate. The more suitable approach will be to design the TDF in order to accommodate a diversity of land-uses once it has reached safety and stability standards.

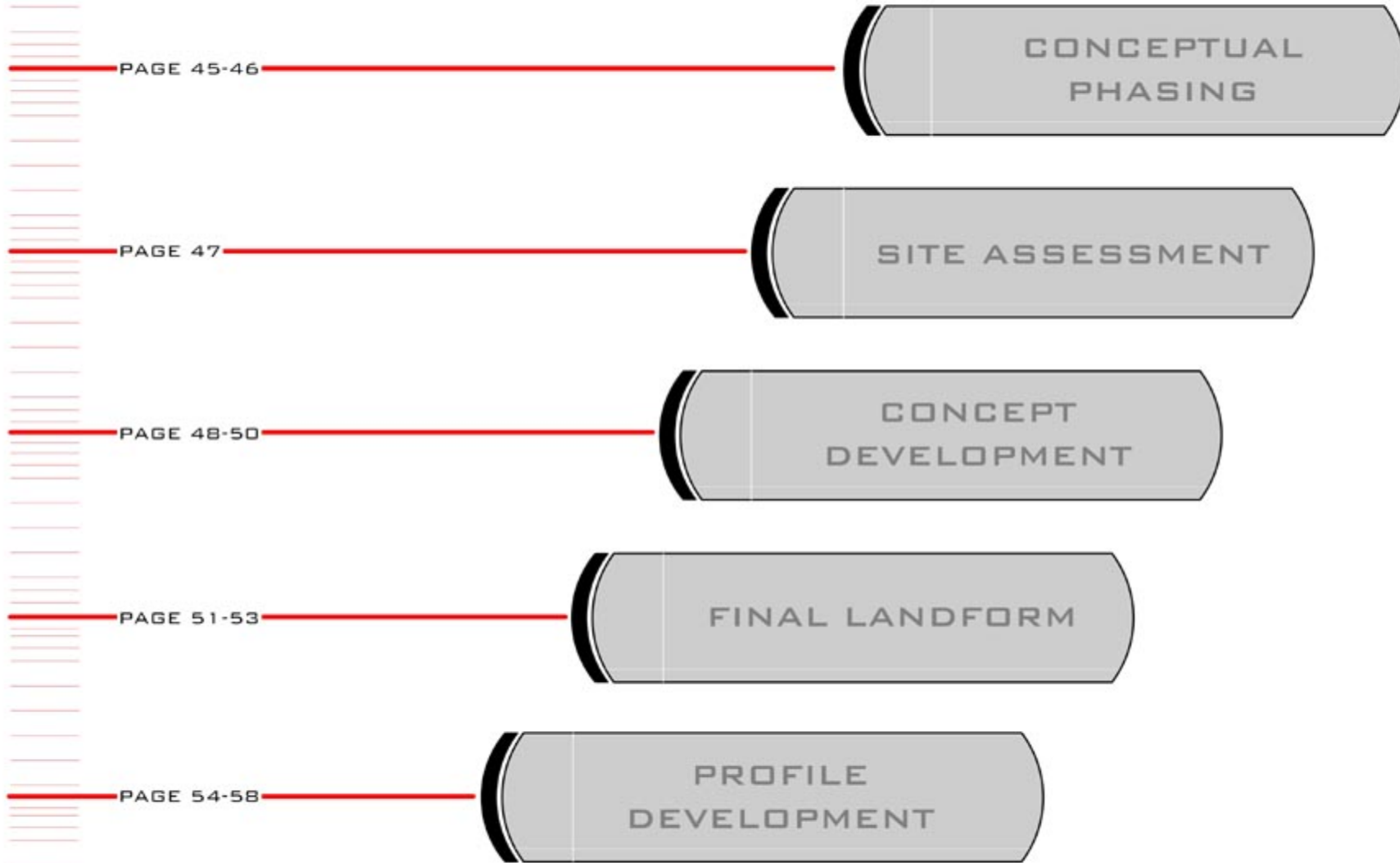
Land-uses on differing slopes

Figure 4-16 illustrates certain land-uses associated with gradients in the landscape. It is apparent that steeper gradients can only accommodate certain specialised land-uses. The lower the gradient, the more land-uses are expected to be facilitated on the TDF. This can be a useful guideline for development on a TDF.

There will always be a need for arable land as well as pasture. Slopes steeper than that can be set aside for wilderness areas.



CONCEPT DEVELOPMENT



CONCEPTUAL PHASING

SITE ASSESSMENT

CONCEPT DEVELOPMENT

FINAL LANDFORM

PROFILE DEVELOPMENT

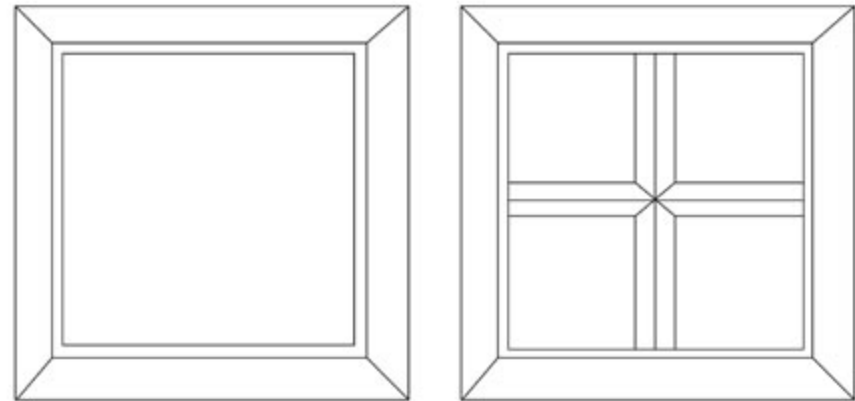
Introduction

The possibility of compartmentalising one impoundment (fig 5-1), creates the opportunity for an irregular final landform. The conventional construction methods still apply, but it is exploited to achieve the desired rehabilitated state within the parameters of structural safety and stability.

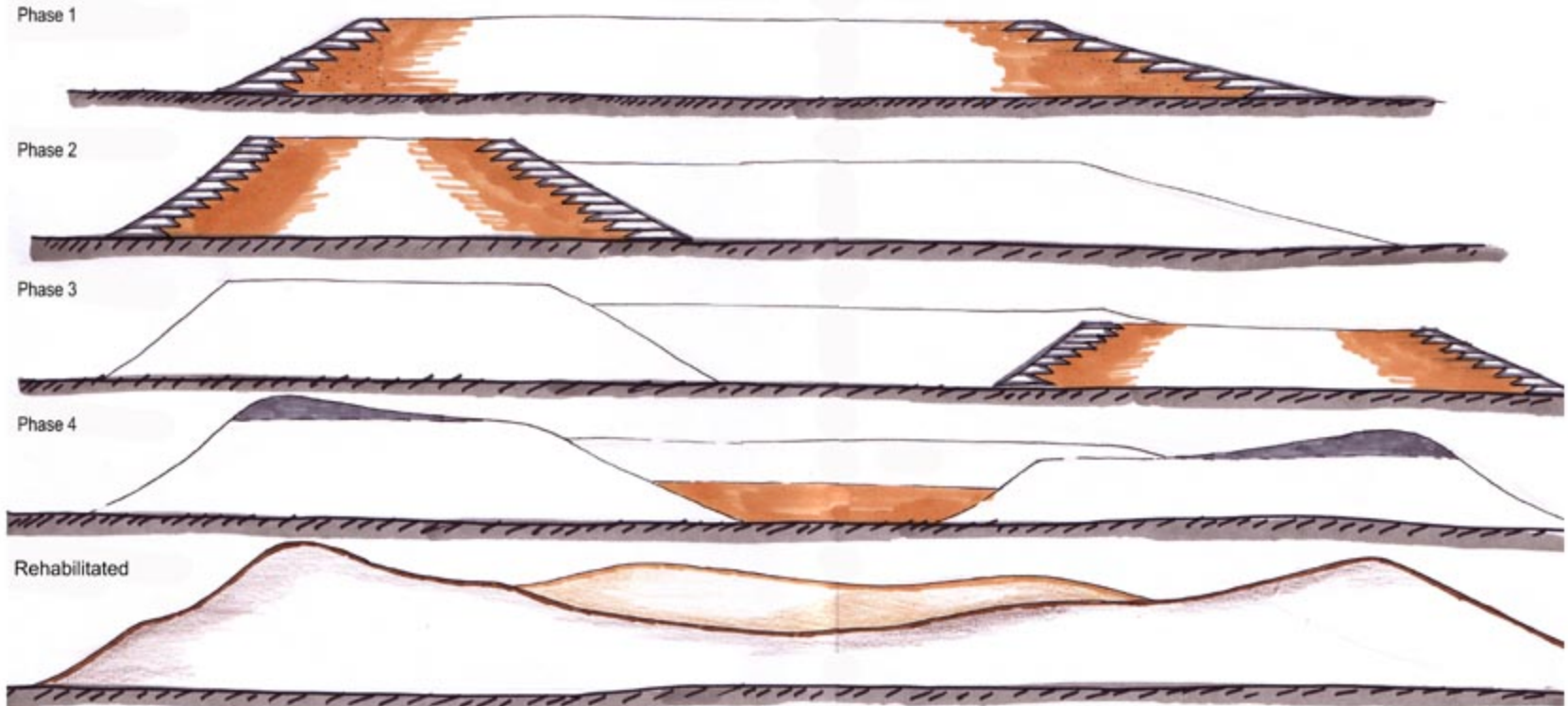
Benefits of compartment-construction:

- Smaller footprint areas per phase, thus better control over environmental impacts.
- Rehabilitation can start as soon as first phase is complete.
- First phases can act as visual buffers for future expansion
- A height difference between compartments is possible, thus creating level changes and subsequent irregularity of the profile (Vick 1983).

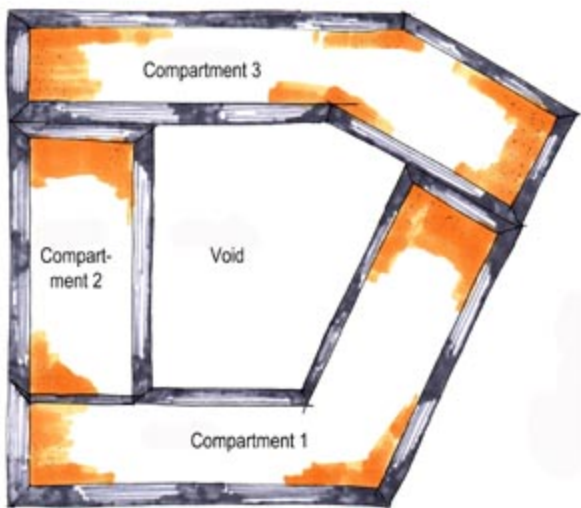
(i) COMPARTIMENTALISING OF TDFs (VICK 1983)



(j) CONCEPTUAL PHASING



3 CONCEPTUAL PHASING



Conceptual phasing

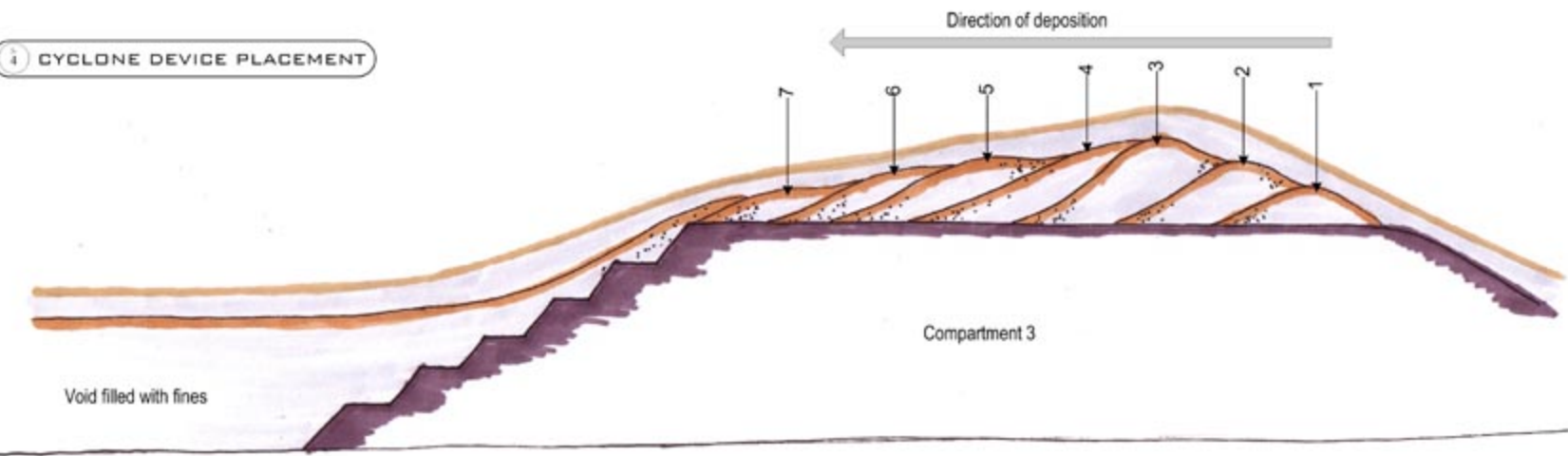
Compartment 1,2 and 3 is constructed in order to create a void in the centre. Compartment 1,2 and 3 can be operated simultaneously if the deposition rate is high. Either cyclone or spigot deposition can be used.

After completion of the first 3 stages, cyclone deposition must be implemented in order to fill the void with the fine fraction (overflow). The coarse fraction (underflow) is applied on the flat surfaces of phases 1,2 and 3 to create an irregular top surface. The cyclone devices can be positioned at any point on the surfaces to build an outcrop to the specified height. It must be mentioned that progression of phase 4 are only possible once compartment 1,2 and 3 is declared stable.

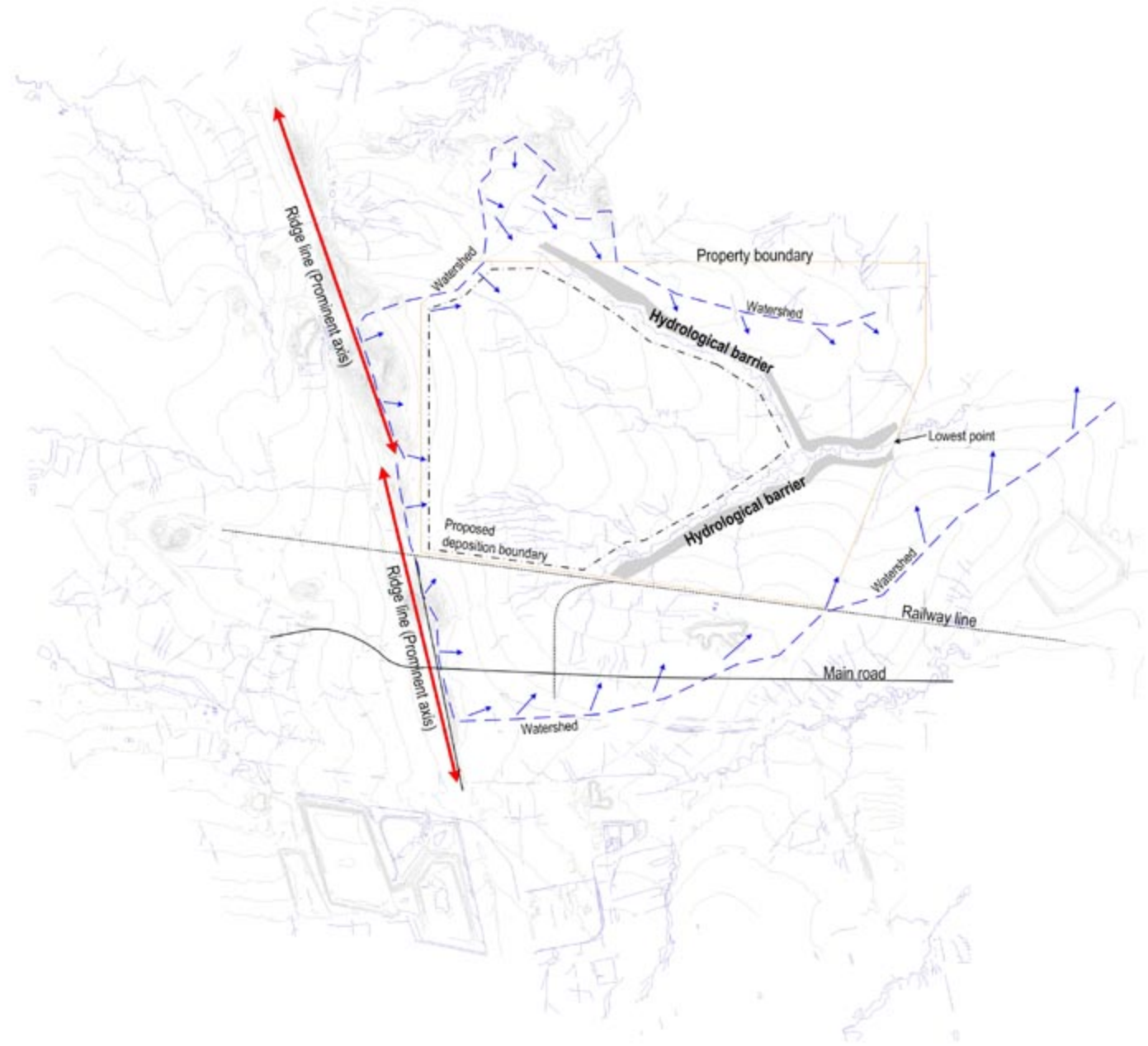
This method of deposition enables one to achieve a wide variety landform profiles. The emphasis is on creating habitats that will function in harmony with the associated surface covering and context. Safety and stability is still the primary concern and sufficient planning and design must focus on drainag patterns on the landform.

Stabilisation of the slopes must occur as soon as possible. For this reason, access routs must be present in the design.

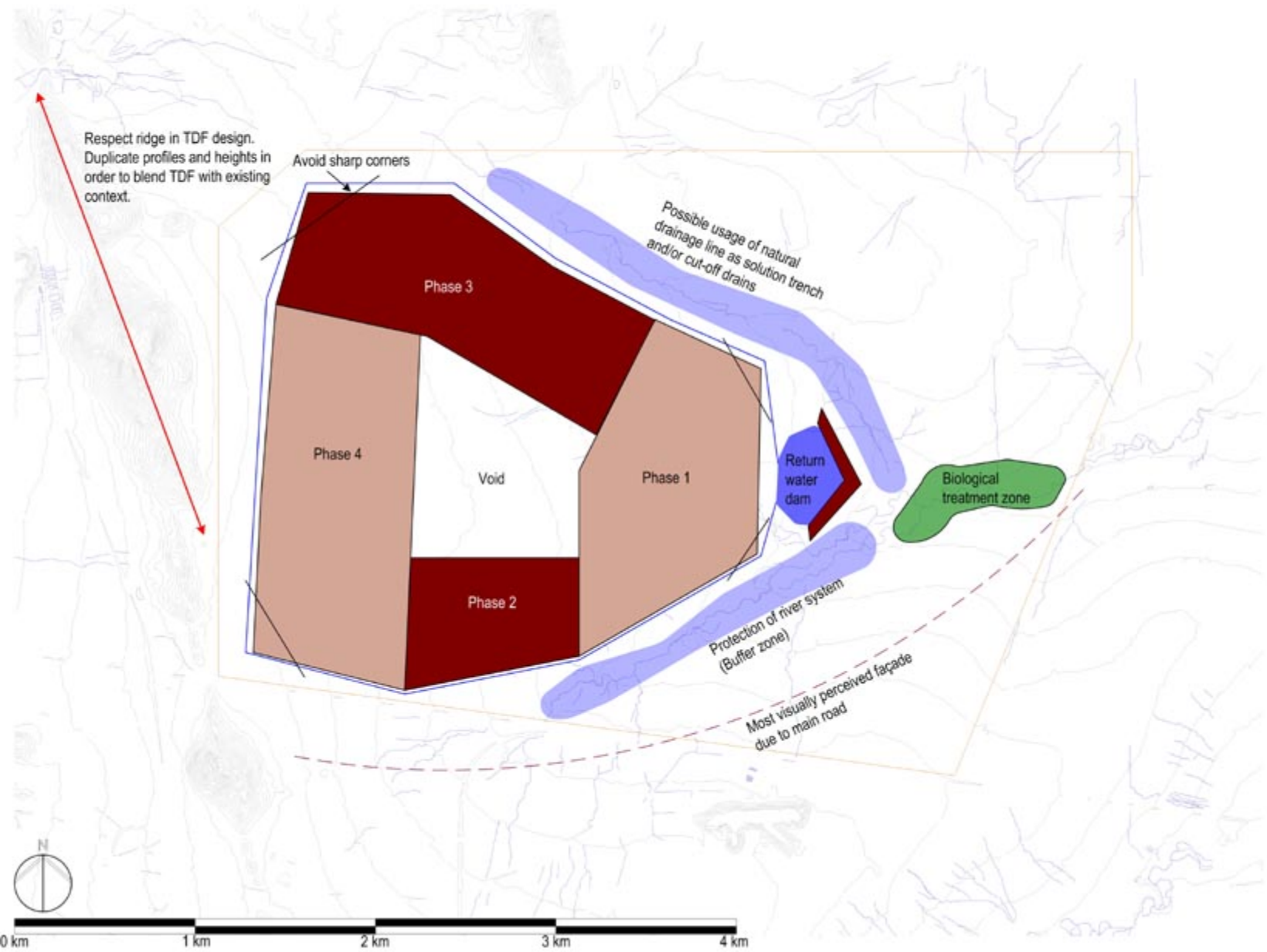
4 CYCLONE DEVICE PLACEMENT



- CONCEPTUAL PHASING
- SITE ASSESSMENT**
- CONCEPT DEVELOPMENT
- FINAL LANDFORM
- PROFILE DEVELOPMENT



(fig 5-6)



- CONCEPTUAL PHASING
- SITE ASSESSMENT
- CONCEPT DEVELOPMENT**
- FINAL LANDFORM
- PROFILE DEVELOPMENT

CONCEPTUAL PHASING

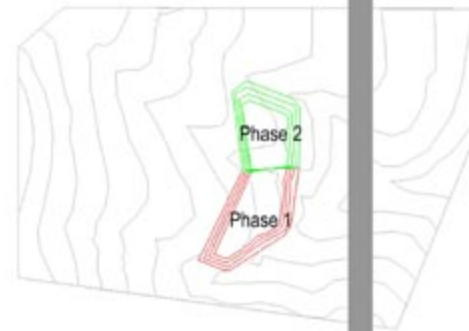
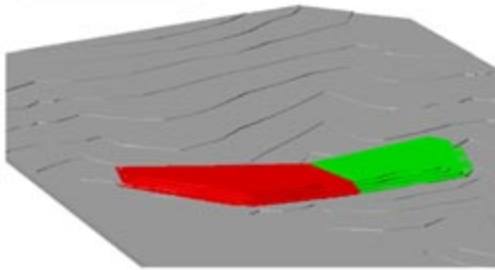
SITE ASSESSMENT

CONCEPT DEVELOPMENT

FINAL LANDFORM

PROFILE DEVELOPMENT

PHASE 1 & 2

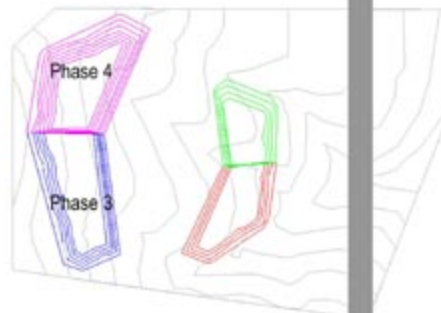
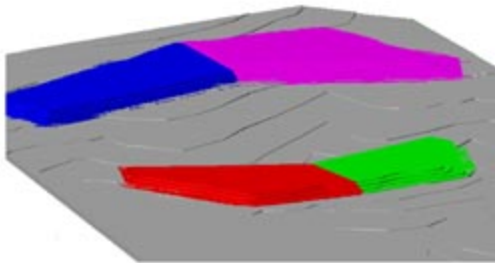


Phase 1 & 2

Phase 1 and 2 is the construction and operation of 2 TDFs in the eastern corner of the deposition boundaries as determined by the natural drainage lines. Phase 1 and 2 can be operated simultaneously or separately depending on the rate of deposition.

To accommodate a 400 tons per month (tpm) deposition rate, phase 1 and 2 need to be operated simultaneously. A safe rate-of-rise of 2.5 m per year is achieved, thus implying that spigot deposition must be implemented. A 12 year operation period is required in order to reach a height of 30 m for phase 2.

PHASE 3 & 4



Phase 3 & 4

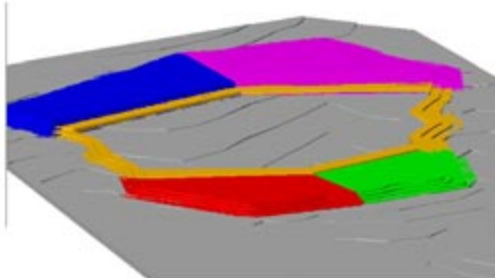
Phase 3 and 4 consist of the construction of 2 larger impoundments near the western boundary of the site. These TDFs will define the western embankment of the void.

A rate of 450 tpm deposition is achievable. Spigot deposition must be implemented in order to maintain a safe rate-of-rise if phase 3 and 4 is operated simultaneously. Phase 3 and 4 will each reach a height of 30 m and 40m respectively. A 14 year operation period is required to complete and decommission the impoundments.

It must be noted that all four phases can be operated simultaneously thus implying that deposition rate can be increased to almost double the current rate of 400 tpm - 450 tpm. Economically, it is a viable option. From an environmental point of view, area of impact is much higher.

Phase 5

PHASE 5



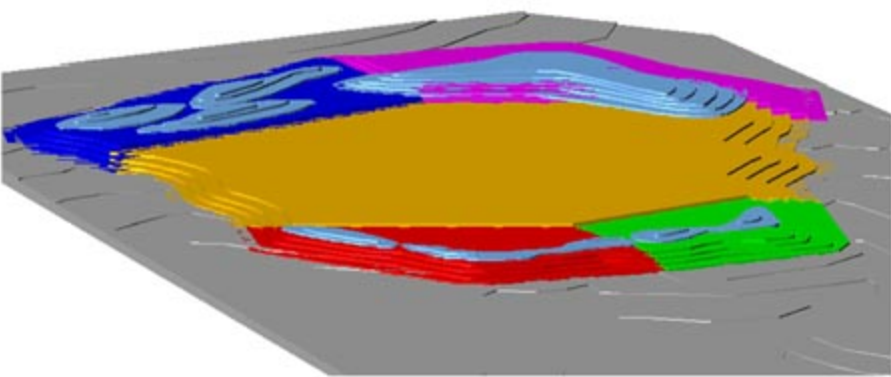
Effectively, the filling of the void can start as soon as phase 1-4 provides a sufficient embankment height to contain tailings. This is not recommended as geo-technical stability of phase 1-4 can be jeopardised.

The first stage requires the construction of embankments in order to completely close the void on the northern and southern façade, making use of cyclone deposition. Within a short period of time the embankments will provide a sufficient freeboard to contain a large volume of tailings.

At this stage, rehabilitation of the other phases will be at an advanced level, thus decreasing the visual and associated environmental impacts.

- CONCEPTUAL PHASING
- SITE ASSESSMENT
- CONCEPT DEVELOPMENT
- FINAL LANDFORM
- PROFILE DEVELOPMENT

10 COMPLETION OF PHASE 5

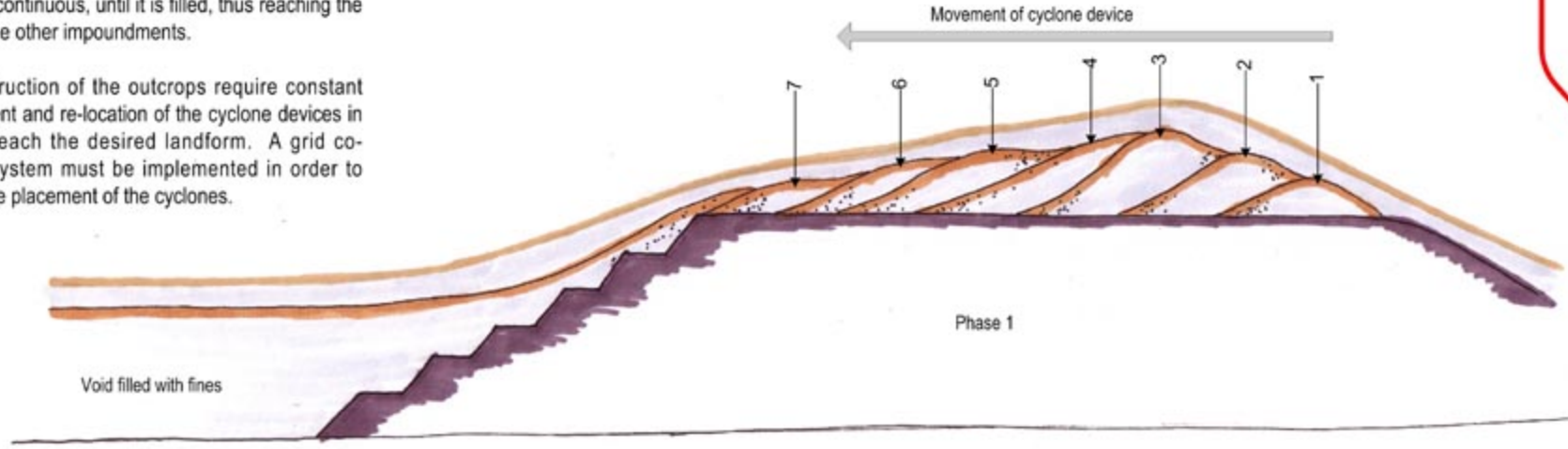


COMPLETION OF PROJECT

Subsequent completion of the embankments for phase 5 is completed, the cyclone devices can be re-located to the top of phase 1-4. The coarse fraction (underflow) is utilised to build outcrops on the flat surfaces in order to achieve an irregular profile. Deposition in the void with the fine fraction and water (overflow) continuous, until it is filled, thus reaching the height of the other impoundments.

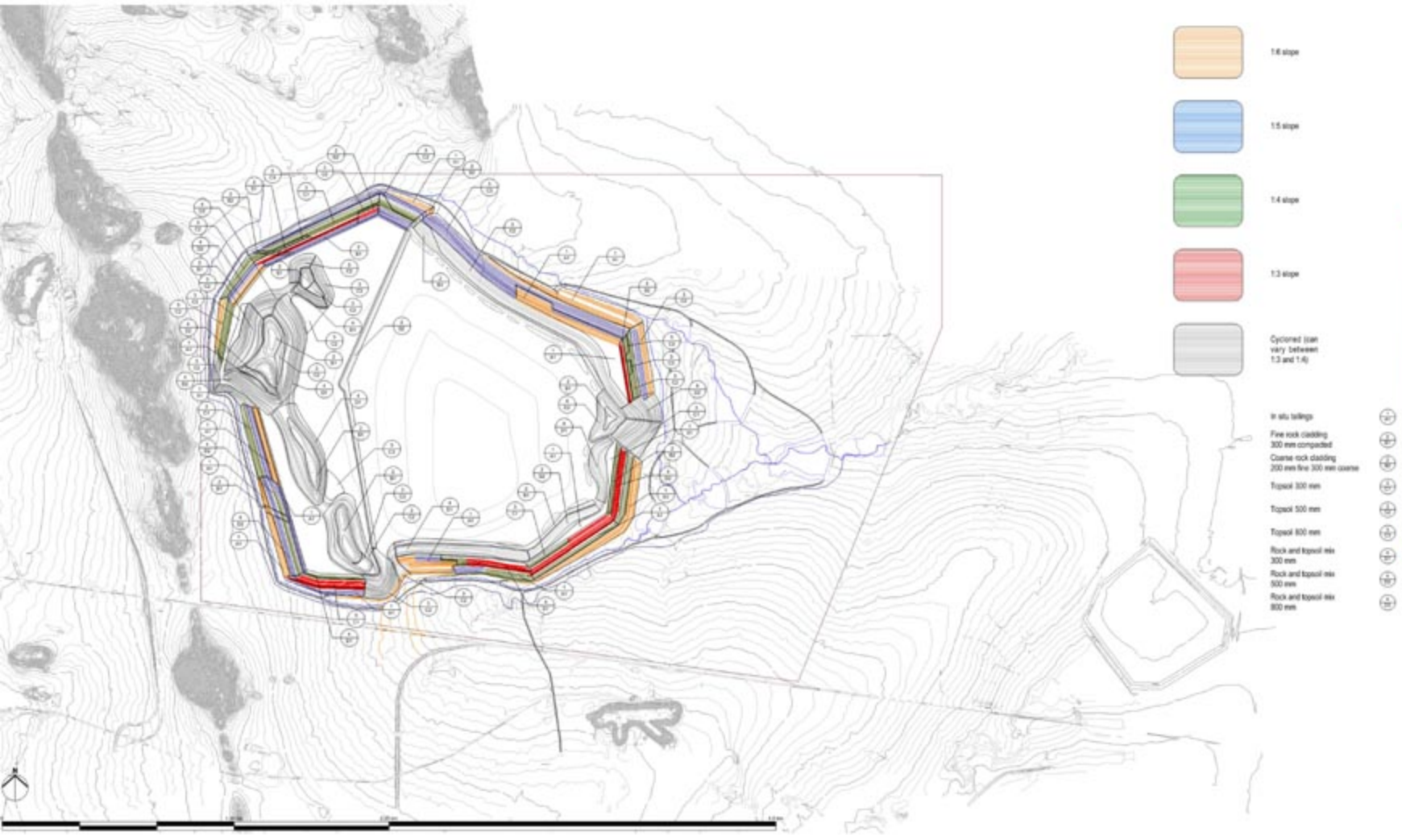
The construction of the outcrops require constant management and re-location of the cyclone devices in order to reach the desired landform. A grid coordinate system must be implemented in order to manage the placement of the cyclones.

REPEAT OF FIGURE 9-4



- CONCEPTUAL PHASING
- SITE ASSESSMENT
- CONCEPT DEVELOPMENT
- FINAL LANDFORM**
- PROFILE DEVELOPMENT

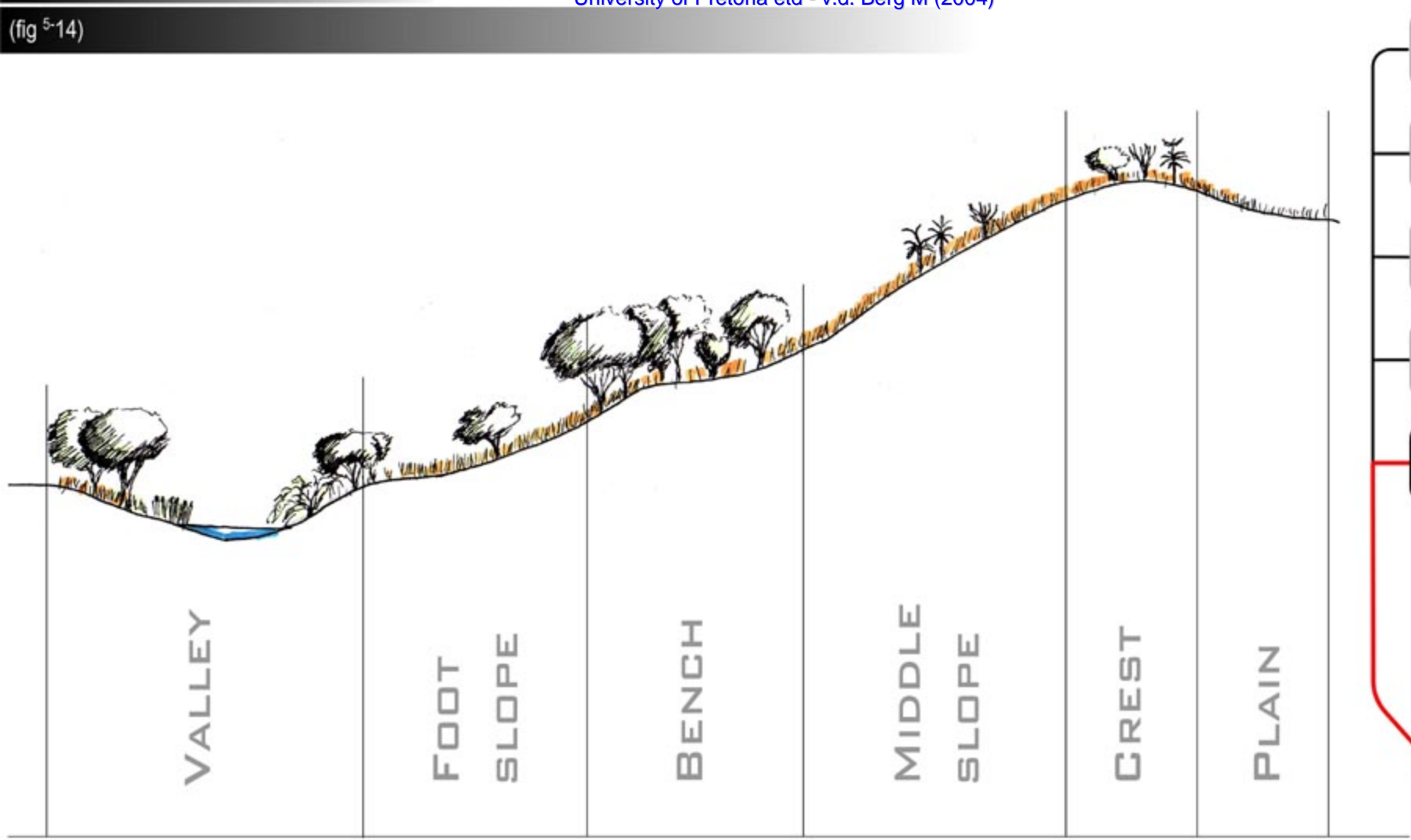




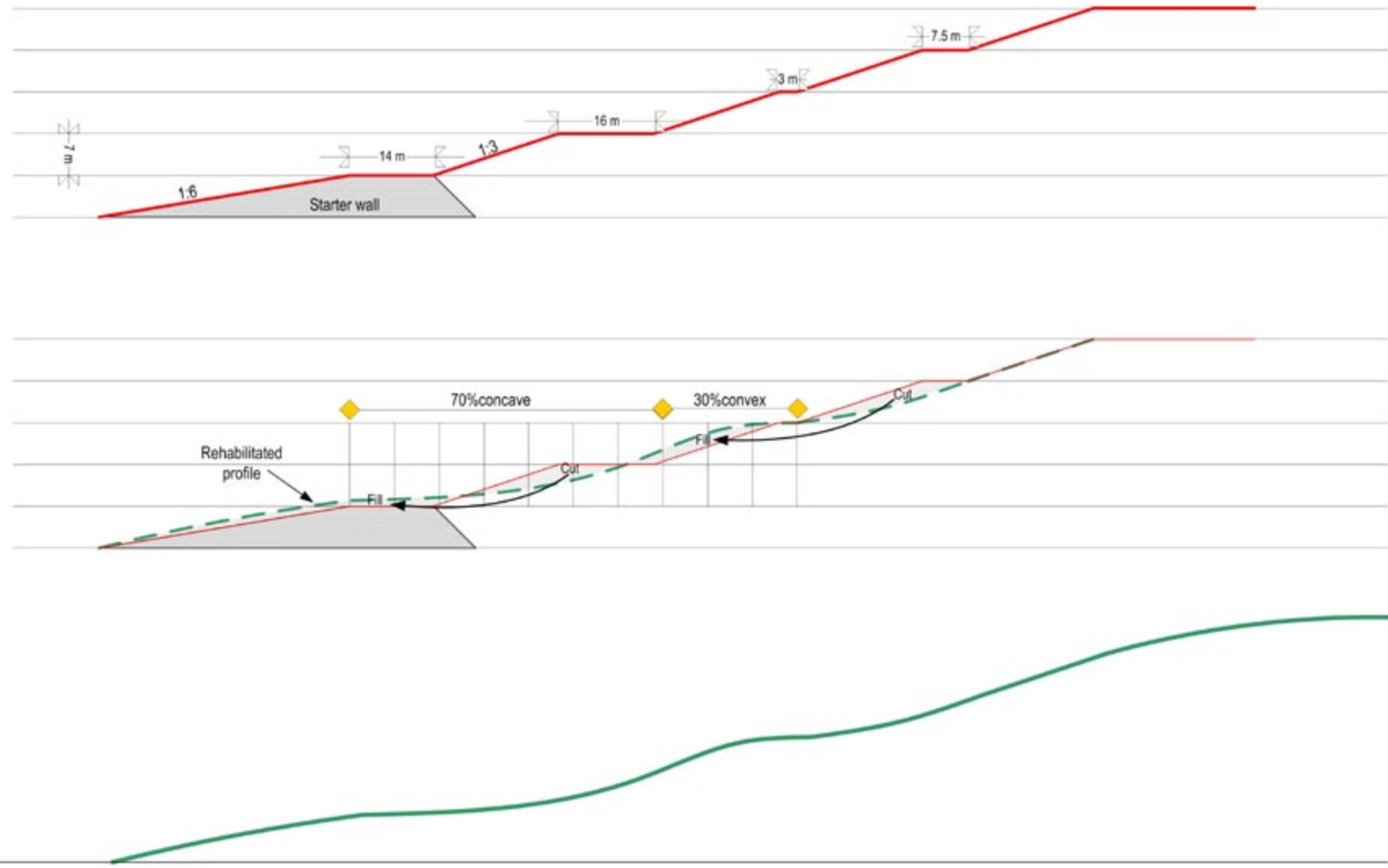
- CONCEPTUAL PHASING
- SITE ASSESSMENT
- CONCEPT DEVELOPMENT
- FINAL LANDFORM**
- PROFILE DEVELOPMENT



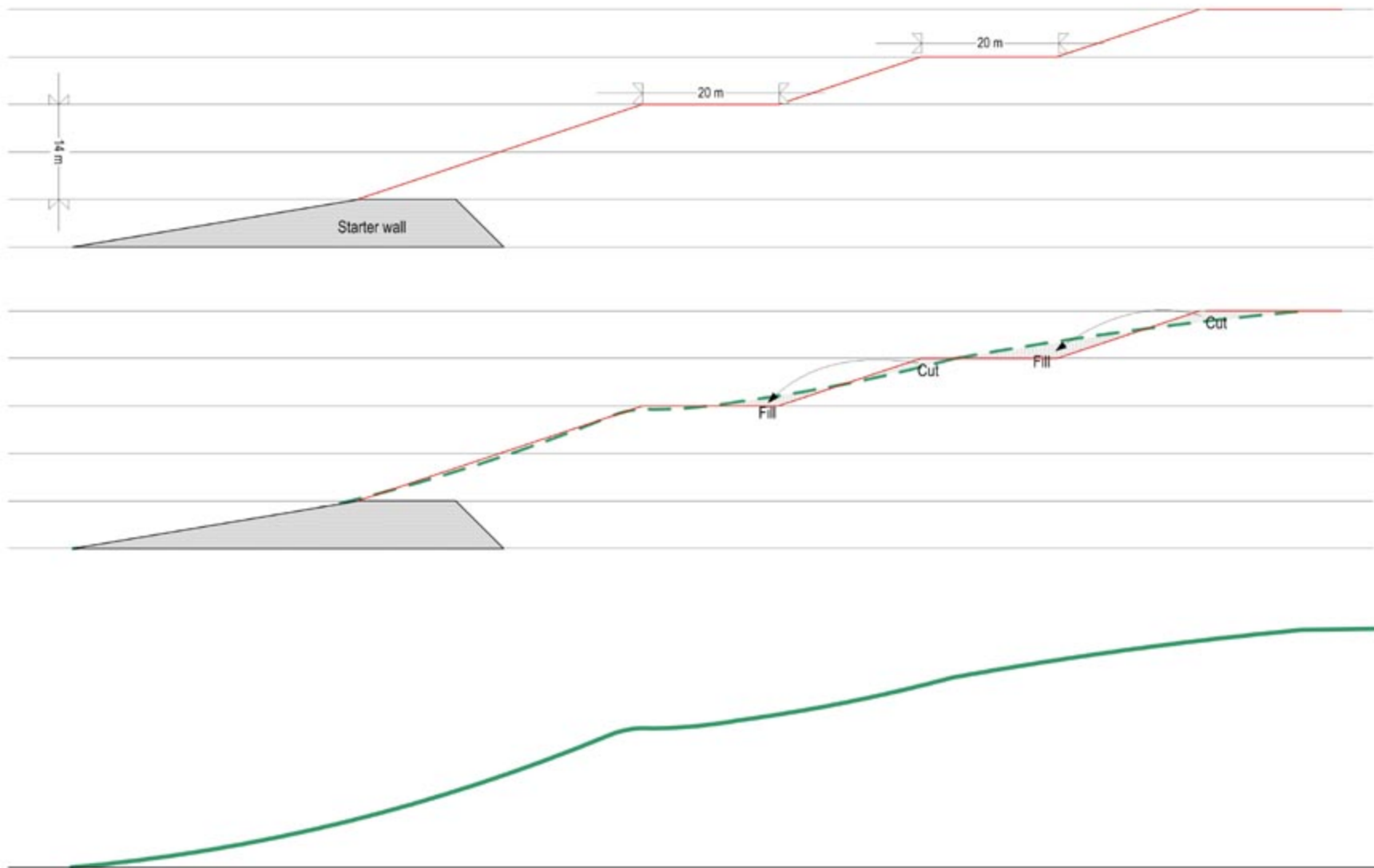
(fig 5-14)



- CONCEPTUAL PHASING
- SITE ASSESSMENT
- CONCEPT DEVELOPMENT
- FINAL LANDFORM
- PROFILE DEVELOPMENT**

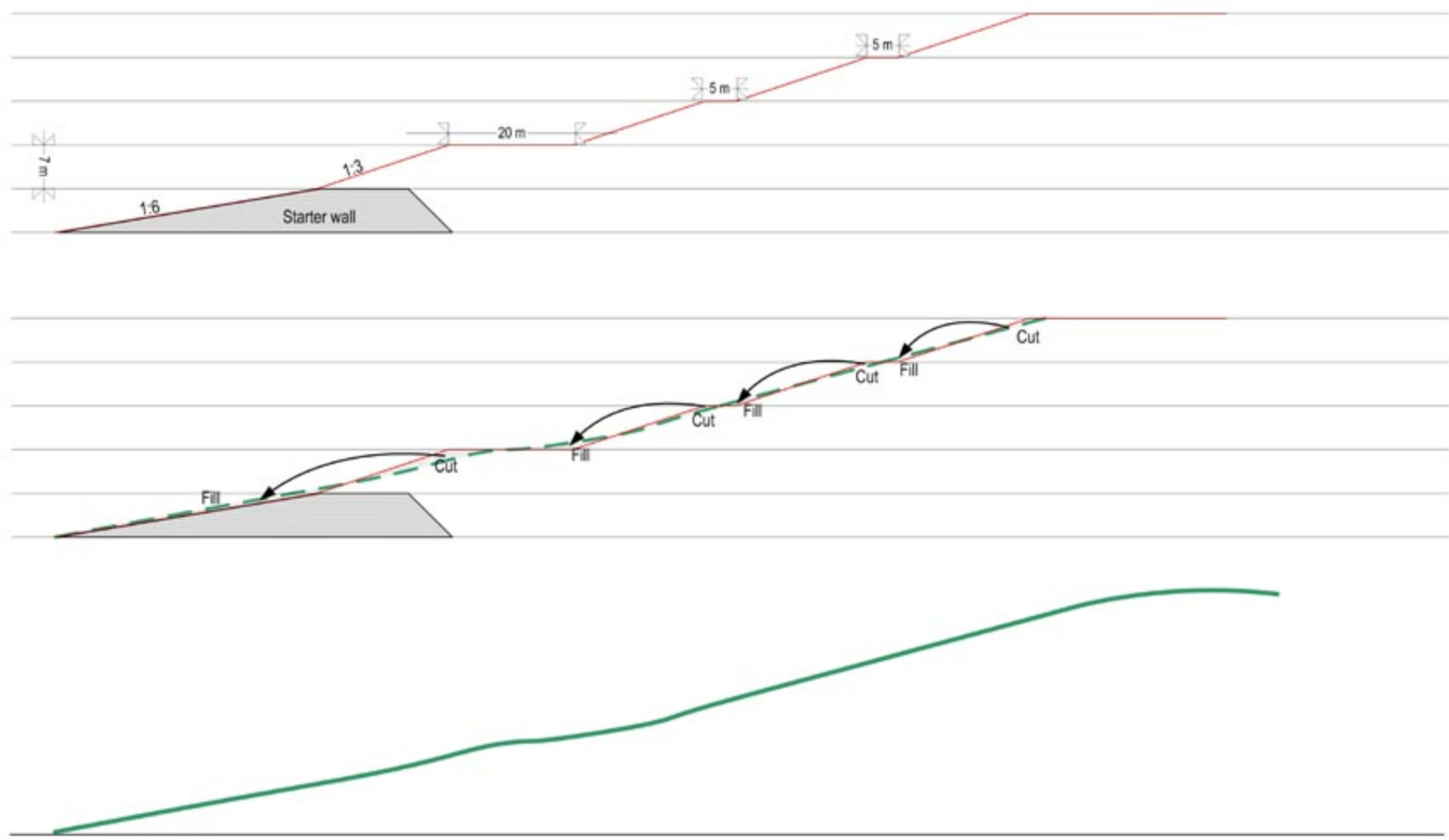


(fig 5-16)

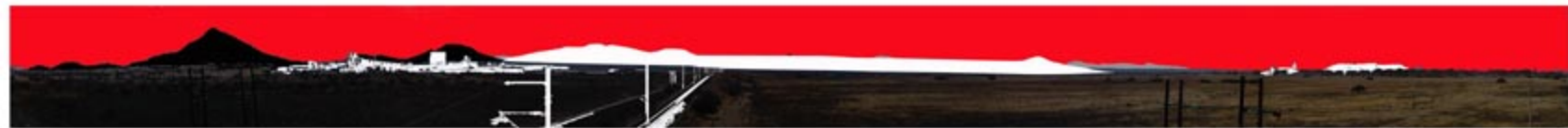


- CONCEPTUAL PHASING
- SITE ASSESSMENT
- CONCEPT DEVELOPMENT
- FINAL LANDFORM
- PROFILE DEVELOPMENT**

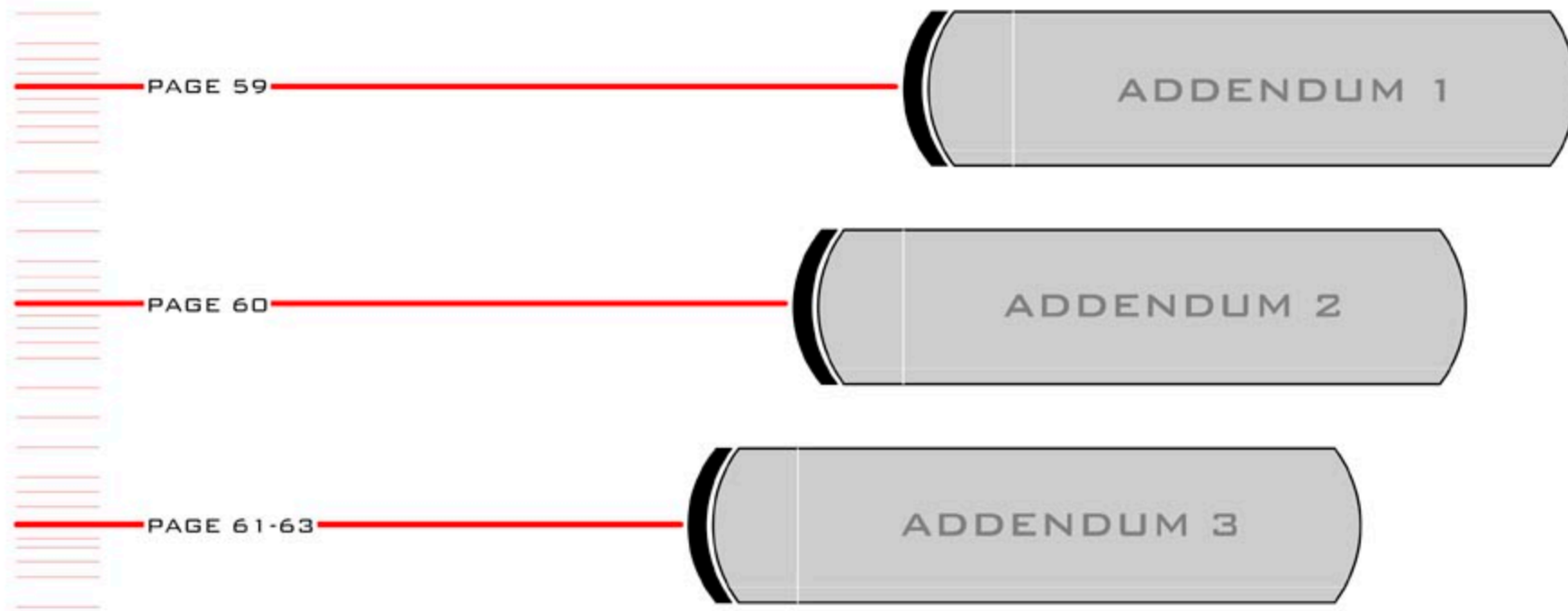
- CONCEPTUAL PHASING
- SITE ASSESSMENT
- CONCEPT DEVELOPMENT
- FINAL LANDFORM
- PROFILE DEVELOPMENT**



(fig 5-18)



ADDENDUM



PAGE 59

ADDENDUM 1

PAGE 60

ADDENDUM 2

PAGE 61-63

ADDENDUM 3

SOIL STRIPPING, STOCKPILING AND PLACEMENT OF SOIL DURING REHABILITATION

(From Botha *et al* 2002)

ADDENDUM 1

ADDENDUM 2

ADDENDUM 3

Soil Stripping

It is recommended that all usable soil is stripped and replaced after final removal of mining infrastructure. As a minimum measure, however, no less than 800mm of soil should be stripped. These estimates take into consideration a possible 10% topsoil loss through compaction, and allow the rehabilitated areas to be returned to the pre mining land capability, i.e. arable land. During the construction phase it is recommended that the topsoil be stripped and stockpiled in advance of construction activities that might contaminate the soil. It is recommended that the cut off depth of stripping be determined by using interception of the underlying geology as criteria.

The stripped soils should be stockpiled upslope of areas of disturbance or mining development to prevent contamination of stockpiled soils by dirty runoff or seepage. All stockpiles should also be protected by a bund wall to prevent erosion of stockpiled material and deflect surface water runoff.

Hutton and Arcadia soils should be stockpiled separately because they have different textures and soil structure. These soils should not be mixed when used for rehabilitation purposes and it is recommended as far as possible to replace the Hutton stockpile to its original position.

Stockpiles can be used as a barrier to screen operational activities. If stockpiles are used as screens, the same preventative measures described above should be implemented to prevent loss or contamination of soil. The stockpiles should not exceed a maximum height of 6m and it is recommended that the side slopes and surface areas be vegetated in order to prevent water and wind erosion. If used to screen mining operations, the surface of the stockpile should not be used as a roadway as this will result in excessive soil compaction.

Wherever possible, the volume of soil stockpiling should be kept to a minimum through the live placement of soils stripped in advance of mining operations onto mined out areas where spoils have been levelled in preparation for rehabilitation.

Rehabilitation and closure

When stockpiled soils have been replaced during rehabilitation, the soil fertility should be assessed to determine the level of fertilisation required to sustain normal plant growth. The topsoil should be uniformly spread onto the rehabilitated areas and care should be taken to minimise compaction that would result in soil loss and poor root penetration.

When returning soil to the rehabilitation site care should be taken to place soil in a manner that will allow for levelling of soil to take place in a single pass. The soil profile should not be built up using a repeated tipping and levelling action to increase the soil depth.

Proper water control measures should be implemented to ensure a free draining rehabilitated landscape. Re-seeding should occur as recommended in the fauna and flora report (Report number: WMB 4940/2761/1/E).

The soil depth at all sites exceeded 600mm resulting in the classification of all areas as having arable land capability. When the sites are rehabilitated a minimum of 700mm of soil should be replaced to return the post-mining land surface to arable potential. A post-mining soil depth of 700mm is recommended in order to buffer against soil depth reductions through settlement or poor soil placement and profiling.

RSA POPULATION CENSUS STATISTICS

Table 1: Age distribution in the Bojanala Platinum District Municipality (BPDM):

Age (yrs)	Total	Percentage
0-6	38 588	12.6
7-13	32 945	10.8
14-18	22 912	7.5
19-22	20 927	6.8
23-64	175 635	57.6
65+	10 486	3.4

(Source: RSA Population Census, Statistics South Africa, 1996)

Table 2: Education and income levels

Level	Numbers	Percentage
Gr. 1 - Std. 5	96 656	31.6
Std. 6 - 10	111 506	36.3
Diploma with Std. 9	4 767	1.6
Diploma with Std. 10	5 939	1.9
Degrees	4 551	1.5
Total	306 354	100.0

(Source: RSA Population Census, Statistics South Africa, 1996)

Table 3: Language distribution

Language	Formal settlements			
	Boitekong	Hfidike	Photsaneng	Thekwane
IsiNdebele	9	5	-	-
IsiXhosa	991	1285	649	422
IsiZulu	164	84	40	1
Sepedi	148	90	51	65
Sesotho	213	263	149	68
Setswana	5848	1521	1955	1903
Siswati	35	113	20	9
Tshivenda	36	19	-	-
Xitsonga	402	235	66	163
Afrikaans	25	3	-	4
English	7	4	-	-

(Source: RSA Population Census, Statistics South Africa, 1996)

It is alleged that the BPDM's average per capita income is higher than that of the province. In 1996, for example, the average per capita income in the Bafokeng and Rustenburg was R7 172 and R12 333 respectively, while the provincial average was R5 033. This is attributed to the relatively high salaries earned by the mineworkers in the district.

ADDENDUM 1

ADDENDUM 2

ADDENDUM 3

Design guidelines

1. Exterior berm construction

- The purpose is to regulate and contain water within specific flow paths
- Keep berms as small as possible for aesthetic reasons
- Provide a freeboard sufficient to prevent overtopping during a rain event with a frequency of 25 years or more
- Consider berm soil consolidation and subsidence as well as gradual wetland fill with vegetation and sedimentation thus reducing capacity
- Berm height = maximum desired normal operation level + return storm rainfall amount + (lifetime loss of freeboard due to sedimentation, plant accumulation and sediment).

- Provide clay lining to reduce permeability of mother berm material is too pervious or install external seepage collection channels
- 3m wide at top for vehicle access, 1m wide for pedestrian access
- Water containment berms are subject to local dam safety regulations

2. Flow diversion banks

- The purpose is to divert water through the wetland thus creating a longer flow path to improve efficiency via increased hydraulic residence time
- The top may be above of below water level

3. Detention time and pollution removal

- Between 5 and 14 days for soluble pollutants removal (Reed et al. 1988; Watson et al. 1989; Watson & Hobson 1989; Hammer 1989; Crites 1994; Kadlec & Knight 1996)
- Between 0.5 and 3 days for suspended pollutants removal (Ibid)
- Pollution removal efficiency reduces as temperature drops

4. Hydro-period and water regime

- Hydro-period: "...the number of days per year of surface water at a given wetland location." (Kadlec & Knight 1996)
- Water regime: "...the hydro-period as well as the combination of water depth and flooding duration."
- Duration and depth of flooding affects plant physiology because of soil oxygen concentration, soil pH, nutrients and toxic chemical concentrations.
- Suggested hydro-periods:
 - o Channel zones - 360 days per year
 - o Reed bed area - 300 days per year
 - o Shrubs and trees - 0-60 days per year

5. Hydraulic preferential ways

- A sinuous pattern of open flow channels are recommended to avoid hydraulic short circuiting
- To minimise short circuiting a uniform longitudinal bottom slope from inlet to outlet should range from 0%-5% (Hammer 1989)

6. Length to width ratio

- A high length to width ratio is recommended in order to minimise short circuiting and maximise the contact with bio film substrate for biological removal of pollutants
- Minimum length to width ratio for an economical design (i.e. to reduce berm construction cost) is in the order of 2:1 (Knight 1978)
- The optimum length to width ratio is in the order of 10:1 (Hammer 1989)
- Effective flow distribution can also be achieved by providing:
 - o Adequate inlets
 - o Deep zones
 - o Islands
 - o Flow diversion banks, etc.
- The aspect ratio of the macrophyte zone should range from 4:1 (length : width) to 10:1 (DLWC - New South Wales 1998)

7. Drainage

- Draining of a constructed wetland can be beneficial for the following reasons:
 - It allows supplementary planting if initial results was poor
 - The control of weeds are possible
 - It aids in mosquito and fish management
 - It facilitates control over potential erosion
 - It allows repair of the wetland
- Design deep zones to provide a refuge for fish and amphibians during dry periods

8. Inlet zone

- The inlet should provide a controlled entry of water to the wetland
- An effective flow distribution is a requirement from the inlet in order to minimise short-circuiting and dead zones as well as to increase the frictional resistance
- Water velocities less than 10cm/s are recommended for unprotected bottoms (Marble 1992)
- Peak water velocities should not exceed 45cm/s through the wetland (Jones 1995)
- Energy dissipation may be required to counteract erosion
- To reduce the possibility of a potential algae bloom in the inlet zone, it is necessary to minimise direct sunlight contact with the water
- In the case of poor oxygen saturation of incoming water it may be necessary to allow oxygenation to enhance nitrification before the macrophyte zone
- The slope of the bottom in the inlet zone should be practically zero to ensure an equal water distribution

9. Islands

- Islands enhance hydraulic efficiency by diverting the flow and increasing the contact area as well as providing visual and habitat variety
- The size and shape are determined by the following (DLWC-New South Wales 1998):
 - Flow conditions and wetland characteristics
 - Visual impact
 - According to the function of the wetland (flow diversion, energy dissipater, etc.)
- An island should be greater than 25m² and separated from the wetland's shoreline with permanent deep water (Marble 1992)
- The island's surface should be 30cm or higher then the normal water level
- To minimise erosion of the island banks, it is necessary to establish vegetative cover right to the water's edge
- Provide walk access for water fowl

10. Littoral zone

- The littoral zone is the interface between terrestrial and aquatic habitats
- Gentle slopes provide excellent littoral habitat for most fauna and flora associated with this zone
- Littoral vegetation provide bank protection against erosion
- Habitat opportunities can be maximised by:
 - Constructing gentle slopes
 - Vegetating with diverse littoral species
 - Incorporating sinuous edge conditions to maximise the littoral habitat

11. Fetch and resuspension

- Fetch: "...the maximum length of exposed water surface, in the direction of the wind, over which wind can blow unimpeded to generate waves."
- To prevent the effect of fetch the wetland open water zones should be located perpendicular to the prevailing wind direction
- Resuspension: "...the process that takes a particle from the sediment and moves it in the water body."
- Minimal fetch and exposure to wind will discourage the resuspension and transportation of sediment
- If the selected site is exposed to long fetch and a risk of bank scouring and resuspension exists, sufficient protection from the adjacent topographic relief or vegetation

should be provided

12. Vegetation

- It is necessary to provide access to vegetation to facilitate the required maintenance
- The ratio of open water surface to reed bed area depends on the following objectives and their priority to each other:
 - Water quality
 - Habitat diversity
 - Aesthetics/recreation
- A ratio of 1 to 3 (open water area : reed bed area) is suggested for a multi-objective design
- If water quality is the highest objective a ratio of 1:5 should be considered
- Habitat diversity suggest a ratio of 1:1

ADDENDUM 1

ADDENDUM 2

ADDENDUM 3

13. Outlet zone

- The design of the outlet zone should consider
 - Avoiding dead zones
 - Controlling water level
 - Avoid blocking
 - Facilitate monitoring of flow and water quality
- A deep water zone is suggested to collect and route flows to an outlet weir
- This terminal deep zone must be kept small to discourage long residence time and subsequent algae bloom
- Outlet structures are often sensitive to accumulation of debris and subsequent blocking
- A final filtering of biomass is desirable to reduce biomass export
- A rock filter or mesh debris fence can alleviate this problem but need to be cleared from time to time
- It is desirable to control the water level of the wetland at the outlet zone. The choice of structure used should be dependent on the condition and the objective

14. Gradient of water-land interface

- Reed beds should slope very gentle ranging between 1:6 and 1:8 to provide shallow water for wetland processes (DLWC-New South Wales 1998). These slopes are also conducive to public safety
- A gradual slope between 1:4 and 1:6 permits free movement for many waterfowl species (Green & Salter 1987; Proctor et al 1983; Bartoldus et al 1994)
- Recommended minimum water to land slope is 1:6 to 1:10

15. Variety of substrate

- A variety of substrates along the shoreline is desirable in providing a diversity of habitats for fauna and flora

16. Macrophyte zone

- The depth of the reed beds or macrophyte zones may vary from a minimum depth of 0.1 to a maximum of 0.5m with 0.4m as the optimum depth (DLWC-New South Wales 1998)
- An aspect ratio from 4:1 (length : width) to 10:1 should be considered to discourage short circuiting and to increase the hydraulic efficiency

17. Water flow and depth control

- Water depth and flow velocity are important factors influencing the dissolved oxygen concentration of wetlands
- Higher flow rates in shallow water tend to increase the dissolved oxygen concentrations caused by atmospheric aeration
- A higher dissolved oxygen concentration directly correlates with higher aquatic invertebrates and vertebrate presence and activity
- Water depth is the main factor affecting wetland plant growth. Each zone as an optimum operational level and should stay constant to minimise stress for vegetation

18. Deep open water zones

- The depth of open water can vary between 1.3m and 2.5m (DLWC-New South Wales 1998)
- The slopes for open water areas can be relatively steep, i.e. 1:3 to 1:5 (DLWC-New South Wales 1998), however if an island is present then slopes of 1:5 - 1:8 should be

considered

19. Water level fluctuation

- Severe fluctuations will have severe negative effects on the ecological balance of a wetland
- Maximum daily water level fluctuations of 300mm is acceptable without any negative results (Smith et al 1981)
- Fluctuations greater than 900mm have adverse effects (Fisher & Lavoy 1972)

20. Wetland morphology

- In order to maximise macrophyte growth the wetland should be shallow, sheltered, soft-bottomed and unshaded

21. Wetland soils

- Soils with a high humus and sand component are suitable with regard to vegetation establishment