GUIDELINE FOR AN ENABLING OPERATING ENVIRONMENT FOR ASH BACKFILLING INTO DISUSED MINES

Version 01

Report to the

WATER RESEARCH COMMISSION

by

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FOREWORD

The purpose of these Guidelines is to assist those industries that generate ash as a by-product of coal combustion or gasification processes, to understand the requirements for implementing an ash management strategy that would involve the backfilling of ash into disused mines. These Guidelines are also applicable to the mining industry (especially the coal and gold mines), as the receivers of the ash for backfilling into operating or decommissioned mines. Currently there is no well-defined evaluation process available to ash producers and receivers allowing them to determine the conditions under which ash backfilling is feasible and/or beneficial. The value of these Guidelines is in developing the technical and regulatory framework for using ash in the backfilling process to enable the ash generator or ash receiver for any particular site to make an initial assessment regarding the requirements and value of undertaking a site-specific investigation into the technical or practical feasibility of backfilling.

The Guidelines were developed so that regulatory authorities, ash producers, mine managers, and practioners involved in the management of ash can easily understand them. At the same time, in the interest of transparency, the scientific basis, assumptions, thought processes and the extensive consultation process were also documented as separate documents that are available from the WRC. These Guidelines are living publications and will be reviewed periodically based on comments received on the current requirements and approach. All users are urged to take a critical view regarding the Guidelines in terms of usefulness and appropriateness. It is believed that valuable feedback will ensure continual improvement.

ACKNOWLEDGEMENTS

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Eskom and Sasol are thanked for making data available from their ash research programmes.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ABA	- Acid Base Accounting
AMD	- Acid Mine Drainage, historic name for ARD
ARD	- Acid Rock Drainage
ASR	- Alkali Silica Reaction
BPGs	- Best Practice Guidelines for water resource protection in the South African mining industry
CCP	- Coal Combustion Products
CSM	- Conceptual Site Model
DEA	- Department of Environmental Affairs
DSS	- Dense Slurry Systems
DWAF	- Department of Water Affairs and Forestry (predecessor department to DWS)
DWS	- Department of Water and Sanitation
EA	- Environmental Authorisation
EMP	- Electron Micro Probe
EMPr	- Environmental Management Programme report
FBC	- Fluidised Bed Combustion
FGD	- Flue Gas Desulphurisation
GN.	- Government Notice
GN R.	- Government Notice (Regulation)
LC	- Leachable Concentration
LCT	- Leachable Concentration Threshold
LEAF	- Leaching Environmental Assessment Framework
MPRDA	- Mineral and Petroleum Resources Development Act, 2002 (Act No 28 of 2002)
NAG	- Net Acid Generation
NEM:WA	- National Environmental Management Waste Act, 2008 (Act 59 of 2008)
NNP	- Net Neutralisation Potential
NWA	- National Water Act, 1998 (Act 36 of 1998)
PCC	- Pulverised Coal Combustion
QEMSCAN	- Quantitative Evaluation of Minerals by Scanning Electron Microscopy
RA	- Risk Assessment
RMP	- Risk Management Plan
SEM	- Scanning Electron Microscopy
SPR	- Source-Pathway-Receptor approach

TC	- Total Concentration
TCT	- Total Concentration Threshold
TDS	- Total Dissolved Solids
TS	- Total Solids
TSS	- Total Suspended Solids
WCMR	- Waste Classification and Management Regulations
WMLA	- Waste Management License Application
WULA	- Water Use License Application
XRD	- X-Ray Diffraction
XRF	- X-Ray Fluorescence

DEFINITIONS

Boiler Slag: molten bottom ash that turns into pellets that have a smooth glassy appearance after it is cooled with water.

Bottom Ash: a coarse, angular ash particle that is too large to be carried up into the smoke stacks so it forms in the bottom of the boiler.

Brine: A brine is a solution which has a high concentration of dissolved salt, which can range in salinity (i.e. >5% up to 26-28% max). In the context of this document a brine is considered as a by-product of industrial waste water treatment processes (i.e. boiler feed water treatment, reverse osmosis, desalination, etc.).

Coal combustion: is a high-temperature (>1000°C) exothermic redox chemical reaction between a fuel (coal) and an oxidant, usually oxygen, that produces oxidized, and often gaseous products. Coal ash is a by-product.

Conceptual Site Model: a visual representation of the site/s showing contaminant sources, surface and sub-surface infrastructure, surface water resources, groundwater depth and flow direction, soil type and depth, geology and the location of human settlements as well as other potential receptors.

Deformation: Change of the shape and the size of a body due to applied forces (external forces and internal forces).

Flow: Irreversible deformation (matter is not reverted to the original state).

Flue Gas Desulphurization: a material leftover from the process of reducing sulphur dioxide emissions from a coal-fired boiler that can be a wet sludge consisting of calcium sulphite or calcium sulphate or a dry powdered material that is a mixture of sulphites and sulphates.

Fly ash: fine-grained ash particles, typically silt-sized, ranging from 1 to 100 µm in diameter.

Gasification: a process that converts fossil fuel based carbonaceous material or organic material into a syngas fuel, largely composed of carbon dioxide, hydrogen and carbon monoxide. This is achieved at high temperatures (>700°C), without combustion and with a controlled amount of oxygen and/or steam.

Monolith / Monolithic waste: A waste that has been deliberately treated to be solidified (e.g. solidified wastes).

Net Environmental Benefit: The concept recognizes that there are risks and benefits associated with all options. In a system with two main components (such as a colliery and a thermal power station), if the alternative option (or design) poses a risk less than the sum of the conventional (or compliant) designs for the two main components, then a net environmental benefit is realised.

Newtonian Fluid: A fluid that follows Newton's law of viscosity. Shear stress linearly proportional shear rate.

Non-Newtonian Fluid: A fluid that does not follow Newton's law of viscosity. Shear stress and shear rate are different.

Paste/Dense Slurry: Acts as a non-Newtonian suspension exhibiting a yield stress. Closely packed fine particles form a network which behaves as a net, holding the coarser particles in suspension. This accounts for the non-settling and non-segregating nature of pastes and dense slurries.

Permeability: the ability of a porous rock or sediment to permit the flow of fluids through its pore spaces.

Pozzolan: Siliceous or siliceous and aluminous materials which, in themselves, possess little or no cementitious value but which will solidify in the presence of water and lime or brine.

Rheology: The science of the flow and deformation of matter (liquid or "soft" solid) under the effect of an applied force.

Risk: The likelihood of unacceptable impact on receptors which will lead to objectives not being realised.

Risk assessment: The evaluation of the potential frequency of occurrence and consequence of events of unacceptable impact.

Slurry: Exhibits Newtonian fluid properties which implies suspended particles will settle and segregate when velocities are not maintained.

Workability: Easily transported, placed, compacted and finished without any segregation.

Yield stress: A fundamental parameter defining a paste or dense slurry material. It is measured in units of pressure and is related to the force required to initiate movement of a paste.

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1 INTRODUCTION

1.1 Purpose of This Guideline

The purpose of these Guidelines is to assist those industries that generate ash as a by-product of coal combustion or gasification processes, to understand the requirements for implementing an ash management strategy that involves the backfilling of ash into disused mines. These Guidelines are also applicable to the mining industry, (especially the coal and gold mines) as the receivers of the ash.

The purpose of these Guidelines is to assist the reader to:

- Select the appropriate ash management option for various ash types.
- Select an ash disposal system that best deals with environmental, operational, and regulatory requirements from the perspective of the ash producer and receiver.
- To provide an ash management strategy that considers a waste disposal option in which ash can be disposed alone, or in which solid and liquid wastes can be co-disposed.
- Implement the monitoring and reporting requirements for the selected option(s).
- Understand the regulatory framework governing the backfill process both from the perspective of the ash producer and ash receiver.
- be able to determine the net environmental benefit of implementation or non-implementation for various ash disposal scenarios (i.e. conventional vs. paste backfilling vs. slurry backfilling).
- A technical understanding of the chemical and physical material characterisation and the associated test methods required to evaluate the suitability of backfill materials, both in terms of material / backfill properties and in compliance evaluation.

Definition: Ash

The term “ash” in the context of this document refers to:

- Fly ash.
- Gasification ash.
- Bottom ash.
- Incinerator bottom ash, a form of ash produced in incinerators.

These Guidelines do not apply to:

- Boiler slag.
- Flue gas desulphurization (FGD) by-products (i.e. gypsum and calcium sulphite), gasification condensate or any other by-products of coal combustion or gasification.

Aspects of these guidelines may be applicable to wood ash, but the characterisation programme has been designed for the coal ashes discussed above.

1.2 Who Should Use This Guidelines?

These Guidelines were developed to assist industries (i.e. coal mines, gold mines, ash producers), to understand the technical, environmental and regulatory framework that governs the process of ash being backfilled into mines. The focus of these guidelines has been on coal ash produced from the combustion and gasification processes, however other producers of ash, not derived from coal may also find these Guidelines of value, as many of the discussion points presented would still be applicable, irrespective of the ash type. A person who effectively applies the Guidelines will be well placed to comply with environmental, social and regulatory requirements. The Guidelines were developed for:

- Industrial producers of ash – to understand the requirements for managing ash generated from combustion or gasification processes, specifically in the context of ash being backfilled into mines.
- Mining companies (especially coal & gold mines) – to implement and manage ash backfilling as part of the broader mine closure/rehabilitation strategy.
- Regulatory authorities – as a guide to understanding the technical basis behind compliance in applicable cases, alongside the site-specific studies submitted by an applicant.
- Engineers/Scientists – to serve as a baseline for the development of improved methods, disposal options and monitoring which will assist in industry improvement.
- Educators – to use as training material in order to build capacity.

1.3 Overview of the Guideline

This section gives an overview of the structure and content of the Guidelines for An Enabling Operating Environment for Ash Backfilling into Disused Mines.

Part 1: Introduction

The motivation behind these Guidelines together with the objectives.

Part 2: Background

Introduction to the concept of backfilling in terms of terminology, backfill materials and backfill methods.

Part 3: Feasibility Assessment

Briefly introduces the potential benefits that stakeholders can expect when considering backfilling from a commercial feasibility perspective.

Part 4: Regulatory and technical framework for ash backfilling.

This section is at the core of understanding the numerous regulations governing the disposal/use and backfilling of ash into a disused mine. The concept of Net Environmental Benefit is introduced here together with the required testing needed when evaluating your ash material for backfilling.

Part 5: Assess Receiving Environment

The concept of preliminary site investigation, conceptual site model (CSM) and conceptual source pathway Receptor (SPR) are introduced and discussed in terms of ash backfilling.

Part 6: Option Selection

The concepts discussed in the earlier sections (NEB, etc.) are briefly discussed in the context of determining how a final backfilling option is made.

Part 7: Predictive Plume Modelling

Applicable to the mining environment, this section looks into environmental and water balance aspects such as determining drainage chemistry, pathways and volumes post backfilling.

Part 8: Risk assessment

Gives an overview of the risk assessment process in terms of risk identification, evaluation and appraisal for each of the backfill options discussed.

Part 9: Risk management Plan

Deals with the process of identifying and mitigation of risks for each of the backfill options discussed.

Part 10: Monitoring Plan

The different monitoring protocols that one needs to be aware of when backfilling ash into disused mines. Each of the backfill options are discussed separately as each of the options have unique monitoring requirements.

Part 11: Reporting
From a regulator perspective the required monitoring required during and after the backfilling operation.

1.4 Motivation

Using ash with or without brine to backfill disused mines potentially have positive and negative impacts on the environment. While it has the potential to minimise water ingress and consequently the generation of saline or acid mine drainage, the impacted mine water in many cases is near surface water sources and becomes a threat for contamination and building integrity. Ash typically has high neutralisation capacity which has the potential to mitigate/ minimise the risk of acid mine drainage. Ash could exhibit pozzolanic characteristics and can form cementitious material with low permeability which limit the movement of contaminants to water resources. Additional benefits of backfilling may include prevention of illegal mining activities, stabilisation of unstable landscapes and decreased risk of spontaneous combustion.

Although brine is not mentioned explicitly in the title of this project, it regularly occurs in the context of facilities where ash backfilling is an option. Coal utilizing technologies such as combustion and gasification customarily include the production of steam requiring boiler feed water treatment processes that result in the formation of concentrated wastewater, consisting of predominantly inorganic dissolved substances (salts). The term brine is used here to refer to this wastewater stream. A concentration of 5% and greater is typically an indicator of concentration although it is not uncommon to find brackish membrane-based desalination systems operating at coal fired facilities in the order of 2%.

Currently there is no well-defined technical evaluation process to determine the conditions under which ash backfilling is feasible and/or beneficial. The value of this project is in developing the technical and regulatory framework for using ash in the backfilling process to enable any particular site to make an initial assessment regarding the value of a site-specific investigation into the technical or practical feasibility of backfilling.

This project supports the sustainable development solutions. Unfilled mine compartments associated with surface placed ash bodies which is likely to remain in perpetuity, is not a sustainable option. Backfilling can have a beneficial effect on the environment by addressing water quality impacts (including, but not limited to acid drainage), reducing waste disposal requirements, reducing ground fissuring, increasing long-term strata stability and providing roof support which can potentially limit the impact of subsidence. The footprint of surface placed ash bodies could become available for other economic activities and in the case of mines enveloped by housing, a safer environment for housing compared to the unacceptable surroundings of some informal settlements where open cavities and dust generating ash dumps are prevalent. This is especially feasible for derelict and ownerless mines where closure or re-mining is considered, contributing to transformation and redress and empowering communities to participate in economic activities.

1.5 Objectives

The objectives of this study include the following:

1. To document a scientific, evidence-based position and recommendation on ash slurry / paste characterisation and classification (from steam generation, combustion and gasification);
2. To develop a technical framework which includes recommended tests/procedures, and which provides guideline values to facilitate the evaluation of the suitability of dry ash, ash slurry / paste backfilling for specific objectives (acid neutralisation, potential minimisation of surface subsidence, an environmentally acceptable alternative to surface disposal, etc.);
3. To develop a risk assessment framework for ash backfilling into disused mines including:
   a) Risk quantification via modelling;
   b) Recommended verification or test work (technical evaluation of ash as well as mine areas);
   c) Criteria or guidelines on long-term ground water data evaluation;
4. To develop a mitigation plan for key risks (environmental, engineering, stability, etc.);
5. To develop typical conditions which the regulator could enforce to ensure future sustainability of ash backfilling including a generic monitoring plan; and
6. To map the integrated regulatory plan to authorise an ash backfilling into disused mines.

2 BACKGROUND ON BACKFILLING

2.1 History

Backfilling is commonly practiced in the mining industry around the world with a history going back to the early 1900's when mine tailings and other mine wastes began to be placed in underground mines. The early motivation for practising mine backfill was largely the disposal of waste and the impact of this activity was initially not very well understood. Early methods were very rudimentary and often included no more than dumping material in voids wherever access made the practice possible. Hydraulic fill methods were gradually developed and became common around the middle of the century. The placement of raw tailings in underground openings lead to significant mine accidents, prompting the removal of the finer portions before placement to control catastrophic flows during failures. This approach was further improved upon when the addition of Portland cement to portions of backfill materials was initiated in the late 1950s. The 1970s saw several significant developments in backfill systems. The adaptation and improvement of different mining methods as a result of a better understanding of backfill properties. Numerical modelling started to emerge and to bring about a better understanding of the backfill interaction with the surrounding rock masses and the role played by backfill in overall mine support. Modern day numerical modelling techniques utilize sophisticated software tools (e.g. Rocscience's software RS2(two-dimensional) and Itasca's finite-difference software FLAC3D (e.g. Masniyom, 2009; QueensMineDesignWiki, 2011; Emad, 2017). The introduction of fill in bulk stopes and the requirements for greater free-standing backfill faces necessitated the use of increased quantities of cement with the attendant cost implication. This led to the investigation and use of alternative binders for fills. Controlled pours and the use of pozzolans lead to lighter bulkhead designs for open stopes.

2.2 Terminology

The use of ash and brines to backfill disused mines requires a minimum level of common understanding for all parties involved in such a project, from the mine engineer to the regulator and stakeholder. It is therefore necessary to develop the concept of ash backfilling in a manner which is both clear and simple to understand so that the test work required to enable the success of backfilling may be effectively planned, executed and the results communicated to decision makers in a meaningful way. An understanding of the concept and how the various testing protocols support it relies on the reader being familiar with the basic terminology that applies to the practice of backfilling. The following discussion aims to introduce key terms that will be helpful when using this framework focusing on the different mining methods, properties of the backfill material test work required to develop the process that will impart these properties on the backfilled material.

2.3 Backfilling Materials

Coal ash produced during the pulverised coal combustion (PCC) process is the most widely used process in South Africa. The ash produced is managed in different ways depending on the waste management system adopted by the ash producer. Conventional ash management systems include either slurry/wet sluicing or dry ash management. The "dry ash" management term can be misleading because the transport and disposal to an impoundment or landfill typically involves the addition of 20 to 25 percent water, which is used to suppress dust (Timmons, 2015). In addition to the dry ash option, three other methods that can be considered and which differ in their solid-to-liquid ratio are shown in Table 1. The information as shown in Table 1 compares a slurry/wet sluicing with dense slurry and a paste, with the differences between these materials in terms of their physical characteristics highlighted. The dense slurry and paste materials are not the industry standard when compared to slurry/wet sluicing, however the physical and chemical benefits of these materials, especially in terms of backfilling are being recognised. Dense Slurry Systems (DSS) and pastes as an alternative to the standard ash management systems is likely to increase in the future, with only a few coal ash power plants globally choosing to utilize these materials currently (Timmons, 2015; Timmons et.al., 2017; Longo, 2015; Housley et.al., 2015; Lutz et.al., 2017).

Table 1: A comparison of ash backfill materials and their properties (Lutz et al., 2017).

Description	**Solid-to-water ratio**	**Definition**	**Yield Stress /" Stiffness"**	**Material Segregation**	**Water Content**
Slurry /Wet Sluicing	~1:10 to 1:15	Newtonian Fluid	None	Yes	High
Dense slurry	~1:1	Non-Newtonian	Yes	No	Moderate/Low
Paste	~3:1	Non-Newtonian	Yes	No	Low

It should be noted that the intent of this document is not to dictate to the reader on which backfill material to utilize. This choice will be dependent on a number of factors (operational, economical, risk based, environmental, etc.) that require collective stakeholder agreement. However, in order to cover the range of ash management systems (i.e. backfill materials) that stakeholders could encounter, the document attempts to capture and present a balanced view, so that an informed decision on which option to pursue can be made by stakeholders.

2.4 Backfilling methods

There are several backfilling methods used in the mining industry. These methods may be classified in various ways, and combinations of two or more methods are common. There does not appear to be a universally accepted classification but for the purposes of this framework the following methods are highlighted (See Shespari, 2015 for a more comprehensive discussion on some of these methods):

Rock backfill: This method uses mostly coarse materials in the dry form such as waste rock, gravel, sand and lumps of consolidated tailings materials. The method of placement is relatively crude with the materials dropped down a raise or tipped into an open void with the use of mechanized mining machinery. The method is typically high in capacity to store / place waste rock but is labour intensive.

Hydraulic backfill: In a hydraulic backfill system, water is used as a medium for the transportation of the materials. The backfill mixture is typically produced in a backfill plant on the surface, from where it is pumped to the void through a fill hole (Figure 1). The water content of this method varies in a range and the mixture can be described as a slurry. The terms “high density slurry” or “low density slurry” are often described to emphasize the solids to liquid ratio in an application. These slurries are pumpable and therefore more easily delivered to the target void (i.e. less energy and labour intensive than rock fill methods. Since this type of backfill mixture is highly flowable the material requires containment barricades (such as specially designed bulkheads) in the underground mine to make it safe.

The term “hydraulic sand fill” refers to a hydraulic fill where the finer fraction (slimes) of a tailing’s material is removed by various mechanical means. This method developed as a safety improvement of hydraulic tailings fills that caused mine accidents due to uncontrolled flow incidents in underground mines. The slimes reduce permeability but also act a lubricant for coarser materials thus creating the risk of uncontrolled flow when the barricading structure fails.

Hydraulic fills tend to settle over time as solids segregate from the liquid phase. The design. of a hydraulic backfill system therefore needs to take this excess water into account through inclusion of drainage systems in the design.

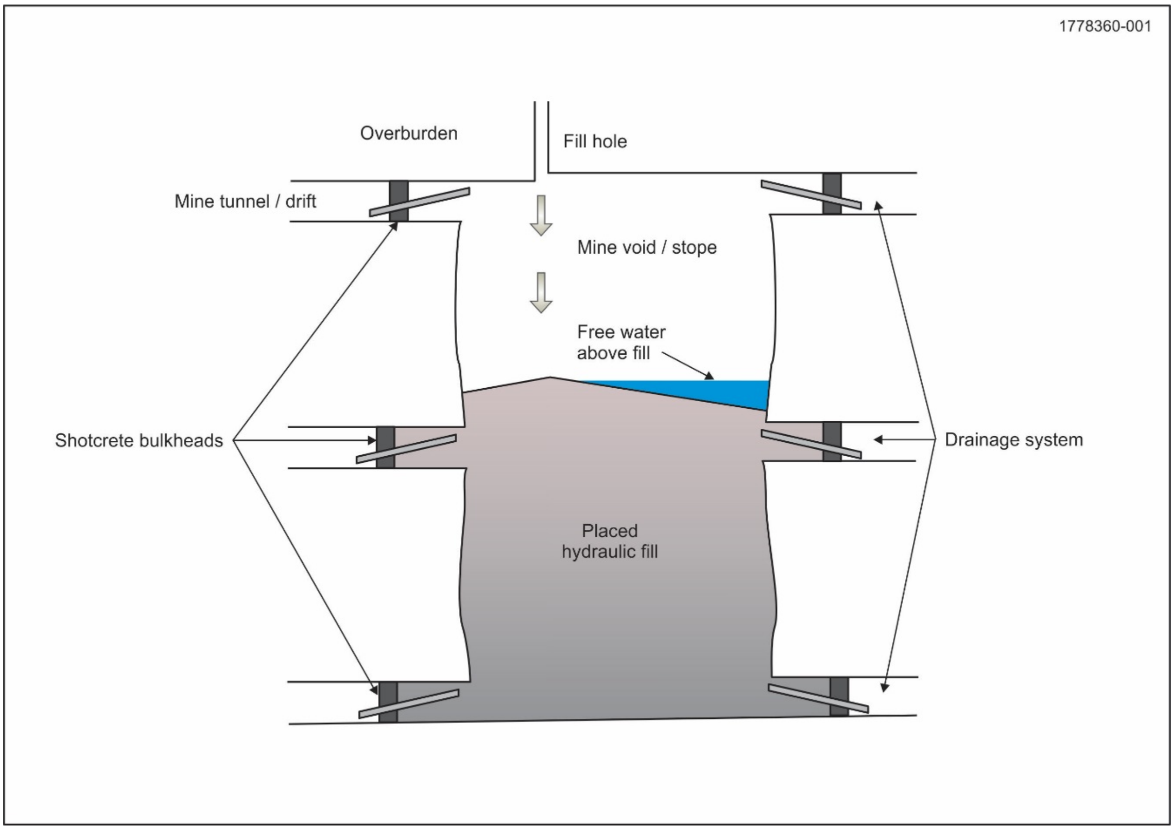

Figure 1: Example of hydraulic fill (Potvin et al., 2005)

Cemented paste backfill: In cemented paste fills we note two new terms added to the backfill concept; “cemented” and “paste”. Both these terms are particularly significant in the context of this document. A paste is often described as a non-segregating, non-settling suspension of solids in a liquid medium with a non-zero yield stress. What this means is that the solids in an ideal paste will not separate from the liquid carrying medium while it will also flow only after a certain minimum force is applied (the yield stress). In the context of a mine backfill operation this provides the benefit of no free water requiring additional management. Real-world pastes often deviate slightly from this idealized description with small amounts of excess fluid forming on the surface of a paste fill after placement. This fluid is called bleed water.

Compared to hydraulic fill of materials of similar particle size distribution, paste backfill is less prone to uncontrolled flow due to the presence of the yield stress while still retaining the benefit of being pumpable to enable placement. To enhance longer term stability cement (or specially formulated binders) are added to the mixture to increase strength thus producing a cemented paste backfill. The figure (Figure 2) below shows an example of a cemented paste back fill system recently commissioned and operated by Golder at Giant Mine, Northwest territories, Canada. In the top left of the figure, a constructed barricade can be seen while a partially filled mine void is seen on the right. The bottom three photographs show parts of the underground paste distribution system. In the picture in the middle of the bottom row show the entry point of the fill hole.

Figure 2: Cemented paste backfill operations at Giant Mine (Golder, 2018)

Fly Ash Paste and other Silica-alumina based self-cementing backfills: A silica-alumina based backfill system is a variant of the methods described above. Materials rich in silica and alumina are used to produce a self-cementing material. The most common material that fits this description is fly ash, although other coal combustion residuals (e.g. bottom ash and gasification) or industrial wastes (e.g. blast furnace slag) may also be used. The benefit of using these materials is that they display pozzolanic activity under certain conditions. This involves cementitious reactions that bind the particles of the material together resulting in increased strength and significantly lower permeability. The use of these materials in mine backfill applications are not as common as conventional portland cement for example, but the fly ash materials have added to the mix design of backfill systems for decades. The potential for increasing the beneficial use of these materials in backfill applications are very promising and increased research efforts have been reported (Pretorius et.al, 2010; Yao and Sun, 2012; Jiang et.al., 2017; Huang et.al. 2011).

2.5 Backfilling in the Context of Different Mining Methods

The choice of backfilling and the type of backfill material will be in part dependant on the mining operations, especially with respect to the chosen mining method employed by the mine. In the context of the South African coal mining industry several different methods of mining can be employed (i.e. Bord and Pillar, Longwall, and Retreat mining), the choice of which will be dependent on factors such as seam thickness, selected mining height, depth of workings, number of economic seams, thickness of the parting between seams, overburden characteristics, immediate roof and floor conditions, type of equipment available and market requirements (van der Merwe *et.al*, 2002).

The backfilling strategy for an individual mine needs to be developed taking into consideration the specific mining method in the context of the overall objective of backfilling the mine (i.e. mine rehabilitation, ARD prevention, and subsidence minimization, etc.). For example, if the objective of mine backfilling is to minimize the impact of subsidence, then backfilling will need to be done con-currently (i.e. backfilling needs to immediately follow the extraction process for a given mine block / compartment) if retreat mining is the chosen mining method. If extraction is by bord and pillar method, then a choice can be made to backfill con-currently or backfill after mine closure.

In addition, pillar safety factors, and the impact that water filled mines have on mine stability are just some of technicalities that also require an understanding in order to develop a successful backfill strategy. Ultimately there needs to be a close relationship between mining engineers who are engaged with the mining requirements (i.e. safety, engineering, environment, and geotechnical, etc.) and engineers engaged with the backfilling operations so that there is no disconnect between all stakeholders when evaluating or undertaking an ash backfill process. For a more in-depth technical understanding of South African underground coal mining the reader is encouraged to source the following (van der Merwe *et.al*, 2002).

2.6 Objectives of ash backfilling

The drivers of backfilling include:

- Minimize or eliminate flow through old mine workings (Figure 3), which can assist with mitigating the formation of acid rock drainage;
- Maximize the immobilization of contaminants in the co-disposed brines; and
- Improve the structural stability of mined-out ground.

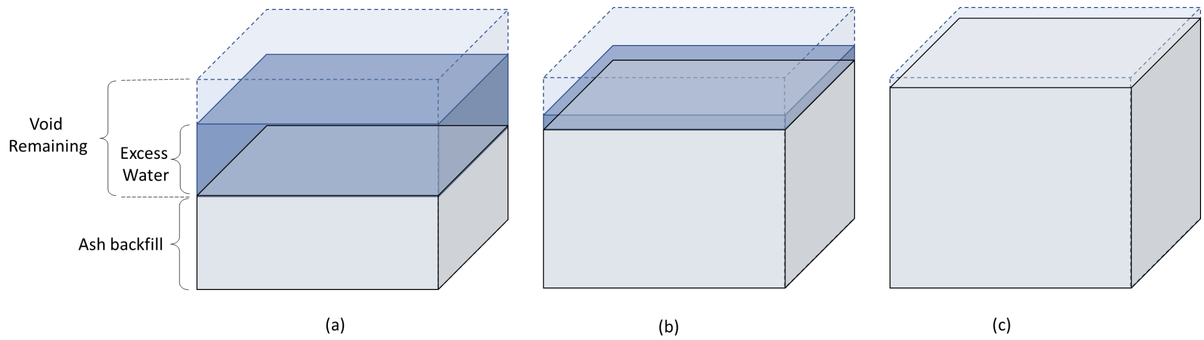

Figure 3: Elimination of water flow through open voids (Golder, 2018)

3 COMMERCIAL FEASIBILITY

The technical and regulatory framework described in sections 4 and 5, assumes that a cost benefit assessment has already been completed, indicating that backfilling is feasible. Typical feasibility considerations would include:

- Pump and/or conveyance distance;
- Availability of water;
- Volumes to be handled;
- Liability over the ash deposits in cases where owners of ash and the mine is not the same entity;
- Benefit to the receiving mine;
- Wet or dry placement;
- Potential for resource sterilisation;
- Health and safety;
- Mine life cycle; and
- Mine plan, etc.

4 TECHNICAL AND REGULATORY FRAMEWORK

This technical and regulatory framework was developed to create an enabling roadmap for the assessment and authorisation of an ash and/or brine backfilling scheme.

The sections that follow provides guidance on:

1. The legal requirements and authorisation process;
2. Determining the Net Environmental Benefit (NEB) and motivating a preferred option;
3. Characterisation of the backfilling material:
    a. Analyses (physical, chemical); and
    b. Specifications and guideline limits/values to assess suitability for the intended use.

4. Assessment of the receiving environment for both surface placement and backfilling to inform the risk assessment and guidance on the key elements that should be investigated such as:
    a. Site investigation – location, climate, hydrology, geology, geohydrology, receptors, etc.;
    b. Conceptual Site Model (CSM); and
    c. Conceptual source-pathway-receptor (SPR) assessment to establish the links between the source and potential receptors.

Should the work done up to this point clearly show that the NEB of the backfilling scheme outweigh that of a surface placement scheme, the user proceeds with the detailed environmental feasibility assessment which includes:

1. Predictive SPR (geochemical and geo-hydrological) modelling to show impact over time;
2. A risk assessment with special consideration of the following:
    a. Chemical interactions between ash, mine water and wall rock;
    b. Accelerated mine decant due to placement of ash;
    c. Geo-mechanical / hydrogeological effects on neighbouring mines;
    d. Above ground infrastructure (mixing plant, injection wells, pipelines, electricity) and whether it triggers additional permitting requirements (EIA/ BA); and
    e. Spontaneous combustion.
3. Developing a risk management plan addressing:
    a. Requirements for backfilling; and
    b. Mitigation measures for key risks.
4. Monitoring plans: Sampling, analyses and interpretation related to:
    a. Paste/slurry used for backfilling;
    b. Surface water quality; and
    c. Groundwater quality;
5. Reporting to Authorities as per licence requirements, including criteria/guidelines for long term surface- and groundwater data evaluation

Note to Reference Group: Once the content of the document has been agreed on, visual aids will be added to simplify navigation through the document using a roadmap highlighting the relevant section.

5 REGULATORY PROCESS

The South African government promotes the implementation of the waste management hierarchy and hence responsible beneficial use of waste materials. To this effect, the Department of Environmental Affairs (DEA) developed an enabling mechanism (Waste Exclusion Regulations, GN. 715 of 2018) to exclude a waste from the definition of waste if the intended use of such waste is proven to be beneficial.

The primary legislation underpinning the GN. 715 of 2018 are described in this section, as are related regulations.

5.1 National Environmental Management Waste Act, 2008 (Act 59 of 2008) (NEM:WA)

The National Environmental Management: Waste Act, 2008 (Act 59 of 2008) (NEM:WA) commenced on 01 July 2009. The previous procedures for the permitting of waste sites in terms of section 20 of the Environment Conservation Act, 1989 (Act 73 of 1989) (ECA) were replaced by new provisions in the NEM:WA. It provides measures for the prevention of pollution and ecological degradation. In terms of this Act, all listed waste management activities must be licensed and the licensing procedure must be integrated with either a basic assessment (BA) or an environmental impact assessment (EIA) process under the National Environmental Management Act, 1998 (Act 107 of 1998) Environmental Impact Assessment Regulations, 2014 (GN. R. 982, *GG* 38282, 4 December 2014 (as amended)).

The National Environmental Management: Waste Amendment Act (Act 26 of 2014) (NEM:WA) has introduced Schedule 3 of Defined Wastes. The Act now includes a definite "end of waste status", opening more possibilities in the recycling market. The terms "recovery" and "re-use" have also been superficially amended and the regulation of residue deposits and residue stockpiles have also been included within the scope of NEM:WA.

5.1.1 Waste Exclusion Regulations (GN. 715 of 2018)

Regulations regarding the exclusion of a waste stream or a portion of a waste stream from the definition of waste (GN. 715 of 2018), was promulgated in *GG 41777,* 18 July 2018, under NEM:WA after consultations undertaken by the Department of Environmental Affairs (DEA).

The intent of these regulations is to promote diversion of waste from landfill towards beneficial use. It prescribes the application process to be followed by a person or group of persons who generate the same waste, for the exclusion of waste intended for beneficial use from the definition of waste. However, the regulations do not exempt a holder of waste which has been excluded from the definition of waste, from complying with any other legislation applicable to the beneficial use of the waste.

The application must be logged by the Waste Generator with the Minister (National DEA) on a prescribed application form obtainable from the DEA or the South African Waste Information Centre (SAWIC; http://sawic.environment.gov.za/). The applicant must demonstrate, through a risk assessment process, that the beneficial use will not result in significant negative environmental impact when managed according to a risk management plan which should also accompany the application. Templates for the Risk Assessment and Risk Management Plan are available on the SAWIC website. The risk assessment and risk management plan are site specific and will therefore be required for each mine receiving the ash and paste.

Additionally, the exclusion application can be made by a group of waste generators (mines, power stations, etc.), who generate the same type of waste, rather than by a single waste generator on their own.

The Minister must acknowledge receipt of the application within 14 days of the date of receipt, after which the application will be considered. Before taking a decision on the application, the Minister must undertake a consultative process, including a Public Participation process according to sections 72 and 73 of NEM:WA. A government notice needs to be published in the Government Gazette, indicating the exclusion of the waste stream from the definition of waste. A Register of waste streams excluded from the definition of waste will be published on SAWIC.

Once the exclusion has been granted and beneficial use has commenced, the Waste Generator need to report annually on the volumes of waste used beneficially (diverted from landfill) to DEA (on the anniversary of the granted exclusion).

5.1.2 SANS 10234 Waste Classification

Classification of the ash/paste according to the Waste Classification and Management Regulations, GN. R.634, *GG 36784*, 23 August 2013 (GN. R. 634 of 2013) will be required for the application process.

GN. R.634 of 2013 was promulgated in terms of NEM:WA with the following associated Norms and Standards:

- National Norms and Standards for the assessment of waste for landfill disposal (GN. R.635 of 2013); and

- National Norms and Standards for disposal of waste to landfill (GN. R. 636 of 2013) including detail on the barrier design based on the classification of the material.

Waste classification according to SANS 10234 (based on the Global Harmonised System) indicates physical, health and environmental hazards. The SANS 10234 covers the harmonised criteria for classification of potentially hazardous substances and mixtures, including wastes, in terms of its intrinsic properties/hazards. A Safety Data Sheet (SDS), compiled according to the requirements of SANS 10234, will be required for hazardous waste.

5.1.3 Waste assessment

In terms of GN. R.635 of 2013, the potential level of risk associated with disposal of materials/wastes can be determined by following the prescribed and appropriate leach test protocols. The results must be assessed against the four levels of thresholds for leachable and total concentrations, which in combination, determine the waste type (Figure 4) and associated barrier design / liner requirements. The terminology is as follows:

- LC = means the leachable concentration of a contaminant in a waste, expressed as mg/l;
- TC = means the total concentration of a contaminant in a waste, expressed as mg/kg;
- LCT= means the leachable concentration thresholds for contaminants in a waste (LCT0, LCT1, LCT2, LCT3); and
- TCT= means the total concentration thresholds for contaminants in a waste (TCT0, TCT1, TCT2).

Although the waste will not be disposed to landfill, waste assessment is recommended as a motivation of the risk level associated with disposal and to assess the potential impact on the receiving environment.

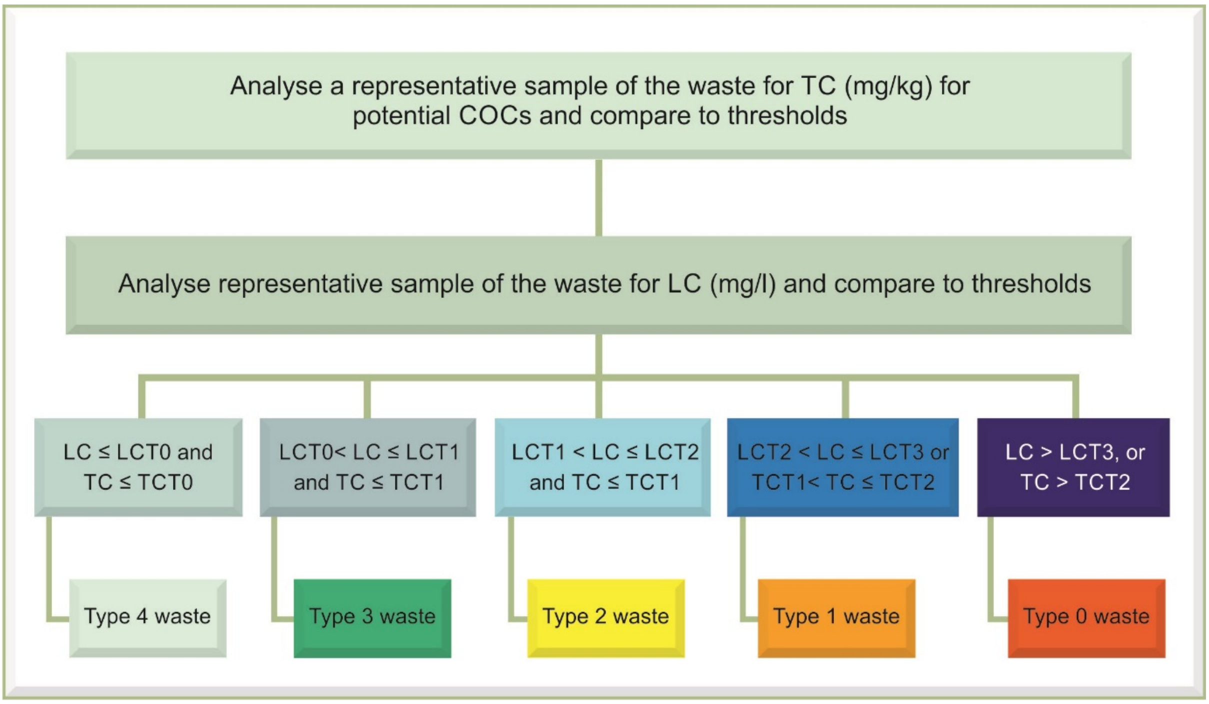

Figure 4: Waste Assessment flow diagram

5.2 National Water Act, 1998 (Act 36 of 1998) (NWA)

5.2.1 Water Use Licence

The National Water Act, 1998 (Act 36 of 1998) (NWA) was promulgated in 1998. In terms of Chapter 4, section 22 of the NWA, an applicant may only make use of water if the particular water use is a permissible water use as defined in terms of the NWA. The authorisation in terms of Chapter 4 of the NWA may be in the form of one of the following:

- Water Use Licence;
- General Authorisation;
- Permissible water use under Schedule 1 of the Act; and
- The responsible authority dispensed with a licence requirement.

The NWA defines the following eleven water uses in section 21 of the Act:

a. Taking water from a water resource;
b. Storing water;
c. Impeding or diverting a flow of water in a watercourse;
d. Engaging in a stream flow reduction activity contemplated in section 36;
e. Engaging in a controlled activity identified as such in section 37(1) or declared under section 38(1);
f. Discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit;

g. Disposing of waste in a manner which may detrimentally impact on a resource;
h. Disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation;
i. Altering the bed, banks, course or characteristics of a watercourse;
j. Removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people; and
k. Using water for recreational purposes.

After consultation with the Department of Water and Sanitation (DWS), it is envisaged that the 21(g)-water use will be triggered by backfilling (Disposing of waste in a manner which may detrimentally impact on a resource). Section 21(h) and Section 21(c&i) may also come into play depending on the specific application and the associated infrastructure:

- S 21(h): Disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation;
- S 21(c): Impeding or diverting a flow of water in a watercourse; and/or;
- S 21(i): Altering the bed, banks, course or characteristics of a watercourse.

A water use assessment is recommended for each project in order to confirm the water uses that trigger a Water Use Licence.

The Water use licence application and appeals regulations, 2017, GN. R. 267, *GG 40713,* 24 March 2017 (GN. R. 267 of 2017) provides the legal framework for a water use licence application (WULA). The prescribed process commences with a pre-application consultation meeting with the Department of Water and Sanitation (DWS) where, *inter alia, the* proposed water uses, public participation requirements and information requirements are discussed and clarified. The pre-application meeting is followed by submission of an application in the prescribed form as set out in Appendix B of GN. R.267. Submission of the form is followed by a site inspection by a DWS case officer; confirmation of water uses and technical reporting requirements; compilation of the WULA and agreed technical reports; public participation; and submission of the WULA to the DWS.

5.2.2 GN. 704 of 1999

Regulations on use of water for mining and related activities aimed at the protection of water resources, GN. 704, *GG 20119,* 4 June 1999 (GN. 704 of 1999) published under the NWA should also be considered during the authorisation process as well as during implementation. Section 4 (c) of GN. 704 states that: "*No person in control of a mine or activity may place or dispose of any residue or substance which causes or is likely to cause pollution of a water* *resource, in the workings of any underground or opencast mine excavation, prospecting diggings, pit or any other excavation*."

However, backfilling can be motivated in terms of section 11 (a) and (b):
"Any person mining or establishing coal residue deposits must rehabilitate such residue deposits so that-

(a) all residue deposits are compacted to prevent spontaneous combustion and minimise the infiltration of water; and
(b) the rehabilitation of the residue deposits is implemented concurrently with the mining operation."

5.3 National Environmental Management Act, 1998 (Act 107 of 1998)

The National Environmental Management Act, 1998 (Act 107 of 1998) (NEMA) is South Africa's framework environmental legislation. It encompasses a set of principles that govern environmental management and against which all Environmental Management Programmes (EMPs) and actions are measured. These principles include and relate to sustainable development, protection of the natural environment, waste minimisation, public consultation, the right to an environment that is not harmful to one's health or wellbeing, and a general duty of care. The latest amendment to NEMA, the National Environmental Management Amendment Act 2014 (Act No. 25 of 2014) was gazetted on 2 June 2014 and commenced on 2 September 2014.

5.3.1 EIA Regulations

The current Environmental Impact Assessment Regulations, 2014, GN. R. 982 (GG 38282, 4 December 2014 (as amended)) outlines the BA or EIA processes to be undertaken when applying for an Environmental Authorisation (EA). Listing Notice 1 (GN. R. 983) (as amended) lists those activities for which a BA is required. Listing Notice 2 (GN. R. 984) (as amended) lists the activities requiring a full EIA (scoping and environmental impact reporting process). Listing Notice 3 (GN. R. 985) (as amended) lists activities and competent authorities in specified geographical areas.

It is anticipated that activities associated with using ash and brine to backfill disused mines will trigger several listed activities associated with, *inter alia;* infrastructure requirements; transportation; storage and handling; and mine decommissioning and closure. Depending on the activity that is triggered, either a BA or EIA process will be required. A public participation process as stipulated in the EIA Regulations and NEMA will also be required.

It must further be noted that independent compliance audits of all EAs and performance assessment of the EMPr must be undertaken in accordance with the frequency specified in the EA. Audit intervals may not exceed 5 years. If, after conclusion of an audit, it transpires that the measures to mitigate environmental impacts are insufficient or that there is insufficient compliance with the EA, the EMPr must be aligned and updated as per the requirements of regulation 35 of the EIA Regulations, 2014 (as amended). Amendments to an EMPr, unrelated to an audit, can also be made under regulations 36 and 37.

The EIA Regulations further stipulate under regulation 26 (h) that EAs, EMPrs and findings of independent audit reports submitted to the authorities must be made available on site, on request or where possible on a publicly accessible website.

5.3.2 Financial provisioning regulations (GN. R.1147 of 2015)

The Regulations pertaining to the financial provision for prospecting, exploration, mining or production operations, GN. R.1147, *GG* 39425, 20 November 2015 (as amended) created a framework for the determination and management of the costs associated with closure, rehabilitation and decommissioning. All mines will be required to comply with reporting requirements of GN. R.1147 by 19 February 2019.

5.4 Mineral and Petroleum Resources Development Act, 2002 (Act No 28 of 2002) (MPRDA), as amended

In terms of section 22 of the Mineral and Petroleum Resources Development Act, 2002 (Act 28 of 2002) (MPRDA), any person who wishes to apply for a mining right must simultaneously apply for an environmental authorisation. The application must be supported by environmental reports as required under Chapter 5 of NEMA and a public participation process as set out in the NEMA EIA Regulations, 2014 (as amended). Under this legislative regime, a mining right application must therefore be submitted along with an Environmental Management Programme (EMPr).

It is envisaged that the applicant will have to submit an EMPr amendment to accommodate new activities associated with a backfilling project, their impacts, management measures and associated costs. The EMPr amendment process will require a section 102 application in terms of the MPRDA, to be submitted to the DMR via the SAMRAD online application portal (portal.samradonline.co.za). A basic public participation process is required for a section 102 application. While the MPRDA is not particularly prescriptive regarding the public participation process, it is accepted that the NEMA process may be followed, thus the public consultation methodology should be in line with the EIA Regulations, 2014 (as amended).

In terms of regulations 53 and 54 of the Mineral and Petroleum Resources Development Regulations, GN. R.527, GG 26275, 23 April 2004 (as amended), the holder of a mining right must make financial provision, in a manner acceptable to the DMR, for the rehabilitation of negative environmental impacts, both for planned closure at the end of the life of the mine, and for an unplanned closure during the life of the mine. Regulations 53 and 54 are applicable to mining companies that obtained their authorisations prior to November 2015. All authorisations granted by the DMR after November 2015 must comply with the requirements of GN. R.1147 of 2015.

Depending on the circumstances, the ash and brine backfill activities may be associated with a MPRDA section 43 closure application. In these circumstances, an applicant is required to lodge a closure application within 180 days of cessation of operations. The application must be supported by, inter alia:

- A Basic Assessment Report;
- Final Rehabilitation Plan;
- Final Decommissioning and Mine Closure Plan;
- EMPr Performance Assessment Report; and
- Financial provision for final rehabilitation and environmental risk report.

5.5 National Heritage Resources Act, 1999 (Act 25 of 1999)

If any structures older than 60 years need to be demolished (for example a shaft-head), a permit under the National Heritage Resources Act, 1999 (Act 25 of 1999) will be required from the South African Heritage Resources Agency.

5.6 Anticipated authorisations required for backfilling

The anticipated authorisations that will be required for different mines considering backfill can be summarised as follows:

5.6.1 For Operating or disused mine:

- The Generator of the ash and/or brine:
  - Waste Exclusion from the definition of waste (GN. 715 of 2018: Waste Exclusion Regulations).
- The Receiver of the ash and/or brine:
  - Section 21(g) WULA and other applicable WULs;
  - Application for an EA under NEMA, supported by either a BA or EIA process; and
  - EMPr Amendment.

5.6.2 For Abandoned mines:

- The Generator of the Ash and/or Brine is assumed to be a going concern: Waste Exclusion from the definition of waste (GN. 715 of 2018: Waste Exclusion Regulations);
- The Receiver of the ash and/or brine will in this case be abandoned mines. In this case the State will appoint an implementing agent to decommission the mine(s). The implementing agent therefore apply for the;
  - GN. Section 21(g) WULA and other applicable WULs; and
  - Application for an EA under NEMA, supported by either a BA or EIA process; and
  - To commence with the MPRDA section 43 closure application at the appropriate time.

5.7 Application and authorisation process

Figure 5-7 show the Regulatory Roadmaps for the application to use ash and paste as backfill material. Figure 6 and Figure 7 include details for an Air Emission Licence (AEL) and Waste Management Licence (WML). This information is included in the EIA and BA diagrams as well should activities to be undertaken trigger an AEL. It is however not foreseen, based on the information currently available, that an AEL will be required. Furthermore, the permitting information for a WML is included in the event that the application for Waste Exclusion under GN. 715 does not succeed.

5.7.1 Waste Exclusion Regulations, 2018

According to section 5 of GN. 715 of 2018, an application must be submitted to the Minister by using an application form obtainable from the DEA and published on the South African Waste Information Centre (SAWIC) web page (http://sawic.environment.gov.za/?menu=75). The following details need to be provided with the application: according to Sections 8 and 9 of GN. 715 of 2018:

- Information that the waste stream or portion thereof is being used or has been used for a specific beneficial purpose either locally or internationally;
- Production process flow chart;
- SANS10234 waste classification (GN R. 634 of 2013);
- A risk assessment providing information on the waste and demonstrating that the use of the specific waste can be managed in such a way as to ensure that the use will not result in significant adverse impacts to the environment; and
- A risk management plan responding to the risks identified in the risk assessment.

A waste assessment (GN R. 635 of 2013) is not explicitly required in terms of GN. 715 of 2018 – given that:

- If the application is successful, the material will not be considered as waste and will therefore not have a waste Type, and
- A waste assessment is a precautionary (threshold-based) assessment, whereas Section 8 requires a risk assessment.

Nevertheless, a waste assessment may well be useful information to include in an application, as a point of departure before carrying out the risk assessment, and in order for a simple comparison to be made with other materials.

After all information and the application form has been submitted to the DEA, a letter of receipt will be sent to the applicant. The DEA will then consider the application and request additional information if required. A consultative process needs to be followed by the DEA, including Public Participation. Once the application is granted, the DEA needs to publish the exclusion in the Government Gazette.

5.7.2 WULA Regulations, 2017

In line with the Water use licence application and appeals regulations, 2017, (GN. R. 267 of 2017) an application for a NWA section 21 (g) WULA must be made. Following a pre-application consultation meeting with the DWS the proposed water uses, public participation requirements and information requirements will be discussed and clarified. The pre-application meeting will be followed by submission of an application in the prescribed form as set out in Annexure B of GN. R.267. Submission of the form will be followed by a site inspection by a DWS case officer; confirmation of water uses and technical reporting requirements; compilation of the WULA and agreed technical reports; public participation; and submission of the WULA to the DWS.

The applicant must also demonstrate compliance to GN. 704 of 1999 as detailed above in section 5.2.

5.7.3 EMPr Amendment under NEMA and MPRDA

The EMPr of the mine should be amended for the backfill process and submitted to the DMR under a section 102 application supported by a public participation process under the NEMA EIA Regulations, 2014 (as amended). This process is outlined in section 5.4.

5.7.4 Application for environment authorisation under NEMA

Once a full description of the proposed activities is available, it can be determined which listed activities under the NEMA EIA Regulations Listing Notices 1 or 2, 2014 (as amended) are triggered. Depending on which listing notice is applicable, either a BA or EIA process will be required in order to obtain an EA. This process must include a public participation process as outlined in NEMA and the EIA Regulations, 2014 (as amended). Further details regarding an application for an EA are set out in section 5.3 above.

The beneficial use, water use, and listed activities cannot commence before receipt of the following:

- An exclusion granted by the DEA has under GN. 715 of 2018;
- A WUL granted by the DWS for the NWA section 21 (g) water use;
- An EA for listed activities triggered under NEMA; and
- An approved amendment of an existing EMPr under MPRDA section 102 and NEMA.

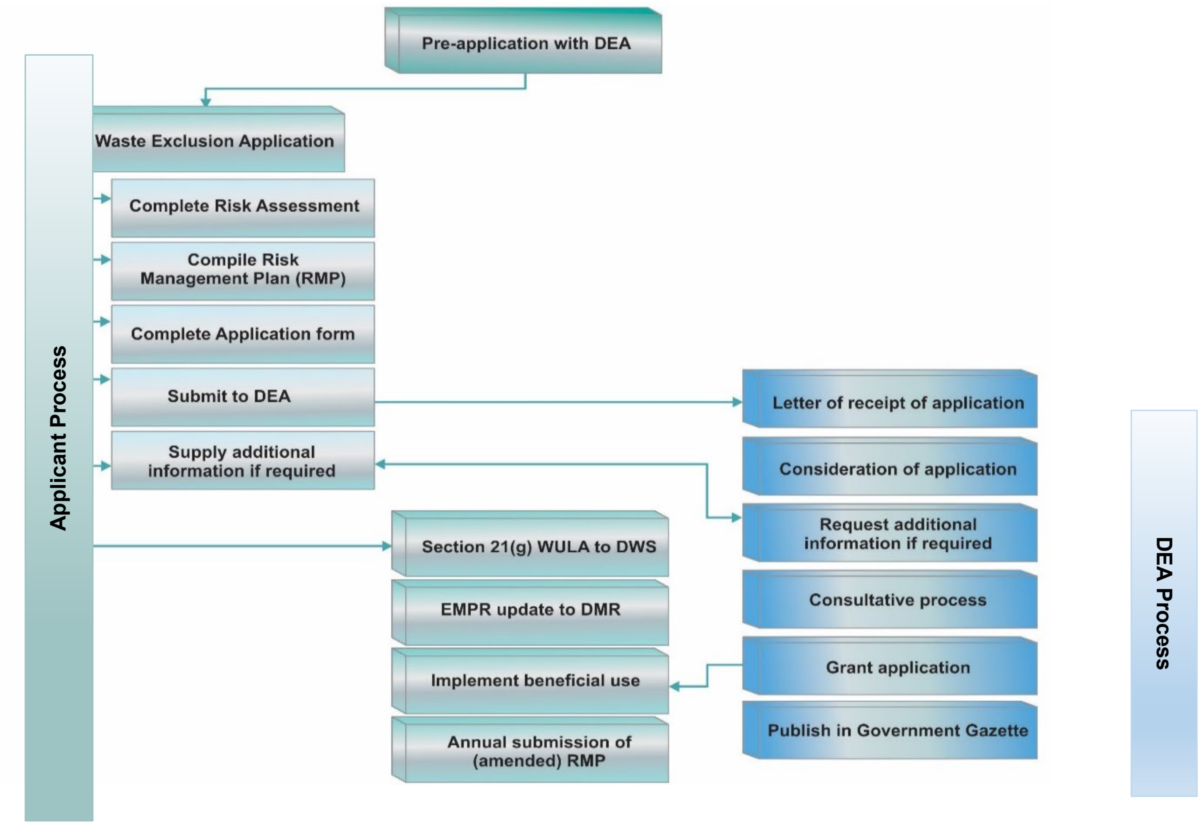

Figure 5: Regulatory Roadmap – Waste Exclusion Application by the Waste Generator

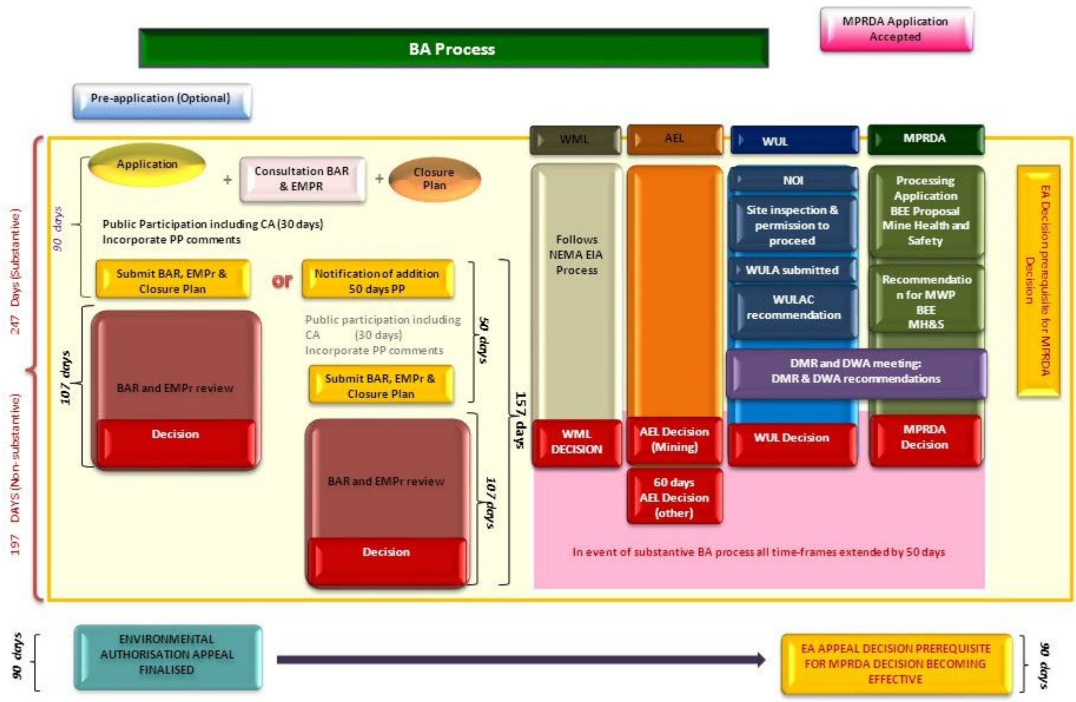

Figure 6: Regulatory Roadmap – BA Process (Source: DEA)

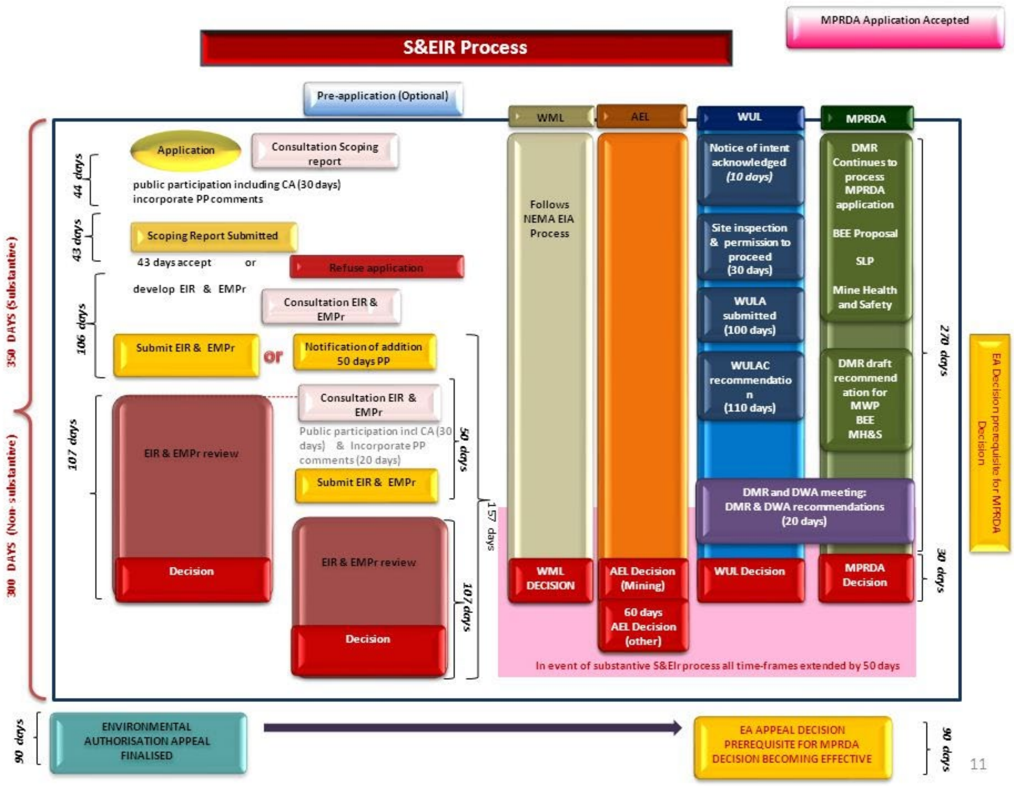

Figure 7: Regulatory Roadmap – EIA Process (Source: DEA)

5.8 Alignment to Closure Process

Active mines

For active mines with a current mining right, annual reporting will be required in terms of the Financial Provisioning Regulations (GN. R.1147 of 2015), consisting of the development and independent auditing of a Final Rehabilitation Decommissioning and Mine Closure Plan, Annual Rehabilitation Plan and Environmental Risk Assessment.

The Final Rehabilitation Decommissioning and Mine Closure Plan will assess the requirements that will be necessary to develop a stable and free draining backfilled landform. Specifically, it is important the post mining topography takes account of the ash backfilling so that materials movement is optimised and the final landform free draining, while any remaining overburden dumps not required for backfilling must be rehabilitation in situ.

The Annual Rehabilitation Plan would typically address the backfilling activities by indicating the surface area to be backfilled in the coming 12 months, whilst reflecting on the success of surface rehabilitation that was conducted on backfilled areas in the preceding period. It is noted that the costs for backfilling would probably be considered as an operational cost and would not impact notably on the financial provision of the mine, except for the concurrent surface rehabilitation (soil cover and vegetation) and monitoring activities to be included in the Annual Rehabilitation Plan.

The Environmental Risk Assessment will include any post closure, residual or latent environmental risks that could manifest due to the ash backfilling activities.

Abandoned mines

The regulatory closure context for ash disposal into abandoned mines is complicated and depends on the legislation that was enacted at the time the mine was operational, as well as whether the mine house that owned the mine still exists. It is recommended that the regulatory context of each abandoned mine to be used for ash backfilling be assessed on its own merits and a customised permitting strategy be devised.

5.9 Enabling Document requirements

The following enabling documents are required under the current environmental legislative regime:

Authority	Authorisation	Report	Submission by	Reporting Frequency
DEA	Waste Exclusion	Risk Management Plan Report volumes of waste used beneficially	Waste generator	Annual
DWS	WUL	Independent Audit	Waste User	As stipulated in WUL
DMR	Amended EMPr	Independent Performance Assessment	Waste User	As stipulated in EMPr
DMR	EA	Independent Audit	Waste User	As stipulated in EA

6 NET ENVIRONMENTAL BENEFIT (NEB)

The use of ash as a backfilling material may be further justified if, in addition to compliance with applicable environmental regulations (discussed above), a net environmental benefit can be realised. For this purpose, the NEB is defined here as the difference between

- The environmental risk resulting from a proposed mine backfilling operation when compared to.
- The environmental risk resulting from an alternative arrangement that would be required to manage the materials that would otherwise be placed in the mine void, as well as the ultimate impacts associated with the mine void itself if it was not backfilled.

Therefore, for a net benefit to exist, the combined total life cycle environmental risk of the backfilling system must exceed the combined total life cycle environmental risk of the alternative system (which comprises, for example, a surface ash disposal facility and a mine void which has not been backfilled). The concept therefore encompasses the following principles:

- *Combined risk:* The ash and brine materials under consideration has the potential to impact all the media that it comes into contact with. It is therefore necessary to evaluate the combined risk on surface water, groundwater, air and soils.
- *Total life cycle risk:* A rational evaluation should aim to include the total life cycle of the mine backfilling system in comparison to the alternative system throughout the entire life cycle of each. This necessitates a projection of expected performance into the future for both systems.

The NEB concept recognizes that there are risks and benefits associated with all options for managing ash and brine. The Tier I evaluation thus evaluates the synergistic benefit (the NEB) that results from backfilling a disused or abandoned mine compared to the alternative systems required to manage the materials if backfilling is not practiced. The mine backfill operation is evaluated in terms of risks to the receiving environment. The result obtained is then compared to the sum of the individual risks posed by:

- The unfilled void of the disused/abandoned mine; and
- An equivalent surface-based ash (and, where applicable, brine) disposal systems.

If the backfilled mine poses a risk less than the sum of these two individual risks, a NEB is demonstrated.

To illustrate the application of the NEB, an example of a typical conventional ash and brine management system is described (Figure 8) and compared to generalised hypothetical examples of backfilling operations involving a paste (Figure 9) and a slurry (Figure 10). The description of these systems is aided by the labels shown in the figures and described in the sections that follow. These examples are not intended to capture all possible variations that may be found in industry although a few alternatives are described in the discussion. The intent is to provide the reader with an example of how a NEB may be demonstrated for the facilities depicted in the diagrams. The risks and benefits of a specific case will of course rely on the details that apply to the case in question.

6.1 A conventional ash and brine management system

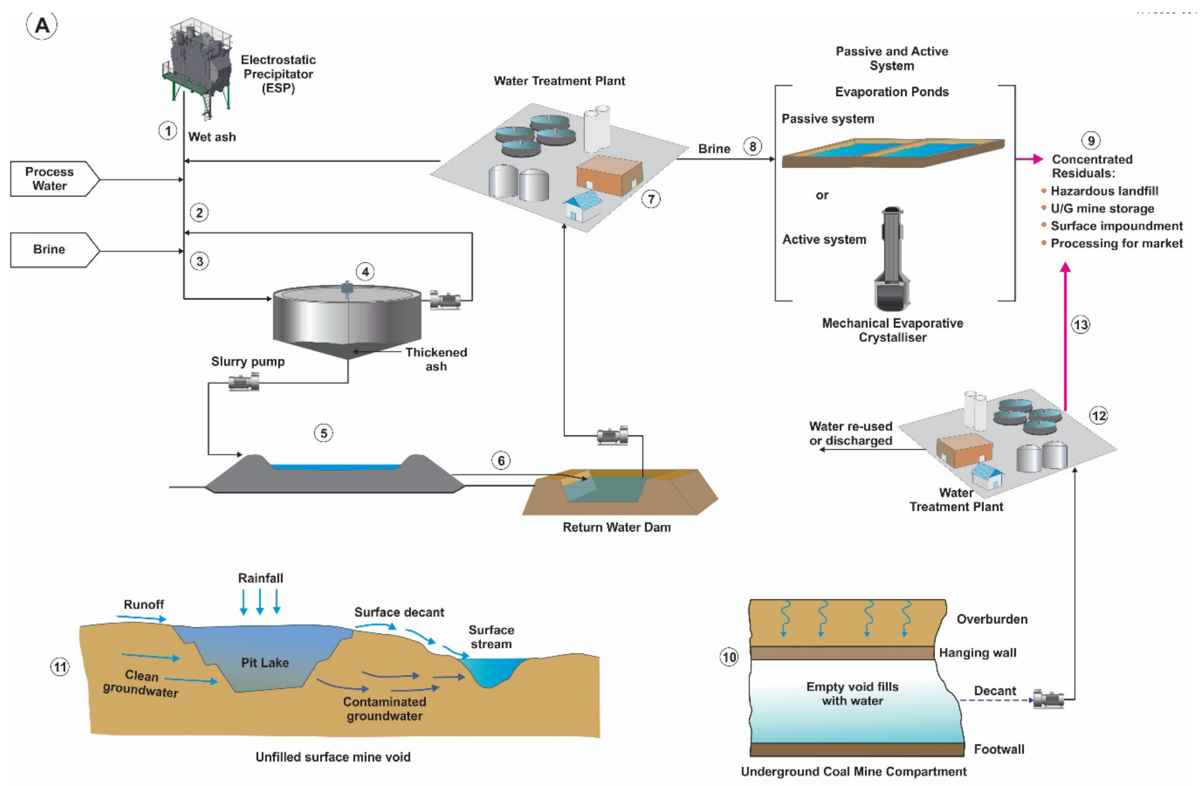

Figure 8: Example of a conventional ash and brine management system

A1: Fly ash is formed during the combustion of pulverized coal and is carried downstream of the boiler in the flue gas stream. The fly ash is separated from flue gas by an electrostatic precipitator (ESP) and collected in hoppers located below the ESP plates. In the example depicted here the hot fly ash is then collected in a wet sluicing system equipped with a hydraulic vacuum (Hydrovac).

A2: Water is used in a wet ash removal system to convey ash away in a dilute slurry. The water used for this purpose is often re-used from other processes in the facility and includes excess water returned from hydraulic ash placement in ash disposal facilities. For example, cooling water blow down or waste water produced during boiler feed water preparation are examples of streams used for ash collection and transport. The typical water to ash ratio at the point of contact with the dry ash is relatively large (around 10-20 times) and can vary considerably from one facility to the next.

A3: The option to dispose of brine generated from water recovery operations into the ash slurry stream is practiced in some facilities. The higher salinity of this stream favours precipitation of salts and at the same time inhibits dissolution of contaminants from the ash.

A4: Ash slurry is thickened in a gravity thickener for conveyance to the disposal facility. The aim of this unit operation is to optimize the water content of the ash to achieve a balance between ease of pumping and minimization of the mass of material to pump. Ash content in the underflow may vary over a wide range from one facility to the next. (Around 50% ash content is often reported as optimal but 20% is possible).

A5: Thickened ash slurry is hydraulically placed in an ash dam. Ash sinks to the bottom of the ash dam pool and forms beaches at the edges. Excess water separates from the ash and is conveyed away from the ash dam through a penstock. A certain amount of water is trapped in the ash as interstitial water. Long term geochemical reactions take place between the ash and contaminants carried in the ash transportation water resulting in the formation of a complex array of reaction products. The typical wet ash dam is operated as a mostly saturated facility over its operating life due to the constant presence of a pool of water at the top of the dam.

A6: Excess water separated from ash is returned for re-use in the process via a return water dam. The fact that this system produces an excess amount of water is only partly the result of the need for water used for ash slurry pumping but in addition, significant quantities of run-off water from rain is collected in the system. This effect is a direct result of the comparatively large footprints associated with surface ash disposal systems which includes the ash dam as well as the return water dam.

A7: In many, if not most climates the water balance requires that the system be equipped with a water treatment plant (*e.g.* membrane desalination) to maintain water levels and prevent un-controlled discharge of contaminants to the environment. The clean water recovered is re-used in the process and contributes to a general increase in the water use efficiency of the facility.

A8: The water treatment plant produces a brine requiring further management. Various options exist but can generally be classified as active or passive. The use of lined evaporation ponds is an example of a passive brine management option that relies on solar energy and wind to drive evaporation of excess water from brines resulting in a smaller brine volume (but higher salinity). An example of an active process is a mechanical evaporator equipped with a crystallisation stage which requires significant energy input in the form of mechanical and thermal energy. In both the active and passive cases, a final concentrated residual requires further management.

A9: A final waste is produced in the form of concentrated residuals (hyper-saline brines or dry salt cake). Options for disposal needs careful consideration as this material is likely hazardous and highly soluble and therefore mobile. Technology options exist that can produce saleable salts that can be sold to offset some of the cost associated with brine evaporation.

A10: The underground mine compartments in the conventional example are not backfilled. An unfilled mine void is left intact after mining ceases. Over time this void fills with water due to infiltration through overburden layers that are prone to cracking as subsidence is triggered by failing mine pillars. The water is typically contaminated with salinity and metals and is often acidic. The emergence of mine drainage decant stream on the surface is a well-documented phenomenon. The contaminated mine water is pumped to a water treatment plant.

A11: In the case were surface mining was practiced the mine void is recharged with rain water, surface runoff and regional groundwater infiltration. Coal discard is typically found in or close to the surface mine void. A decant stream results that require further management.

A12: Excess contaminated mine water is treated for re-use or discharge to the environment. The water treatment plant is similar to the plant required for ash water recovery, but certain differences will exist as the chemistries of the two streams normally differ significantly the most obvious being that ash water is typically highly alkaline with mine drainage tending to range from near-neutral to acidic.

A13: As with excess ash water, treatment of mine decant water results in concentrated residuals requiring safe disposal.

6.2 A hypothetical ash and brine paste backfilling system:

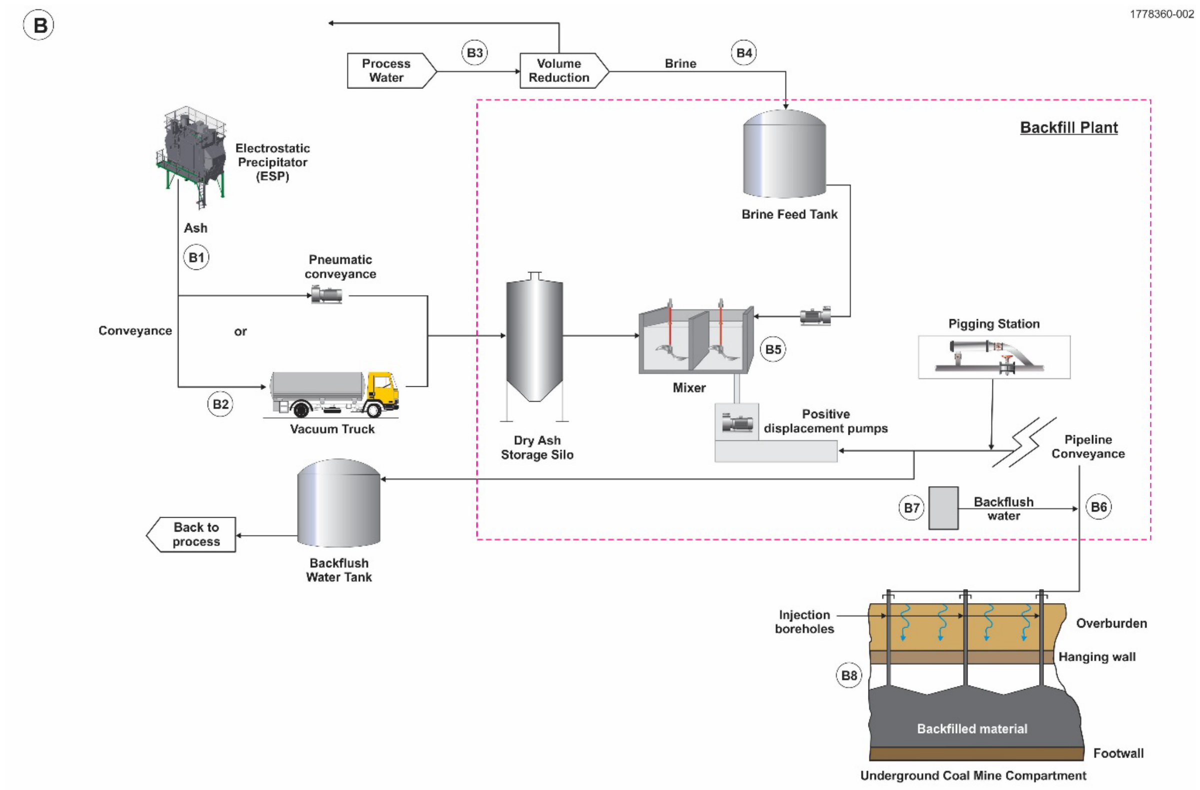

Figure 9: Example of a paste backfilling process flow diagram

B1: Ash is collected from the ESP hoppers in dry form preserving its pozzolanic reactivity for beneficial reactions that benefit the backfilling operation (e.g. strength gain, lowered permeability and stabilization of brine.

B2: Dry fly ash conveyed to the backfill plant by pneumatic conveyance or by truck. The most suitable option will rely on factors such as the distance that the ash is required to be conveyed and the quantity of ash required to achieve the mine backfill objectives. The dry ash is stored in a silo ready for use in the backfill preparation operation.

Although not shown in the example it is possible to add other dry additives to the backfill mix design. Examples of additives include lime, gypsum, clays, ordinary Portland cement (OPC), speciality cements, sorbents and aluminates.

B3: Process waste water is treated in a volume reduction process (*e.g.* desalination and/or thermal evaporation) to reduce fly ash demand as dictated by the optimal mix design of the backfill material and chemistry of the brine produced. Clean water is recovered for re-use and returned to the process.

B4: Brine is conveyed to the backfill plant and stored in a brine feed tank ready for mixing with fly ash.

B5: Brine and ash is combined in a mechanical mixer according to a mix design resulting from extensive prior testing. The resultant mixture is blended to a consistency suitable for backfill objectives (*e.g.* a flowable paste or high density slurry that can be pumped for the required distance and will achieve the desired in-situ characteristics required in the mine void over the long term).

B6: The backfill mix is conveyed to the underground mine via a pipeline and a positive displacement pump where it is injected into the empty mine workings via surface boreholes.

B7: Because the backfill mixture is a reactive cementitious material, backflush equipment and pigging stations are installed on the pipeline to prevent line blockages forming as a result of process interruptions.

B8: The backfilled underground mine compartment is formed as backfill material flows into an empty mine void and assumes its resting form as determined by the beaching angle of the material and cures in place. The mine void is filled to the maximum degree possible. Subsidence risk and water ingress could therefore be potentially limited. Acid rock drainage formation can be decreased due to a smaller surface area of rock for the reactions to take place on (reduction of contact between groundwater and mine compartments), as well as decrease in recharge and mine water flow and the addition of neutralising materials. Active mines could potentially also benefit from backfilling of mined out areas. For example, the backfill material could become the pillars and the resource still present in the original pillars can be accessed.

6.3 A hypothetical ash and brine slurry backfilling system:

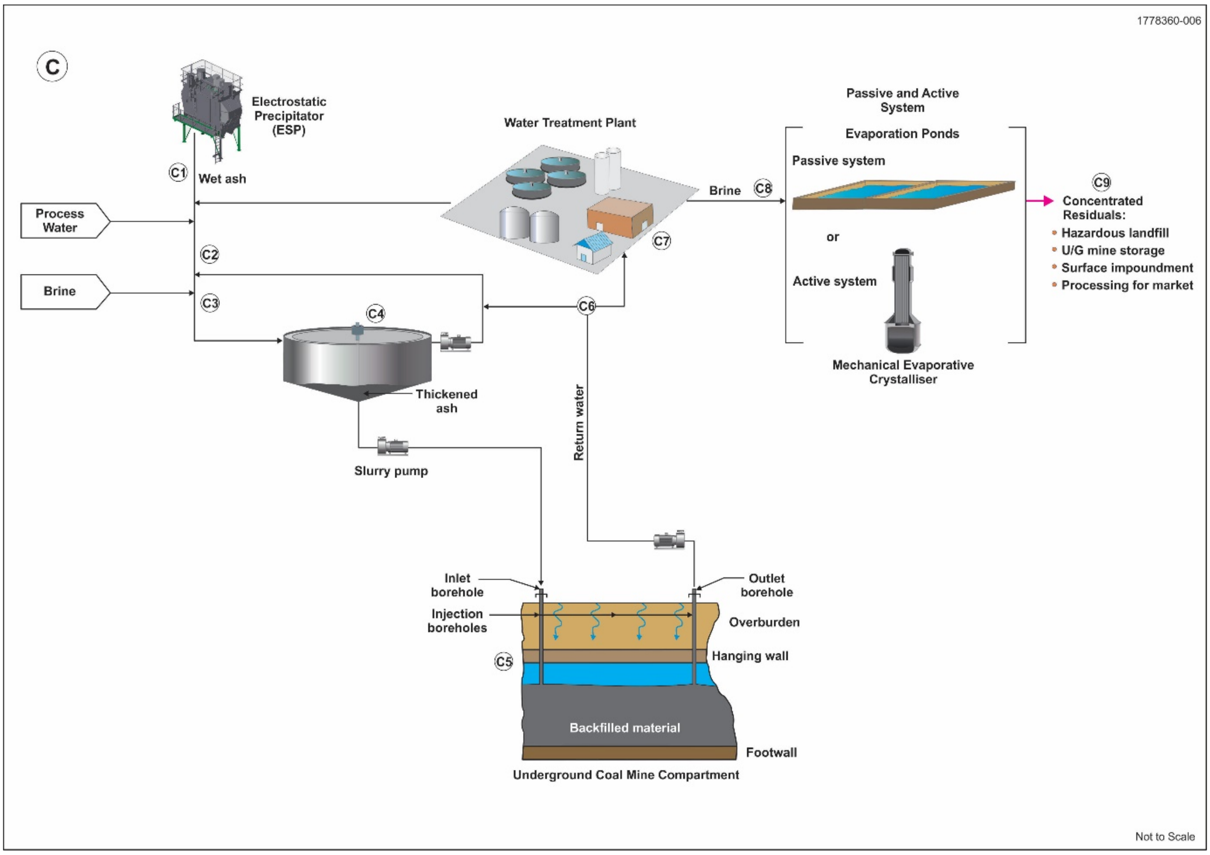

Figure 10: Example of a slurry backfilling process flow diagram

C1: Fly ash is formed during the combustion of pulverized coal and is carried downstream of the boiler in the flue gas stream. The fly ash is separated from flue gas by an electrostatic precipitator (ESP) and collected in hoppers located below the ESP plates. In the example depicted here the hot fly ash is then collected in a wet sluicing system equipped with a hydraulic vacuum (Hydrovac).

C2: Water is used in a wet ash removal system to convey ash away in a dilute slurry. The water used for this purpose is often re-used from other processes in the facility and includes excess water returned from hydraulic ash placement in ash disposal facilities. For example, cooling water blow down or waste water produced during boiler feed water preparation are examples of streams used for ash collection and transport. The typical water to ash ratio at the point of contact with the dry ash is relatively large (around 10-20 times) and can vary considerably from one facility to the next.

C3: The option to dispose of brine generated from water recovery operations into the ash slurry stream is practiced in some facilities. The higher salinity of this stream favours precipitation of salts and at the same time inhibits dissolution of contaminants from the ash.

C4: Ash slurry is thickened in a gravity thickener for conveyance to the underground coal mine compartment. The aim of this unit operation is to optimize the water content of the ash to achieve a balance between ease of pumping and minimization of the mass of material to pump. Ash content in the underflow may vary over a wide range from one facility to the next. (Around 50% ash content is often reported as optimal but 20% is possible).

C5: Thickened ash slurry is hydraulically piped to an underground coal mine compartment. At this point the thickened slurry enters the mine compartment through an inlet borehole. Depending on the water to ash ratio chosen by the operation the slurry will settle in the mine compartment and segregation will occur between solids (ash) and liquids (ash water). Due to this being a slurry there will always be a layer of water separating (Non-Newtonian fluid) and ponding above the settled ash solids, which will not occur with a paste (Newtonian fluid). The quantity of this water layer will depend on the level of thickening (i.e. solid-to-liquid ratio) that can be achieved during the thickening process. The period of settling that occurs when the slurry is underground could potentially result in salt sinking, which would be similar to what occurs in the ash dams with interstitial water being trapped in the ash which enhances geochemical reactions, etc. The amount of time that the water is allowed underground before being pumped back up through the outlet borehole will have an impact on the salt sinking capacity of the ash (i.e. mineral phase formation limited by reaction kinetics).

C6: The excess water from the mine compartment will need to be pumped out through the outlet borehole, and can be considered to be analogous to return water that one would expect to get from the return water dams (Figure 8). However, at the C6 junction the operations could have a lever in which the return water could be diverted back to the thickener so that a closed loop occurs, or the return water can be diverted to the water treatment plant. The choice of which route to follow will depend largely on the quality of return water and the water balance and demand of the entire system. A decision of whether the return quality water meets the standards for water treatment or not after slurry backfilling will need to be assessed. If the water treatment route is chosen, then the process will follow the conventional system (i.e. C7, C8 and C9).

C7: In many, if not most climates the water balance requires that the system be equipped with a water treatment plant (*e.g.* membrane desalination) to maintain water levels and prevent un-controlled discharge of contaminants to the environment. The clean water recovered is re-used in the process and contributes to a general increase in the water use efficiency of the facility.

C8: The water treatment plant produces a brine requiring further management. Various options exist but can generally be classified as active or passive. The use of lined evaporation ponds is an example of a passive brine management option that relies on solar energy and wind to drive evaporation of excess water from brines resulting in a smaller brine volume (but higher salinity). An example of an active process is a mechanical evaporator equipped with a crystallisation stage which requires significant energy input in the form of mechanical and thermal energy. In both the active and passive cases, a final concentrated residual requires further management.

C9: A final waste is produced in the form of concentrated residuals (hyper-saline brines or dry salt cake). Options for disposal needs careful consideration as this material is likely hazardous and highly soluble and therefore mobile. Technology options exist that can produce saleable salts that can be sold to offset some of the cost associated with brine evaporation.

6.4 Potential NEB of backfilling

The potential NEB of mine backfilling with fly ash and/or paste can include:

- Decreasing waste disposal requirements;
- Decreasing ground fissuring;
- Increasing long-term strata stability and providing roof support which could potentially limit subsidence*;
- Decreasing spontaneous combustion;
- Decrease the quantity of decant;
- Speed up the time until decant takes place, with the potential advantage of managing the decant sooner, possibly during the operating life of the system;
- Decreasing the system's land take**;
- Improvement of the quality in mine affected water, due to:
    - Decrease in the formation of acid rock drainage ARD (also known as "acid mine drainage", AMD), or
    - Neutralisation of ARD by the backfill material; and

- Decreasing illegal mining when voids are backfilled.

* Subsidence will still occur unless the strength of the backfill material exceeds that of unmined ground but backfilling the void can decrease the space into which overburden can fall, thus decreasing the surface expression of subsidence and decrease the incidence of sinkhole and fissure formation. This also decreases the risk of breaking the aquifer units in overlying rock.

** Backfilling leaves the footprint of surface placed ash bodies available for other economic activities[1] and in the case of mines enveloped by housing, a safer environment for housing compared to the unacceptable surroundings of some informal settlements where open cavities and dust generating ash dumps are prevalent. This is especially applicable for abandoned mines where closure is considered, contributing to transformation and redress and empowering communities to participate in economic activities. Furthermore, the impact on groundwater quality could be decreased through backfilling.

6.5 Tier I NEB evaluation

For a Tier I assessment the evaluation will be qualitative, achieved by developing a list of criteria applicable to the site for which the backfilling operation is contemplated, weighting the criteria and scoring the two systems according to the best available knowledge. If the total score for benefits outweighs the score for risk, it can be argued that a NEB has been qualitatively demonstrated. This methodology can be subjective in nature and should ideally include subject matter experts from various disciplines to minimize potential bias.

The comparison of these two example systems require the identification of benefits and risks associated with the different aspects both common and unique to the systems. An example of NEB evaluation is shown in Table . The NEB need to be presented in terms of the following environmental and socio-economic aspects:

- Change in mine-affected water quality;
- Change in recharge and/or decant;
- Groundwater impact (ARD, change in pH, mobilisation of constituents of concern, increased suspended solids);
- Surface water impact (decant of contaminated mine water into environment, contaminated storm water, change in pH, change in concentrations of constituents of concern and TDS);

[1] This assumes that the soils and groundwater underneath the old ash dam footprint is rehabilitated to remove legacy contamination

- Land take (loss of agricultural, forest and other semi-natural and natural land to urban and other artificial land development);
- Next land-use;
- Resource reduction/sterilization;
- Biodiversity;
- Air quality & dust;
- Socio-economic impact including visual & noise; and
- Need for perpetual water treatment post-closure of mine and power plant facilities.

Table 2: Example of NEB evaluation

Aspect	Figure label	Conventional System		Mine backfill System	
		Benefit	Risk	Benefit	Risk
Ash collection and conveyance	A1, B1, A4, B2	• Wet ash removal mitigates dust emission risks. • A well-known and proven technology. Many years of operating experience exist in the industry.	• High liquid to solids ratio favours leaching of contaminants and partitioning to the water phase. • Pozzolanic reactivity of the ash is largely quenched in the wet system leading to a loss in potential for realising beneficial physical properties.	• Dry ash removal preserves ash pozzolanic reactivity for contaminant immobilization and strength gain	• Dry ash (prior to mixing of a slurry, if applicable) more prone to dust emissions • Conveyance associated with backfill will likely be longer (farther away) than for conventional system
Ash disposal and associated impoundments	A5, A6	• Disposal system easily accessible for monitoring on surface	• Significant land-take • Larger footprint capturing and contaminating rainwater. • High pressure head in ash dam increases risk of groundwater contamination. • Ongoing vertical flow of water through the ash body transports contaminants out of the ash. • Risk of wind-blown dust	• No surface impoundments required. • Contamination of rain water is minimized or avoided • Risk of ash dam structural failure avoided • Significant reduction in risk of uncontrolled spills. • Avoidance of wind-blown dust. • Preservation or re-instatement of land-use. • Surface water contamination avoided.	• Monitoring of performance more challenging and requires more planning. • Remedial action following poor performance more complex and costly.
Water Treatment	A7, A12, B4	• Water becomes available for the process – decrease in water demand	• Higher total volumes of water requiring treatment (larger surface footprint and water make) • Increased volumes of contaminated mine water generated (higher imine ingress volumes)	• A less energy intensive process as volume reduction required for backfill is less than for brine management. • Hydration reactions consume free water thus reducing water volumes requiring treatment.	• Less volume equalization capacity is available (as there are no large dams). As a result, unscheduled outage of the water treatment process more directly affects upstream operations.

Aspect	Figure label	Conventional System		Mine backfill System	
		Benefit	Risk	Benefit	Risk
			• Higher energy demand to produce concentrated residuals. • Water treatment is required in perpetuity	• Need for water treatment associated with ash may cease once coal facility is closed and mine is backfilled.	• Need for water treatment associated with decant may be accelerated due to smaller mine void and thus faster decant.
Backfill plant	B5, B6, B7	• N/A	• N/A	• Reduced closure liability compared to ash dam facility • Plant becomes an asset	• Higher pressure pipeline and risk of blockages require closer monitoring
Final disposal of concentrated residuals	A13, B8	• Lower risk associated with nature technologies	• Highly soluble and mobile contaminants. • Additional energy demand to produce in a state ready for transportation and final disposal • Likely requires hazardous landfill facilities	• Immobilised in solid matrix of mine backfill material	• Long term performance of mix designs to be proved out
Mine void / Ground stability	A10, B8	• Can act as a groundwater pollution sink during operation	• Closure liability and physical hazard	• Acid rock drainage formation is decreased • Potentially limiting subsidence risk • Recued influx of surface and groundwater into mine workings	• If not well designed access to residual resources may be restricted

Section 27 of the NWA specifies that the following factors regarding water use authorisation must be taken into consideration:

- The efficient and beneficial use of water in the public interest;
- Socio-economic impact including redressing the results of past discrimination;
- Quality and quantity of the water in the water resource which may be required for the Reserve and for meeting international obligations;
- Alignment with the catchment management strategy especially in cases where the treated mine affected water forms part of the water allocation;
- Impact of the water use; and
- Investments made by the applicant in respect of the water use in question.

To inform the qualitative assessment detailed above, the source and the receiving environment needs to be investigated as detailed in Sections 7 and 8.

7 CHARACTERISATION OF MATERIALS (THE SOURCE)

7.1 Introduction

The characterization of materials required to develop mine backfill process envisaged here includes various tests conducted on both the input materials as well as the final product (*i.e.* solids and liquids added in the process).

The objective for the final product is to minimize the mobility of contaminants and to maximize beneficial physical properties such as strength and low permeability through a mix design process aimed at creating an engineered material. The investigator must develop an understanding of how the properties of the raw materials affect the properties of the final product, most often in an empirical fashion. This is achieved by exploring a range of mix recipes based on previous experience and published case studies, Mixtures are prepared, allowed to cure and the end product is subjected to testing to confirm performance.

The characterisation of fly-ash, brine as well as the paste and slurry are required. Figure 11 presents a photograph of fly ash from coal combustion, Figure 12 shows an image of a brine evaporation pond and Figure 13 of a paste made from ash and brine.

Figure 11: Fly ash (South African Coal Ash Association)

Figure 12: Brine pond

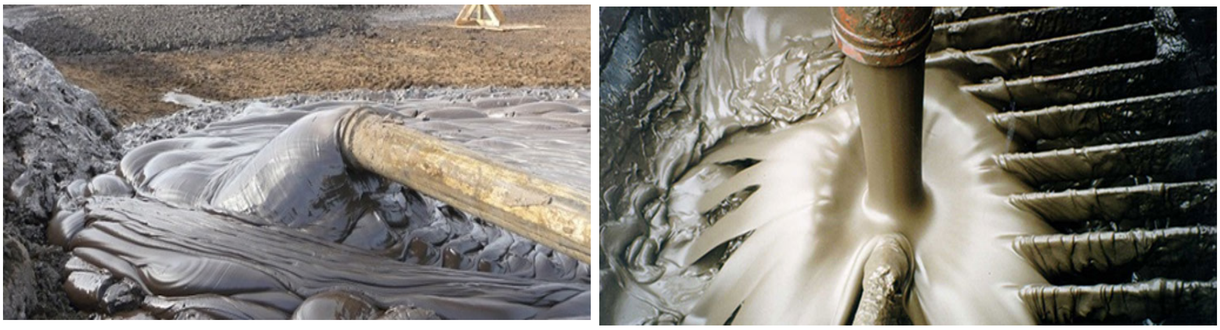

Figure 13: Paste (Golder Associates Paste Team)

In the context of this document, the assumption is that “fresh” (un-altered either physically or chemically and uncontaminated) ash will only be considered for backfilling. This does not imply that weathered ash found on old ash dumps cannot be backfilled, however it should be noted that the physical and chemical properties of the weathered ash together with the possibility of contamination due to waste co-disposal on these old dumps could potentially alter the properties of the ash which would have a direct impact on the backfilling of these materials. If any other ash source either then fresh ash is going to be considered for backfilling, then a comprehensive evaluation process will be required to determine the ash suitability. The same considerations apply to ash which has been codisposed with (typically small) quantities of other materials, e.g. gypsum.

7.2 Chemical Characteristics

7.2.1 Coal and Ash

Most coals contain pyrite, which is an acid-generating mineral whose abundance varies somewhat from site to site and from seam to seam. The neutralisation potential of a coal is due to the occurrence of carbonate minerals which can neutralise acid generated from sulphides in the coal. Since the carbonate minerals are often concentrated in veins and on cleats, their occurrence varies hugely from site to site, seam to seam and coalfield to coalfield, thus the long-term water quality of different collieries can be substantially different, although typically acidic or saline. In some cases, the quantity of carbonate minerals is sufficient to ensure that the resulting mine drainage is not expected to be acidic (Vermeulen and Dennis, 2009).

Backfilling a colliery's opencast pit or underground void will not in itself change the acid-generating or neutralising capacity of the coal, as neither paste nor ash slurry backfill contain minerals which would generate acid or react with neutralising minerals (Golder, 2015). However, ash itself has a neutralisation capacity, meaning that if acid drainage is generated from coal, it may be neutralised by the ash minerals. The chemistry of the resultant drainage is thus dependent upon the balance between acid generated from the coal (nett of neutralisation by carbonate minerals in the coal) against the neutralisation capacity of the ash. Although ash slurry may have the capacity to neutralise acid generated in some coal mines, it is leachable, producing an alkali and saline leachate (pH 8-12, TDS typically 1,000-10,000 mg/L; Golder, 2015).

7.2.2 Fly Ash characteristics

Fly ash is predominantly composed of materials formed at high temperatures under anhydrous, oxidising conditions, predominantly aluminosilicate minerals and glasses. These materials are therefore metastable and reactive and will transform to a more thermodynamically stable assemblage of minerals outside the conditions of the combustion site, for example on an ash dump where the minerals and glasses are exposed to much lower (ambient) temperatures, humidity and crucially, free water. It has been proposed that the weathering of coal fly ash is analogous to that of volcanic ash with the abundant aluminosilicate glass forming clay minerals during weathering (Pretorius *et al.,* 2011). As the material is weathered and hydration proceeds these contaminants become less mobile. The cementitious nature of the ash then makes it more stable.

There are two major technologies that can be used to generate electricity from coal, namely, fluidised bed combustion (FBC) and pulverised coal combustion (PCC). The principal difference between FBC and PCC technologies lies in the temperature and residence time of coal in the combustion chamber, which influence fly ash properties and usability. The characteristics discussed in this section is limited to fly ash produced by PCC boilers which is the common type of ash in South Africa.

Fly ash consists primarily of oxides of silicon, aluminium, iron and calcium (Table 3). Fly ash is classified as either Class C or Class F ash based on its chemical composition:

- Class C fly ash is generally derived from sub-bituminous coals and consist primarily of calcium alumino-sulphate glass, as well as quartz, tricalcium aluminate, and free lime (CaO). It typically contains >20% CaO; and
- Class F fly ash is typically derived from bituminous and anthracite coals and consist primarily of an aluminosilicate glass, with quartz, mullite ($3Al_2O_32SiO_2$ or $2Al_2O_3SiO_2$) and magnetite (Fe_3O_4) also present. It generally has < 10% CaO (ACAA, 2003)

Some of the major element chemical properties of South African fly ash are shown in Figure 14, and trace elements in Figure 15.

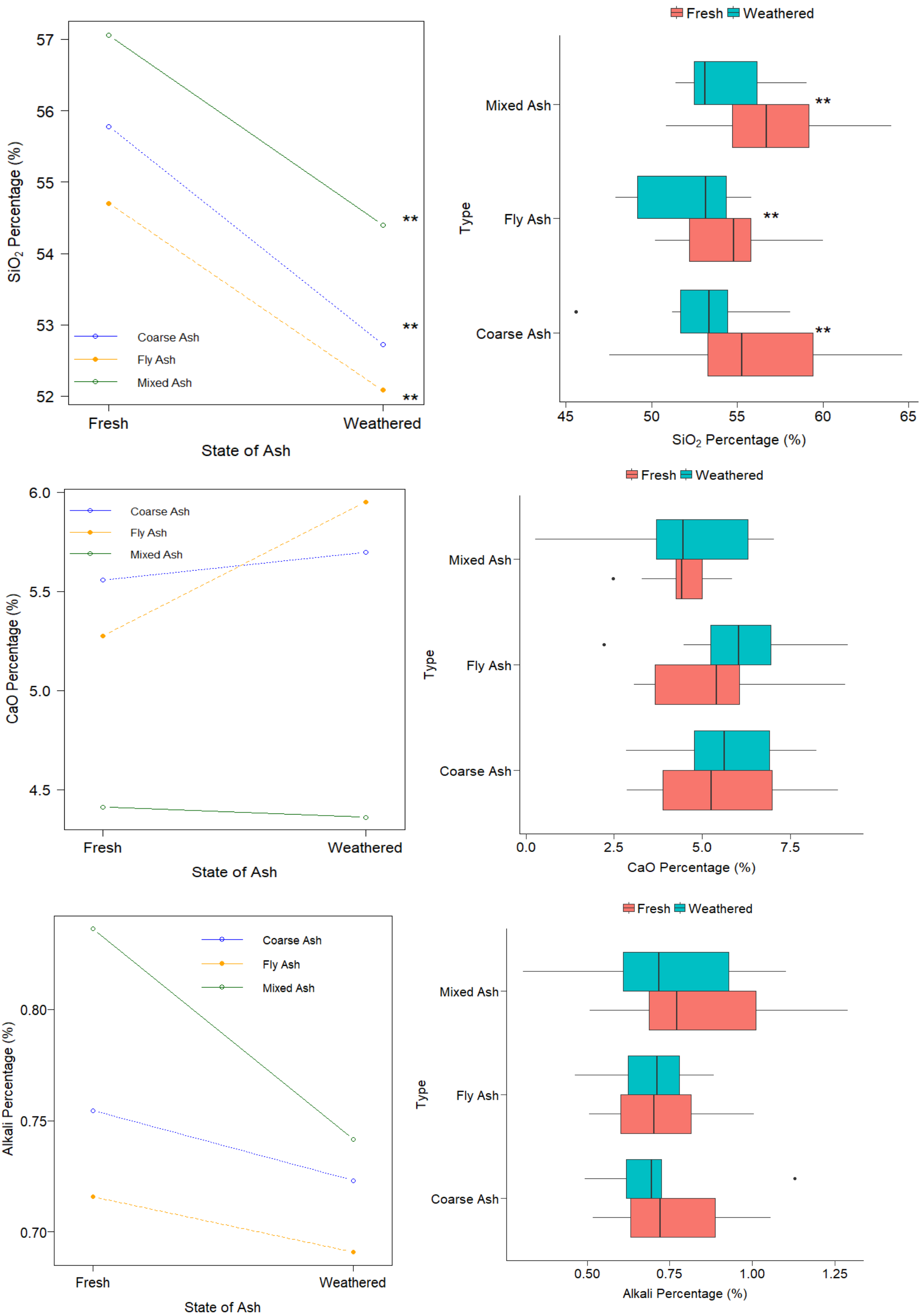

Figure 14: Interaction and Bar plot of silica, calcium and combined alkali metals (sodium and potassium) variation between different ash types and states

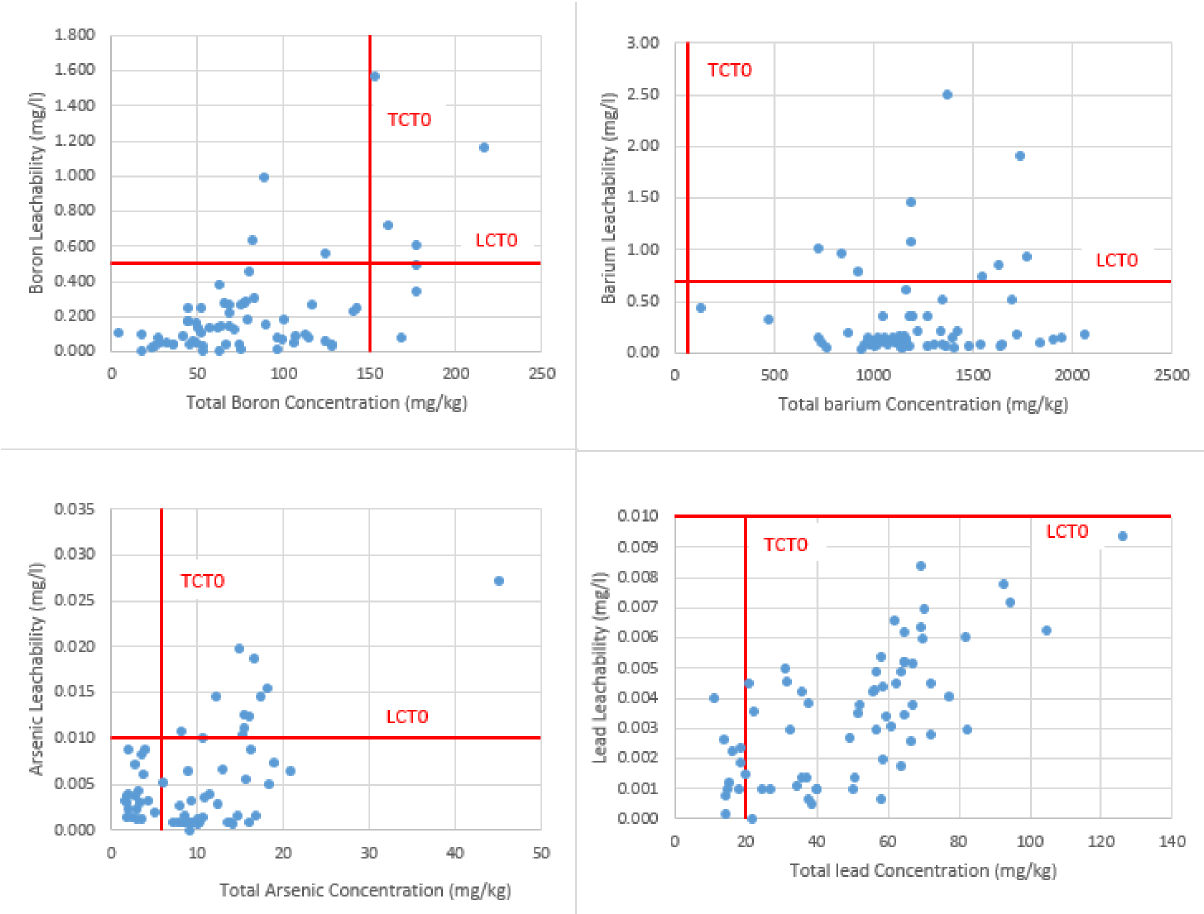

Figure 15: Total and leachable concentrations of selected trace elements in South African fly ash

Most South African energy coals are bituminous or anthracite coals, burned using PCC and producing Class F fly ash which has a pozzolanic nature and contains less than 7% lime (CaO). This is advantageous as the rheology is not impaired and the addition of super plasticisers is not required, eliminating associated costs (Golder, 2015).

Table 3: Typical oxide analyses of fly ash and portland cement (ACAA, 2003)

Major oxides	Fly Ash Class F	Fly Ash Class C	Portland Cement
SiO_2	55	40	23
Al_20_3	26	17	4
Fe_2O_3	7	6	2
CaO (Lime)	9	24	64
MgO	2	5	2
SO_3	1	3	2

7.2.3 Fly Ash chemical analyses required for characterisation

The following analyses on fly ash will be required:

- XRD or QEMSCAN / electron microscope to confirm mineralogy, especially mullite, and the proportion of glass (note that XRD does not determine the composition of glasses, as they are amorphous not crystalline, but the proportion of glass phases is reported);
- XRF to confirm the amounts of calcium and magnesium oxide (among other major constituents);
- Total concentrations of trace elements and leachable concentrations of trace elements (usually by ICP-MS or ICP-OES);
- Particle size (ASTM D422 (hydrometer);
- Specific gravity (ASTM C188 Density of hydraulic cement with Le Chatelier Flask);
- Loss on ignition (LOI) (ASTM D7348) Loss on ignition (LOI) is determined by measuring the loss in mass of the test specimen when heated under controlled conditions of temperature, time, atmosphere, specimen mass, and equipment specifications; and
- Free lime content (ASTM C114 section 28: Free calcium oxide)
- Leach testing. The material requires testing to determine the leachability of constituents of concern, which should be considered under two contexts:
  - Standard procedure as required by regulations (GN R. 645 of 2013) is the Australian Standard Leach test or ASLP. This is AS 4439.3—1997, which for the purpose of dry ash, ash slurries / pastes, or pozzolanified ash monoliths would be 1:20 leach using reagent (deionised) water. Data from this test is used to inform the regulator but may not represent site conditions accurately.
  - Site-specific procedure to determine the likely leachability of materials in the deposition site of choice. Data from such tests is required to demonstrate the actual risk of the material in the selected site under site-specific conditions. This could include
    - Standard tests such as kinetic testing (humidity cells: ASTM D5744-18 and D8187-18), Net Acid Generation leach test, the European two stage batch test (EN12457-3:2002) or Leaf Tests (USEPA 1313, 1314, 1315 and 1316) such as the monolith test (1315) which is designed to provide the mass transfer rates (release rates) of inorganic analytes contained in a monolithic or compacted granular material, under diffusion-controlled release conditions, as a function of leaching time (Pretorius, et. al., 2017);
    - Modified tests using site-specific material preparation, such as ash-walling;
    - Modified tests using site-specific solid : liquid ratios;

    - Modified tests using or site-specific leaching fluids, such as groundwater samples.
- NAG and ABA tests (e.g. USEPA600, MEND 1.16.3) to determine acid generating potential/neutralisation potential of the material.

The above list includes a variety of possible tests, but some may not be applicable in specific cases – for example, particle size is not a consideration for a pozzolanified monolith, nor are monolith tests applicable to dry ash or slurries.

7.2.4 Brine characteristics

Both the thermal coal power generation complexes and coal gasification complexes produce a variety of brines, for example:

- Cooling tower saline waste waters;
- Reverse osmosis brines from treatment of mine water and certain power station or gasification plant process water;
- Ion exchange regen brines from the plants; and
- Water demineralisation brines.

Investigations into the effect of the brine salinity on the rheology of ash-brine paste have indicated that the salinity of the brine influences the pumpability of paste considerably. The use of a more saline brine with the same chemical composition will result in a less pumpable paste in a given solid to liquid ratio, which may elevate energy requirements and susceptibility to pipeline blockages. For instance, a brine with 40 g/l total dissolved solids (TDS) had a yield stress of approximately 100 Pa while a brine with 85 g/l TDS produced a paste with approximately 300 Pa yield stress. The salinity of the brine used during paste preparation therefore has a significant influence on the pumpability and hence the engineering design. The investigation indicated that the salinity range of 40-60 g/l provided pastes with comparable pumpability (Mahlaba et al., 2011a; Mahlaba et al., 2011b; Golder, 2015).

Wastewater sources can vary because of changing conditions such as impurities in the fuel source and operating conditions of the power plant. Variability is further increased as wastewater is treated through volume reduction technologies where the degree of concentration can change.

7.2.5 Brine chemical analyses required for characterisation

The analytical suite required for the brine include the following:

- Total solids (TS), total suspended solids (TSS) & total dissolved solids (TDS);
- Specific gravity;
- pH & Alkalinity;

- Liquid phase:
  - ICP-MS or ICP-OES for major elements & metals; and
  - Anions (Cl^-, F^-, SO_4^{2-}, NO_3^-, NO_2^-);
- Solid phase (suspended solids):
  - Total major and trace elements by XRF, ICP-MS or ICP-OES;
  - Leachable major and trace elements;
  - Leachable anions; and
  - Mineralogy by XRD.

7.2.6 Paste characteristics

Paste technology involves the immobilisation of ash by the creation of a paste-like material from specific brines and fly ash which hardens or "cures" over time due to the pozzolanification of the ash (Pretorius et. al., 2011). Paste technologies have successfully been employed for the surface and subsurface disposal of mine tailings, and cost savings from water recovery have been the main driver to developing paste storage facilities (Verburg, 1997). The resultant cured paste material has very low permeability compared to ash or tailings, which reduces the chance of large-scale re-mobilisation of the entrapped salts. Sasol has conducted extensive laboratory and pilot-scale evaluations of the paste technology, and this has enabled the development of a technology package (Unpublished Reports, Sasol).

In a study of brine paste disposal, monolith testing of ash-brine paste indicates a fairly constant leachate pH of 10.3 to 11.5. The TDS of leachate from salty water brine paste falls from 2,328 mg/l on day 28 to 1,088 mg/l on day 150, and for regen brine ash paste the TDS falls from 970 mg/l on day 28 to 433 mg/l on day 150, which is substantially lower than the TDS of coal leachate which it replaces (Golder, 2015). The effect of fly ash characteristics on paste behaviour after mixing with different brine streams (Mahlaba *et al.*, 2011) showed that paste from Class F fly ash and high salinity brine (> 40 000 mg/l TDS) have substantially higher yield stress than when using brine with lower TDS concentrations.

7.2.7 Chemical analyses required for characterisation

Chemical analyses of the paste should include the following (Ellison et al., 2017):

- Mineralogy: XRD, QEMSCAN, Scanning Electron Microscopy (SEM)and electron micro probe (EMP);
- Leaching tests as discussed above; and

- Field lysimeters allow for the measurement of the volume of leaching/drainage water in trials as well as the concentrations of a chemical and its transformation products. Capability to monitor mass fluxes of water and chemicals (OECD, 2000).

7.2.8 Suitability of ash for use in paste

Fly ash's ability to form a cementitious paste is due to its pozzolanic activity. Pozzolans are siliceous and aluminous materials which in themselves possess little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. The pozzolanic reaction proceeds whereby the amorphous silica reacts with the calcium hydroxide found in the Portland cement and surrounding water to form a hard, stable and insoluble compound of calcium silicate hydrate (Tikalsky et al., 2002). This pozzolanic reaction is very beneficial as it increases the amount of calcium silicate hydrate gel produced which is an important cement binder, improves strength and reduces permeability of the paste.

However, high alkali content ashes coupled with amorphous silica undergo an alkali silica reaction (ASR) which can be detrimental in concrete applications. An ASR is a chemical reaction that occurs in concrete between alkali-hydroxides present in the pore solution and certain types of materials containing reactive siliceous minerals or glass (Harish and Rangaraju, 2011). When sodium and potassium-ion containing compounds react with water, these ions become soluble and the dissolve into the pores. This in turn increases the corresponding hydroxide ions (OH^-) concentration. This increased (OH^-) concentrations dissolves and reacts with the amorphous silica present in the ash forming a gel like substance. This alkali-silica gel is hygroscopic thus absorbing the surrounding water which causes an increase in volume and the gel begins to swell. This swelling can be significant enough to induce expansion and pressure on the surrounding environment and as a result, causes cracks in the concrete and ultimately failure of the paste (Lahdensivu et al., 2018). This reaction is however unstable in the presence of calcium ions (Ca^{2+}) in the form of $Ca(OH)_2$. The gel reacts with these ions to form calcium silicate hydrate which is an important strength binder for the paste. However, over a long period of time, the calcium may be all used up and ASR will begin to occur.

The mass percentages and concentration of specific species contribute significantly to the reactivity of ash and need to be limited or increased depending on the desired outcome. The guidelines for specific elements or compounds as well as their reactivity is discussed below. These guidelines aim to minimise the ASR, promote the pozzolanic reaction, minimize heavy metal leaching and ensure a paste with high strength is achieved.

7.3 Physical characteristics

7.3.1 Fly ash characteristics

The greater the assortment of particle sizes in the material, the more it can be compacted to achieve greater density and shear strength and lower permeability. Fly ash particles are fine-grained, typically silt-sized, ranging from 1 to 100 µm in diameter with a median particle diameter of 20 to 25 µm (EPRI, 2009). The particle size distribution of most bituminous coal fly ash is generally less than 75 µm. Class F fly ash generally has a spherical morphology, resulting in paste which is more workable and stronger than pastes from Class C fly ash (Yeboah et al. 2014).

7.3.2 Paste characteristics

Physical characteristics influencing the suitability of the paste include:

- The paste must be able to retain its consistency and strength when placed. Fly ash must consist of > 15% particles <20 µm in order to form a stable paste (Mahlaba *et al*., 2011a).
- Permeability reflects the rate at which water will seep through the material in a given period of time and provides a first estimate of the rate and quantity of leachate migration. Factors influencing the degree of permeability include the size and shape of particles, the degree of compaction and the viscosity of water/brine. In Sasol studies, permeability of 7.8×10^{-6} cm/s to 3.2×10^{-5} cm/s were determined. The horizontal hydraulic conductivity of Highveld coal seams has been determined at 1.2×10^{-4} cm/s (0.1 m/d, Hodgson & Krantz, 1998), at least an order of magnitude higher. Therefore, post-closure flow through the paste is thus expected to be very low, with preferential flow being through the coal seams. This means that flow through the mine voids, the principal source of acid rock drainage or mine-affected water, is minimised.
- Strength development is directly related to the amount of cementitious material and water content. Most high fly ash content mixes only require 3-5% portland cement by dry weight of the fly ash to develop 28-day compressive strengths in the 345 to 1,000 kPa range. Long-term strength may gradually increase beyond the 28-day strength. Water content of the mix also influences strength development. Water is added to achieve a desired flowability or slump. At a given cement content, increased water content usually results in a slight decrease in compressive strength development over time (ACAA, 2003).

  Unconfined compressive strength (UCS) is used to determine the performance of cementitious materials under mechanical stress. It is an important parameter for paste used in mine void backfilling since the material must provide underground support. The brine chemistry plays an important role in the strength of the paste (Pretorius *et al.,* 2011) with the optimal TDS of the brine between 40 000 mg/l and 60 000 mg/l.

- One of the essential elements required for the utilisation of paste for backfilling underground is the ability to transport the paste to the mine disposal area. Similarly, the ability to discharge paste through a borehole into a mined-out area underground is critical, as well as the ability for the paste to flow when deposited into the mine (Golder, 2015). It is also possible to study the flowability of pastes by slump tests. The setting/curing time for pastes can be manipulated by varying the brine-fly ash mixing ratios and the characteristics of the raw materials. This can result in obtaining a paste which will flow easily initially (low viscosity) and cure into an impermeable monolith over time (Pretorius *et al.,* 2011).

> Rheology is a study of the deformation and flow of material and measures the response when force is applied to a suspension/paste. It is also possible to study the flowability of pastes by slump tests.

- Bleeding and subsidence are possible in paste mixes with relatively high-water contents (corresponding to a 254 mm slump). Evaporation of the bleed water and absorption into the surrounding soil often results in a subsidence of approximately 11 mm/m of depth of the fill. This shrinkage may occur laterally as well as vertically, but no additional shrinkage or long-term settlement of flowable fill occurs after initial set. Prior to hardening, flowable fill mixes are self-levelling (ACAA, 2003)

7.3.3 Tests for paste and slurry mixture characterisation (physical/engineering)

- Particle size distribution.
- Compaction testing (Proctor compaction test ASTM D1557) to determine relation between water content during compaction and dry density of monolith (> moulding water ≥ dry density to maximum point before decrease). During initial testing, use variety of brine: ash mixing ratios to determine optimal moisture content as well as different curing times. Laboratory compaction tests provide the basis for determining the percent compaction and moulding water content needed to achieve the required engineering properties, and for controlling construction to assure that the required compaction and water contents are achieved.
- Testing of flowability (slump test ASTM C143) on bench scale first. A sample of freshly mixed concrete is placed and compacted by rodding in a mould shaped as the frustum of a cone. The mould is raised, and the concrete allowed to subside. The vertical distance between the original and displaced position of the centre of the top surface of the concrete is measured and reported as the slump of the concrete.
- Density of the paste is important to determine energy required to pump/move the paste (ASTM D1429) Specific gravity is an important property of fluids being related to density

and viscosity. Knowing the specific gravity will allow determination of a fluid's characteristics compared to a standard, usually water, at a specified temperature. This will allow the user to determine if the test fluid will be heavier or lighter than the standard fluid.

- Strength during curing: Paste mature with time (solidify) and a penetrometer can be used to measure strength during curing (an instrument for determining the consistency or hardness of a substance by measuring the depth or rate of penetration of a rod or needle driven into it by a known force). Typical standard curing period is 28 days. Reaction during curing influence strength and permeability of the monolith, and ultimately immobilisation of contaminants. Rate of the curing process is influenced by temperature and humidity.
- Hydration reactions are exothermic, and heat is released during curing process. This can be measured with a calorimeter to determine the rate of hydration of different mixtures.
- Rheology: Viscosity of the paste will change with curing due to chemical reactions.
- Strength: Unconfined Compressive Strength test (UCS) The unconfined compression test is used to measure the shearing resistance of cohesive soils. An axial load is applied using either strain-control or stress-control condition. The unconfined compressive strength is defined as the maximum unit stress obtained within the first 20% strain (State of California Dept of Transportation, Engineering Service Center, California Test 221, 2000).
- Density: Lab test on volume and weight of monolith of known dimensions (ASTM C138 Density of freshly mixed concrete; ASTM C642 Density Hardened cement).
- Porosity: Pycnometer (ASTM D854) test methods cover the determination of the specific gravity of soil solids that pass the 4.75-mm (No. 4) sieve, by means of a water pycnometer. When the soil contains particles larger than the 4.75-mm sieve, Test Method C 127 shall be used for the soil solids retained on the 4.75-mm sieve and these test methods shall be used for the soil solids passing the 4.75-mm sieve.
- Permeability: (ASTM D5084) Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter.
- Before and during deposition: Slump (ASTM C143), particle size (ASTM D422), solid content (ASTM D2216), specific gravity (ASTM D854), density (ASTM D7263), paint filter & net water release (SW-846 Method 9095B).
- Static yield stress (during deposition) (ASTM D4648).
- Within 1 hour after deposition: Static yield stress (ASTM D4648), Beach profile measurement.
- After 4 days: particle size (ASTM D422), solid content (ASTM D2216), specific gravity (ASTM D854), dry density (ASTM D7263), Static yield stress (ASTM D4648).
- Released water during deposition & after 4 days: Solid content (ASTM D2216), Fines content (ASTM D1140), basic chemistry (Price 2009).

8 ASSESS RECEIVING ENVIRONMENT

The main potential negative impact on the environment is through surface- and groundwater contamination as well as the release of liquid waste (brine, paste, slurry, etc.). The potential negative impact is due to the potential for constituents leaching from the waste body to contaminate water sources (Zhang, 2014) and ultimately impact on human health, aquatic and terrestrial ecosystems. Due to the fine nature of fly ash, it has the potential to cause dust problems and contaminants can be distributed through this route as well.

The receiving environment should be assessed for both options, that is surface disposal and backfilling. The following should be considered during this process:

8.1 Preliminary site investigation

The location, climate, hydrology, geology, geohydrology and receptors are important variables to consider since they could have a major impact on the suitability of a site for backfilling. This information will also be required for the development of the conceptual site model (CSM) and more than one site visit may be required to obtain sufficient information develop a CSM that sufficiently describes the site to allow for planning site assessment and characterisation (DWAF, 2008a). The more detailed the site characterisation, the more comprehensive the CSM will be which will enable better decision making.

Additional aspects to consider during the site investigation include operational considerations for implementation backfilling include:

- Site life (if the mine will remain operational);
- Depth of excavation/open voids;
- Conveyance methods;
- Availability of open areas for construction of Backfill Plant; and
- Separation of clean and dirty storm water.

8.2 Conceptual Site Model (CSM)

Following the site investigation, a CSM need to be developed to show the interaction between the source(s), pathways and receptor to identify potential active linkages between the source(s) and receptors. The CSM is one of the primary planning tools that can be used to support the decision-making process. It can be used to conceptualize the relationship between contaminant sources and receptors through consideration of potential or actual migration and exposure pathways (Figure 16).

The CSM should be a visual representation of the site/s showing contaminant sources (fly ash and brine ponds), surface water resources, groundwater depth and flow direction, soil type and depth, geology and the location of human settlements/residential areas as well as other potential receptors. Sub-surface infrastructure should also be included in the CSM to easily assess the linkages between shafts, etc. in the underground mine.

ASTM E1689 – 95(2014): Standard Guide for Developing Conceptual Site Models for Contaminated Sites

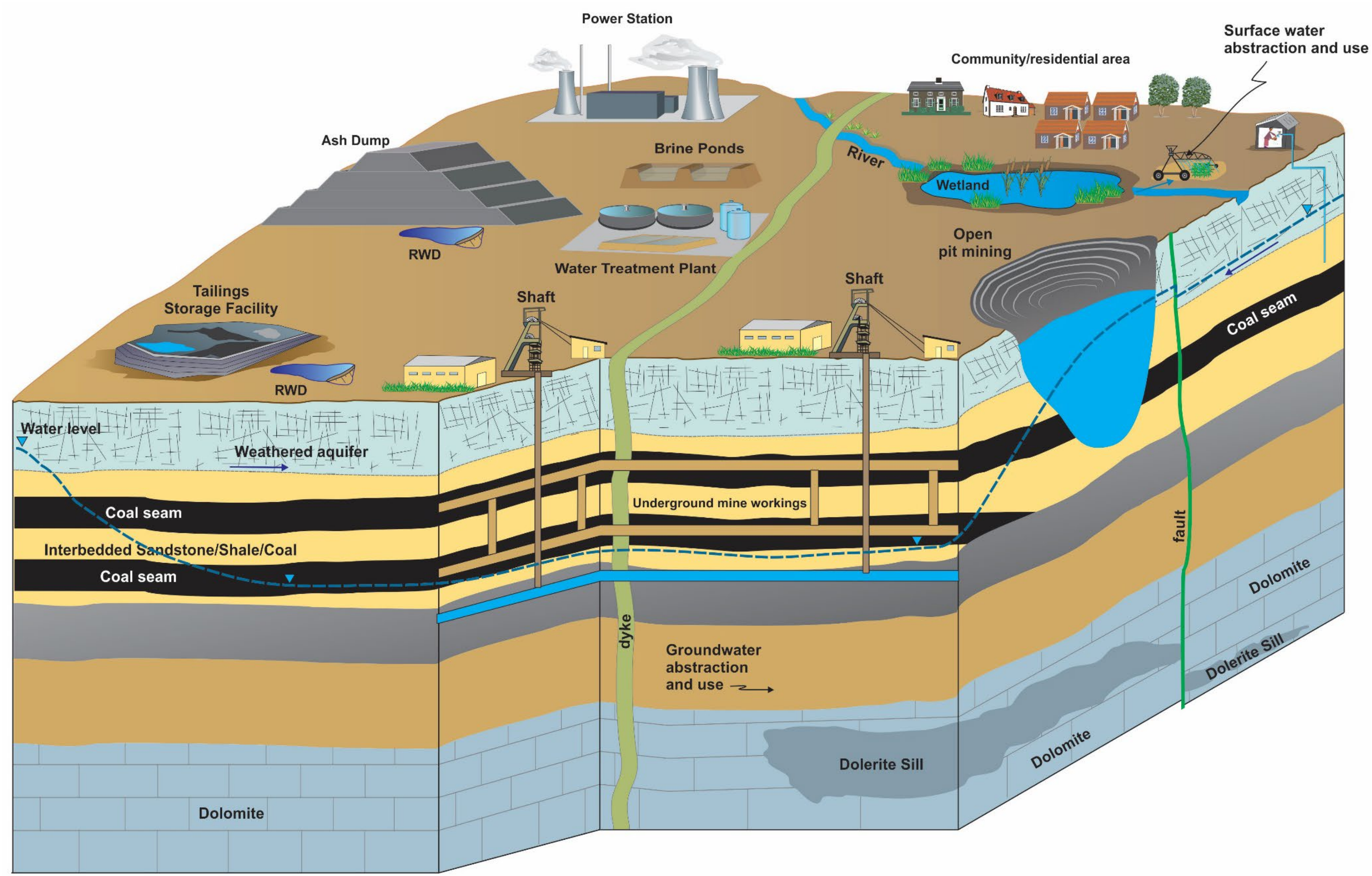

Figure 16: Example of a CSM (Golder Associates)

The best practice guidelines for water resource protection in the South African mining industry (BPGs) emphasise that the conceptual model must be developed, documented, and signed off, before sampling, analyses and assessment work can commence (DWAF, 2008a).

8.3 Conceptual source-pathway-receptor (SPR) assessment

The SPR assessment should show the links between the source and potential receptors to serve as input into the risk assessment.

Sources include:

- The ash or paste backfill – see section 7 above;
- Ash Dams and associated Return Water Dams;
- Brine ponds at Water Treatment Plant;
- The underground mine workings or open void; and
- Spillage or leakage of ash / paste material during delivery.

Possible migration pathways may include:

- Leaching of contaminants through the soil profile to groundwater;
- Downward migration from one groundwater aquifer to another;
- Transport of contaminants via groundwater to surface water;
- Transport of contaminants via surface water; and
- Transport of contaminants through sub-surface infrastructure.

Possible exposure routes may include:

- Direct contact (e.g. skin exposure) with contaminated environmental media;
- Ingestion of contaminated environmental media;
- Inhalation of contaminated media (e.g. dust).

The source-pathway-receptor approach is a risk-based approach. This means that the following aspects should be considered in the context of ash backfilling:

- Cumulative impacts at a system level;
- A conservative approach must be built into assumptions used and interpretations of available information;
- The long-term behaviour of sources must be predicted, for example the extent to which mine and combustion residues may be immobilised by inundation, pozzolanification or other processes;

- The long-term behaviour of pathways must be predicted, including the possibility of the development of new pathways, for example the risk of decant and the risk of sinkhole formation;
- A cradle to grave approach is required for all waste streams; and
- The risk of failure in management strategy or mitigation system must be considered (DWAF, 2008b).

An example of a SPR assessment for a conventional Power Station and mining operation as well as during and after backfilling, is shown in Table 4.

9 OPTION SELECTION

Once all available information has been documented, the NEB need to be assessed. Costing, social implications as well as environmental impacts of both options (surface disposal vs backfilling) need to be assessed during this process. Based on the outcome of the NEB, as well as a cost benefit analyses, the best practicable and cost-effective option need to be selected.

Ideally, a multi-criteria decision support tool should be used to allow for the comparison of options by taking into account the impact of the environmental, social and economic dimensions to sustainably improve waste management practices. The integrated assessment of options should also allow for the addition of technical considerations related to sustainable waste management.

The cost benefit analyses is crucial in the decision making process. Backfilling costs include capital costs (mixing plant, positive displacement pumps, storage facilities, pipelines and boreholes/injection holes, sumps, monitoring instrumentation, etc.) and operating costs (backfill preparation, drainage systems, pumping, operational labour, etc.). Transportation and geotechnical issues are two critical factors which can directly affect the economic and technical feasibility of backfilling (Masniyon, 2009).

Table 4: Example of a conceptual source-pathway-receptor assessment

	Primary sources	Secondary source	Release mechanism	Pathway			Exposure route			Primary Receptor	Secondary Receptor				Notes
				Soil	Surface water	Groundwater	Ingestion	Inhalation	Contact		Human	Fauna	Flora	Aquatic	
Conventional Operations															
Power station	Ash Dams	Waste stream, Contaminated water, Storm water	Run-off, Infiltration, Overflow, Discharge				X	X	X	Groundwater, River, Wetland					Impact on groundwater and river already realised. Community use water for domestic purposes
Power station	Return water Dam	Contaminated water, sediment	Run-off, Infiltration, Overflow, Discharge				X	NA	X	Groundwater, River, Wetland					Impact on groundwater and river already realised. Community use water for domestic purposes
Power station	Brine Ponds	Contaminated water, sediment	Overflow, Discharge				X	NA	X	River, Wetland					Impact on river already realised. Community use water for domestic purposes
Mining Operation	Tailings Storage facility	Waste stream, Contaminated water, Storm water	Run-off, Infiltration, Overflow, Discharge				X	X	X	Groundwater					Contaminated run-off and storm water is diverted to RWD
Mining Operation	Return Water Dam	Contaminated water, sediment	Overflow, Discharge				X	NA	X	Groundwater					Facility sized appropriately to accommodate contaminated water. No direct link with river or wetland
Mining Operation	Water from underground workings	Contaminated groundwater	Discharge, decant				X	NA	X	River, Wetland					Water pumped from workings are used as process water, but access is discharged to wetland
During & After Backfilling															
Backfilled Mine	Conveyance system	Contaminated soil, contaminated water	Spillage, infiltration, run-off				X	NA	X	Groundwater, River, Wetland					Spillage may occur during pumping, unlikely to cause significant contamination
Backfilled Mine	Backfilled voids	Contaminated leachate	Seepage, bleeding				X	NA	X	Groundwater					Quality of leachate unlikely to cause significant contamination
Backfilled Mine	Water from underground workings	Contaminated groundwater	Decant				X	NA	X	River, Wetland					Quality of leachate/decant unlikely to cause significant contamination

Unconfirmed

Confirmed

Unlikely pathway link

Exposure pathway incomplete/insignificant

Exposure pathway complete

10 PREDICTIVE PLUME MODELLING

In the interest of cost sensitivity, it is recommended that the detail modelling studies as presented in this section are undertaken only for the option with the largest NEB. Should the schemes being compared show a similar NEB, the applicant can proceed further with the detailed modelling for both schemes.

10.1 Introduction

Predictive hydrogeological plume modelling needs to be conducted on the backfill option to inform the risk assessment and risk management plan to be included in the application for authorisation. Determination of predicted flow directions should be done using contaminant transport / reactive transport in a numerical groundwater flow model.

The key predictive questions for initiation and operations of a mining operation include:

- Will waste be generated / deposited which can lead to acid, saline or neutral drainage? – see section 0 above;
- Can waste streams be separately managed?
- What are the positive or negative consequences of different waste disposal options? – see section 2; and
- What would be the effect of different disposal sites or techniques on the system? – see section 6 above (DWAF, 2008a).

In the context of backfilling mines for closure, the questions are:

1) What are the drainage volumes and quality for all contaminants of concern for all source terms that pose a potential risk of impacting on the water resource – such profiles to show predictions at least 100 years into the future, or longer if longer periods are required to quantify the impact, as recommended by the specialist and agreed to by the independent reviewer and DWS. (The assessments described for the operational phase of the mine above will need to be extended to ensure that boundaries of confidence can be defined for the predictions and that all models are fully validated and calibrated and that full independent review has been undertaken).
2) What will the long-term impact be at the critical receptor for the contaminants of concern? (The various source term assessments will need to be linked into an integrated model that incorporates regional groundwater and surface water hydrology and quality and that presents detailed time-based water quality profiles at the critical receptor for at least 100 years or until the water quality at this point has reached stable conditions).

3) What additional water management (e.g. covers, infiltration reduction measures, etc.) or treatment measures need to be instituted to reduce the contaminant loads from the various source terms or to intercept the pathways in order to ensure that the critical receptor is not adversely impacted? (Using the models developed to answer closure phase questions 1 and 2 above, apply and evaluate the effects of various mitigation measures in terms of impact at the critical receptor).

While it is critical that the impact prediction assessments, the answers to most of these questions, in terms of the extent and significance of impact will often be determined by hydrogeological plume modelling, making use of the source characterisation discussed in section 2 above.

10.2 Determining Drainage Chemistry

The predicted water quality of the backfill – including the water released from the backfill material – will influence the water chemistry of the mine void. The mixing of the backfill water and leachate with the existing mine water – water in the mine void and inflowing groundwater – needs to be modelled with a geochemical speciation model to determine the resulting mine water chemistry, and any minerals which may precipitate out.

10.3 Determining Drainage Volumes and Pathways within the Mine

During underground backfilling operations, bleed water (and recharge) would mainly seep through the floor (roadways). Migration of the water will be dependent upon dewatering and mine water management during operations and is expected during the closure phase to be along structural trends (faults and dykes). Alternatively, if water is pumped out at a rate exceeding the rate of bleed water production, then a cone of depression will be formed and there will be no water flow away from the backfill site into the environment during operations (Golder, 2015).

Modelling at a backfill into a coal mine, using salty water brine paste, it was found that a contaminant plume of TDS, chloride and sulphate could form, but once backfilling ceases, the long-term chemistry of the water in the backfill compartment has been modelled as having a slightly improved quality compared to the local mine-affected deep groundwater. During backfilling with regen brine paste, a contaminant plume of chloride and boron could form, although TDS in the compartment will be lower, due to lower calcium, sodium, alkalinity and sulphate levels. Post-closure, all parameters in the compartment will be at similar levels to the local groundwater or lower (Golder, 2015). The regen brine paste backfilling option was found to be environmentally more acceptable than the salty water brine backfilling option during operations, but based on the available data neither paste backfilling option is expected to have a significant impact on groundwater quality in the long-term post-closure.

An ash slurry backfilling study indicated a substantial load of TDS, chloride, sulphate, calcium, sodium and potassium during operations – during late deposition sulphate, chloride and TDS drop but still remain an order of magnitude above local groundwater levels. If the 50% recovery rate of return water is not achieved, or if no return water is pumped out, then the ash slurry backfill will become a contaminant source. Flow along the roadways and seepage through the floor would be expected and migration of the water will be dependent upon dewatering and mine water management during operations, thereafter along structural trends (faults and dykes) (Golder, 2015).

From the above examples, it can be seen that the critical factors to understanding the drainage from the backfill are:

1) The nett water content of the backfill material, i.e. the released water content the backfill slurry / paste (measured during deposition), less the water recovered. In the case of paste, the quantity of water that can be lost prior to curing of the paste is the criteria, not the total water content of the paste. This nett water volume constitutes the source from which the plume is generated and must be modelled based upon the physical characterisation tests (see section 7.3 above) and feasibility tests for the recoverability of released water.
2) The difference in permeability between the backfill and the wall rock: it is generally the case that:
    a. Ash backfill has a significantly higher permeability than South African coal seams or host sedimentary rocks, even when fractured by blasting, and so preferential flow is likely to be through the backfill – thus the plume from an ash backfill site is likely to migrate through the workings; and
    b. Paste has a significantly lower permeability than South African coal seams or host sedimentary rocks, and so preferential flow is likely to be through the pillars / wall rock – unless voids are left between the cured paste and the roof, in which case flow will be through the voids.

But this must be demonstrated through tests on the site-specific backfill and host rock materials.

10.4 Determining Pathways from the Mine and Impact

Once the chemistry of the source is understood (section 7 above) and the drainage volumes and pathways in the mine are understood (section 10.3 above), the source can be included in a conventional numerical groundwater model. The questions to be answered by the numerical model relate to decant:

1) Will the (un-backfilled) mine decant post-closure, either decant onto the surface into streams and wetlands, or subsurface decant into shallow groundwater?
2) Will the backfilling of the mine change this – i.e.
    a. Will backfilling cause the mine to decant, when it previously would not? or
    b. Will backfilling cause surface decant to occur, when there was only sub-surface decant in the un-backfilled scenario? or
    c. Will backfilling change the timeframe of decant? or
    d. Will backfilling prevent decant, perhaps by changing the underground flow patterns or blocking a route to decant?

The next questions to be answered relate to the formation, development and migration of a plume in the groundwater, and require contaminant transport modelling:

1) What is the source chemistry – see section 10.2 above – and is it notably different from the un-backfilled scenario?
2) How does this plume migrate away from the mine and does it change the water quality of receptors, compliance points or other monitoring points?
3) If so does the downstream quality deteriorate in terms of the requirements of each of the receptors, or improve?

Depending upon the chemistry of the source, and the difference in drainage volumes, this may represent an impact on the local groundwater that exceeds (overprints) that expected of the flooded underground mine workings (Golder, 2015), or may represent an amelioration or mitigation of the impact of the flooded underground mine workings.

11 RISK ASSESSMENT

11.1 Introduction

All mining and waste management operations have varying degrees of risk associated with them. These risk profile changes as new methodologies and techniques are developed and implemented. This section considers factors that need to be included in risk assessments of paste and slurry backfill applications in underground and open pit mining voids. The risks can have varying degrees of consequence to the mining operation. In some extreme cases these risks could result in injuries or fatalities, suspension of operations and damage to corporate reputation.

Risk is the likelihood of unacceptable impact on receptors which will lead to objectives not being realised. Risk assessment is the evaluation of the potential frequency of occurrence and consequence of these impact/events. Risk ranking helps to determine the most critical events and prioritise efforts for further mitigation.

The key steps to risk assessment include (Figure 17):

- Identification of the key elements for consideration (e.g. safety, finance, environment, legal, government relations, community, operations, etc.);
- Identification of anticipated risk areas (contaminant sources, pathways, etc.);
- Determination of risk effects from potential risk areas;
- Evaluation of risk effects against existing control measures based on frequency and consequence; and
- Ranking of risks and development of post-control measures to mitigate critical risks.

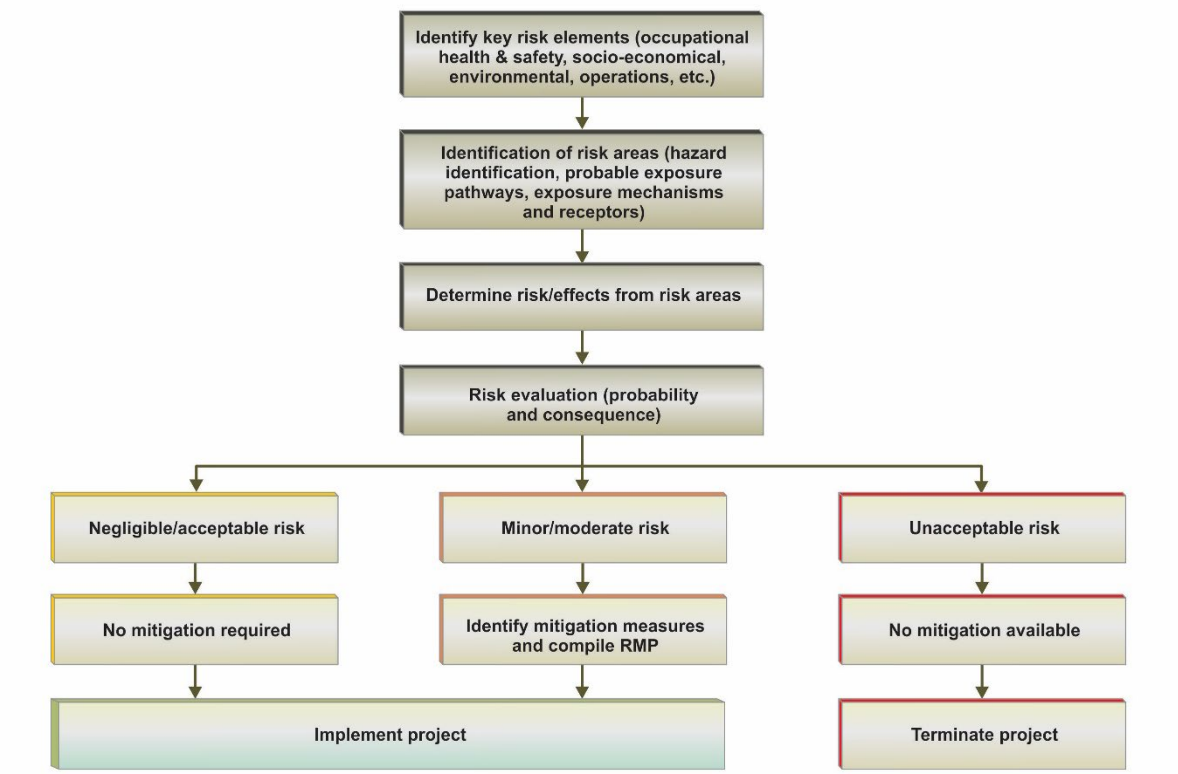

Figure 17: Risk Assessment flow diagram

11.2 Waste classification and assessment

An initial step in the risk assessment is the waste classification and assessment. Although these are not risk-based approaches, they provide useful information as a point of departure for the risk assessment.

The methodology for the waste classification and assessment is detailed in section 5.1 above. Proponents will be required to classify and asses the ash, brine and/or paste. The risk associated with Type 0 and Type 1 waste may be difficult to mitigate due to the high concentrations of contaminants. Typically, fly ash will be Type 3 or Type 4 waste, while ash slurry and paste will be Type 3 or Type 2 waste due to the addition of brine (Table 5). Fly ash may be hazardous to human health according to SANS 10234 due to the alkaline pH. In these cases, a SDS need to be developed to inform safe handling procedures.

Table 5: Examples of typical waste type and classification of backfill material

Backfill material	**Waste Type (GN. R. 635 of 2013)**	**Waste Classification (SANS 10234 and GN. R. 634 of 2013)**
Ash	Type 3	Hazardous to humans (pH > 11.5)
Slurry	Type 3 / Type 2	Non-hazardous
Paste	Type 3 / Type 2	Non-hazardous

Table 6: Typical waste type restrictions and mitigations

Risks / Restrictions	**Mitigation**
Waste type	• Treatment before use (Type 0 or Type 1 waste) • Site specific evidence quantifying risk to receiving environment
Hazardous material handling	• Safety Data Sheet • Industry safe operating procedures • Dry placement: Dust management

11.3 Risk identification – general

This risk identification stage involves the identification of possible risks that could create a hazard and/or exposure to the business, operations, people or the environment. The two risk identification elements are:

- Hazard/risk factors: Inherent hazard, unsafe acts, risky behaviour or defective design; and
- Exposure: Exposure is normally related to occupational health, environmental impairment, legal liability, financial transactions/activities, social pressures and reputation (DEAT, 2006).

The main potential environmental risk associated with the disposal or use of fly ash, brine and paste, is contamination of the water resource. This primary concern relates to the potential for hazardous constituents to leach out and migrate into the surface water or groundwater, and hence contaminate water used by receptors: drinking water, water used for agriculture or other purposes, and the aquatic environment. Factors to be considered include (but not limited to):

- Depth to groundwater, flow and aquifer type;

- Elevation of the disposal site in relation to the water table and the elevation of surface water bodies;
- The presence of groundwater-dependent ecosystems;
- Hydraulic conductivity of the geological unit with which the ash / paste is in contact, and other geological units along the pathway to the receptors;
- Recharge rate of the groundwater body with which the ash / paste is in contact;
- Distance to surface water;
- Distances to local communities and opportunities for human exposure, even in areas where the water resource is not currently used;
- Resulting water quality from chemical interactions between ash, mine water and wall-rock;
- Change to probability or timing of decant due to placement of ash / paste;
- Geo-mechanical/hydrogeological effects on neighbouring mines;
- Location of above ground infrastructure (e.g. mixing plant, pipelines, injection wells) in relation to receptors;
- If the proposed site has risk or known occurrences of spontaneous combustion and the effect backfilling will have on this;
- If the proposed site has risk or known occurrences of subsidence and the effect backfilling will have on this;
- Future land-use sensitive to subsidence (residential, industrial);
- Socio-economic risks and opportunities, such as sterilisation of mineral resources vs establishment of new local businesses (or growth of existing ones)

11.4 Risk identification – paste

With regard to the production of cementitious paste (see section 7.2 above), flowcharts have been developed for considering the risk of alkali silica reaction (ASR) indicated by the silica (Figure 18), calcium (Figure 19) and alkali metal (Figure 20) content of ash that could be used in the production of paste.

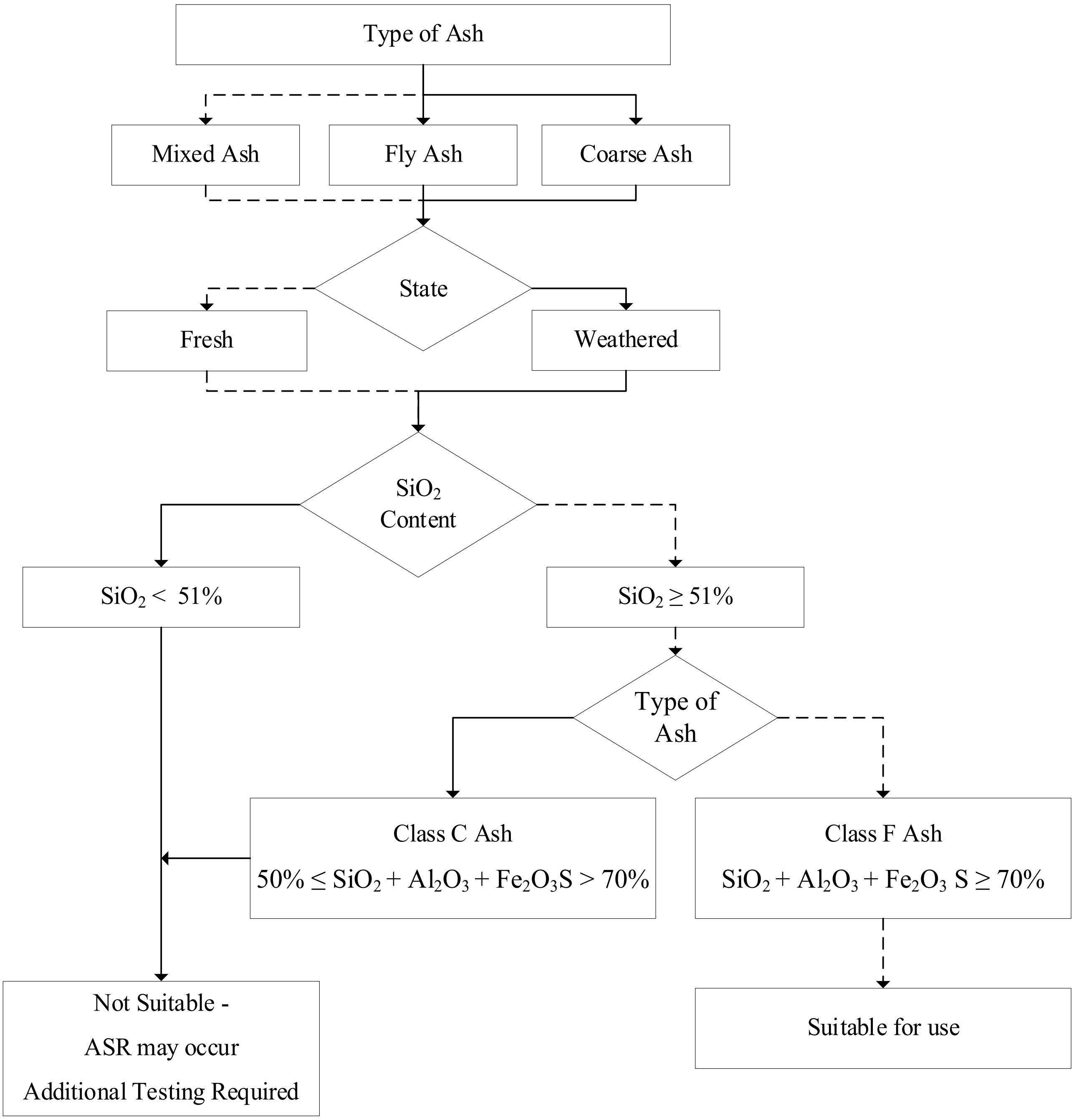

Figure 18: Silica risk assessment flow diagram for paste

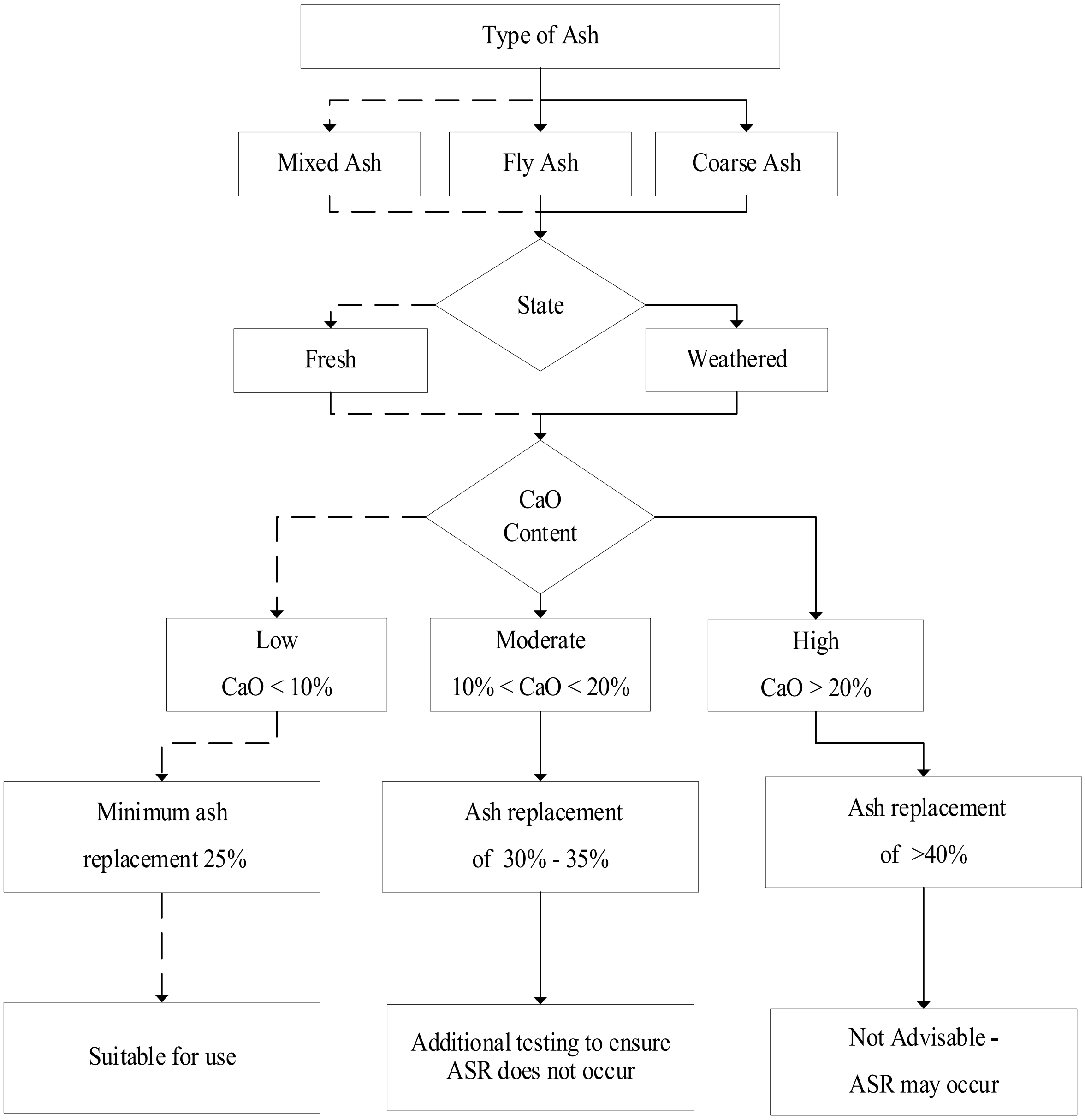

Figure 19: Calcium risk assessment flow diagram for paste

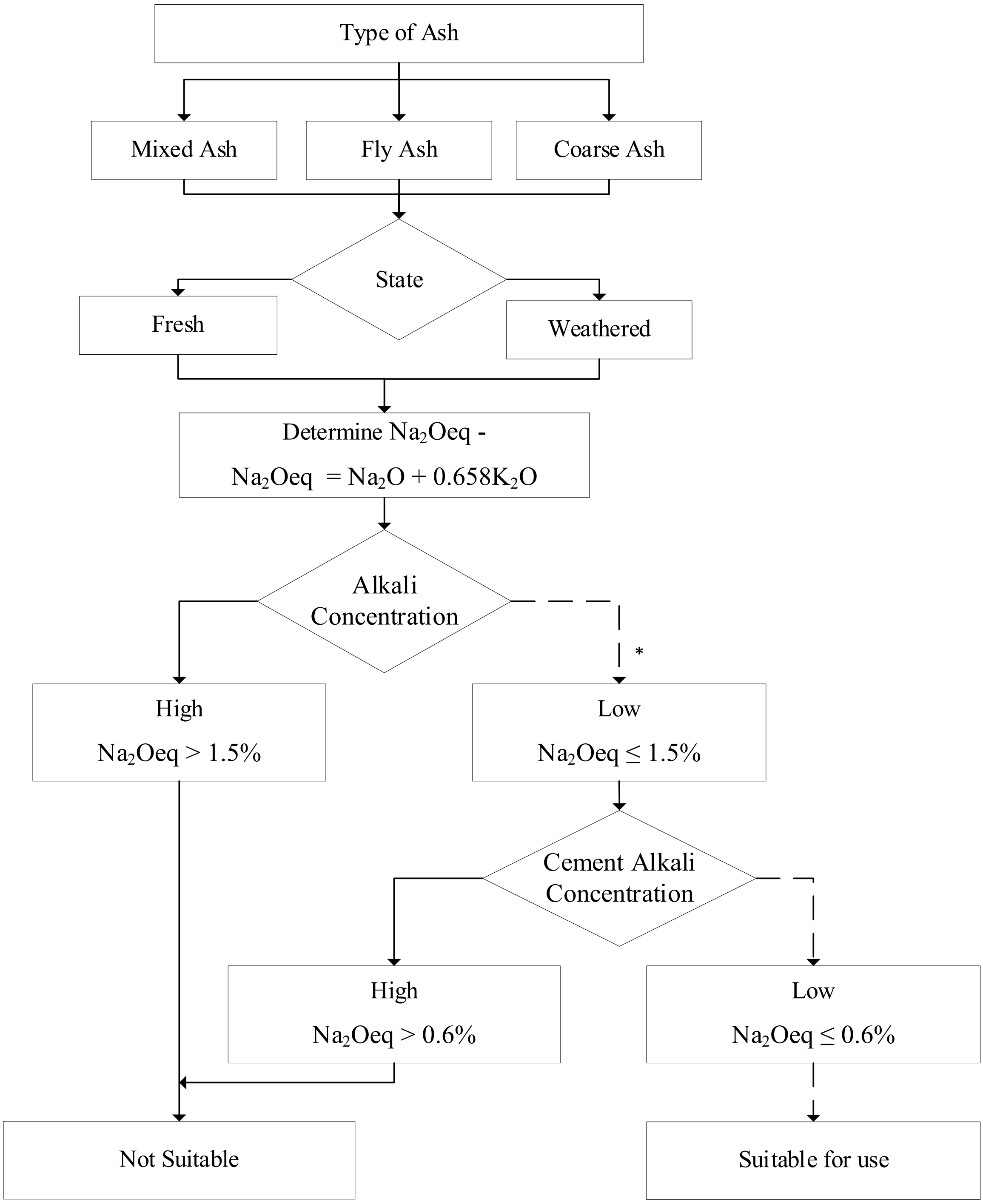

Figure 20: Sodium and potassium risk assessment flow diagram for paste

11.5 Risk evaluation

Risk evaluation is the process of evaluating the magnitude, duration, scale and probability of consequences and risk occurrences of a hazardous nature, activity or exposure. The significance of potential impacts is calculated as follows:

Significance points (SP) = (magnitude + duration + scale) x probability

The proposed Risk Assessment Matrix approach and assessment criteria for this project is shown in Figure . This will be used to develop a risk evaluation matrix for the specific risk identified for backfilling as discussed in section 11.3 above. The example given is of a possible final presentation by the developer to the DEA. The actual risk assessment carried out before presentation to the DEA could be tiered and cover a greater level of detail and depth., including site-specific requirements, company-specific requirements on health safety and the environment and so on.

11.6 Risk appraisal

Once risk evaluation has been applied, there could be several risks that could impact on strategic and/or operational level. Furthermore, several potential risks may impact simultaneously on operations. Acceptability of the risks can be rated on the following scale:

- The potential risk is negligible/acceptable and therefore no mitigation is required (SP < 30);
- The potential risk is moderate, and mitigation is required. If not mitigated, it might prevent implementation (SP 30-60); and
- The potential risk is unacceptable and might prevent implementation (SP >60).

Risk control techniques or measures can be implemented to mitigate the risk to acceptable levels. These will be discussed in the next section.

Risk Assessment Matrix						Magnitude	Duration	Scale	Safety & Health	Water security (access, quality and quantity)	Socio-economic impact	Environment (Surface water; Groundwater; Wetlands; Air)	Operations
Significance points													
0	18	36	54	72	90	10	5	3	> 3 fatalities	Permanent change in water security	>50% of workforce affected	Irreversible impact at Regional level	Total loss of resource / Financial risk affects continued enterprise viability
0	15	30	45	60	75	8	4	3	2 - 3 fatalities	Long term (> 15 years) change in water security	< 50% of workforce affected	Serious but reversible short term Impact at Regional level	Total loss of resource / Long term financial risk
0	14	28	42	56	70	8	4	2	1 fatality / > 3 LTI's	Medium term (5 - 10 years) change in water security	< 20% of workforce affected	Serious effects extending beyond boudaries of project	Acceptable loss of resource / Long term financial risk
0	11	22	33	44	55	6	3	2	Permanent disablement	Short term (1-3 years) change in water security	< 10% of workforce affected	Moderate effects extending beyond boudaries of project	Acceptable loss of resource / Medium term financial risk
0	8	16	24	32	40	4	2	2	Lost time injury / harm	Temporary (seasonal) change in water security	< 5% of workforce affected	Minor effects extending beyond boudaries of project	No loss of resource / Medium term financial risk
0	6	12	18	24	30	4	1	1	Medical treatment beyond 1st aid	Initial change in water security	Re-skilling required to achieve no-net job losses	Limited impact within project boundaries.	No loss of resource / Short term financial risk
0	3	6	9	12	15	2	1	0	First aid/ No injury	No change in water security	No net-job losses	No impact	No loss of resource / Low financial risk
0	1	2	3	4	5								
None/Unforeseen	Improbable	Low probability	Medium probability	Highly probable	Definite								
0 - 0.1 %	0.1 - 5 %	5 - 15 %	15 - 40 %	40 - 75 %	75 - 100 %								
Probability													

Magnitude		Duration		Scale	
10	Very high	5	Permanent (>10 years)	5	International
8	High	4	Long-term (5-10 years)	4	National
6	Moderate	3	Medium-term (1-5 years)	3	Regional
4	Low	2	Short term (<1 year)	2	Local
2	Minor	1	Immediate	1	Site only
				0	None

Acceptable (<30)	**Mitigation not required**
Moderate (30-60)	**Mitigation required. If not mitigated it might prevent implementation**
High (>60)	**May prevent implementation if no mitigation is available**

Significance = (Magnitude + Duration + Scale) * Probability

Figure 21: Proposed Key to Risk Ranking Matrix

12 RISK MANAGEMENT PLAN

12.1 Introduction

According to GN.715 of 2018, the risk management plan should include the following as a minimum:

- SANS 10234 classification of the paste or ash slurry used in backfilling;
- Safety data sheet (SDS) should the material be hazardous;
- List of activities during backfilling (based on process flow chart);
- Risk description and actions to minimise/manage the risk of each activity;
- Who will be responsible for the actions/mitigation; and
- Method of recording volumes/quantities of the material used for backfilling, including the number of enterprises established or supported and the extent to which previously disadvantaged individuals have been supported.

Risk mitigation involves the identification of actions/measures to reduce either the likelihood that a risk will occur (preventative action) and/or reduce the impact of a potential risk that will occur (contingency action). It should also include identifying the stage of the project when the action should be undertaken, either prior to implementation or during the operation of the project.

Restriction and mitigation need to be developed for:

- Underground void;
- Open pit;
- Operational mine; and
- Defunct mine.

Table 7: Examples of mitigation measures for different types of mines

Example of Risk / Restriction	Example of Mitigation Approach
Underground void: contamination of groundwater	• Disposal to take place below confining layer (aquiclude), which separates backfill from clean shallow aquifer which is used • A comprehensive groundwater investigation should be conducted. This should include numerical modelling of flow for the case of an unfilled void as well as for the backfilled case by making use of the material properties of the placed and cured backfill material based on the investigations described above (Section 7)
Underground void or open pit: decant of contaminated water	• Decant would have to be intercepted, pumped and treated
Open pit: contamination of surface water	• Water table in backfilled pit to be kept below subsurface decant point
Operational mine: Collapse of backfill into operating areas	• Backfilled areas to be geotechnically sealed
Defunct mine: incomplete understanding of voids due to illegal mining	• Do survey using geophysical techniques such as ground-penetrating radar

12.2 Conveyance system

Risks / Restrictions	Mitigation
Plugging of pipelines/injection boreholes	• Effective flushing of pipelines at the completion of each backfill pour to ensure that residual material is not retained in the pipes. • Development of a comprehensive understanding of the rheological behaviour of backfill paste/slurry based on laboratory rheometer studies. • Installation of pressure transducers to provide an early warning to operators when paste consistency exceed design limits.

Risks / Restrictions	Mitigation
	• Monitoring of paste density by online densitometer during operations. • For highly reactive ash pastes the use of commercial set retarders may be warranted to slow down cementation.
High pumping pressure	• Divide the system into a series of vertical and horizontal sections to reduce the maximum pressure in the system. • Use pressure relieve systems (burst plates) • Include secure pipeline supports in the design • Appropriate design. of the pipework
Deterioration of injection system	• Use appropriate casing
Pipeline wear	• Avoid sharp bends during design. • Limit linear velocity • Select appropriate inner lining of pipes • Regular inspection • Pipe rotation • Scheduled replacement

12.3 Deposition

Risks / Restrictions	Mitigation
Dry deposition	
• Ground failure	• Ensure adequate ground support above the tipping areas • Ensure stability of the working floor is managed • Control exposure to the backfill material
Slurry	
• Segregation of materials, based on particle size and phase (solid versus liquid) • Barricade failure • Bleeding	• Maintain optimal particle size (< 75 mm) • Minimise the quantity of free water at the surface of the backfill, as this tends to create layers of differential permeability. • Allow for adequate drainage of free water • Minimise the amount of water that will drain from slurry by maintaining optimum solid:liquid ratio

Risks / Restrictions	Mitigation
Paste	
• Barricade failure	• Allow for adequate drainage of free water • Minimise the amount of water that will drain from slurry by maintaining optimum solid : liquid ratio

12.4 Water management

Risks / Restrictions	Mitigation
Decant	• Maximize the proportion of bleed / slurry water recovered as return to prevent decant into the mine workings, and to limit the impact on the groundwater • Backfill recipe should be designed to use the minimum amount of water possible
Water quality	• If water is pumped out of the backfill site at a rate exceeding the rate of bleed water production, then groundwater pollution should be prevented.

13 MONITORING PLAN

The aim of the monitoring program is to protect the receiving environment and ensure that set/prescribed limits are not exceeded. Regular monitoring will be required for:

- Quantity and chemistry of paste/slurry used for backfilling;
- Surface water quality (if applicable, for example if a pipeline crosses a stream or wetland);
- Groundwater quality; and
- Placement of paste and filled voids.

In development of a monitoring plan, consideration should be given to the guidelines set out in the DWAF (2007) Best Practice Guideline for Water Monitoring Systems, and monitoring requirements that may already be specified for the site in a WUL or EMPr – noting that changes in the monitoring frequency, locations or parameters might be required due to backfilling.

13.1 Paste/slurry quantity

- Sampling points: before backfilling
- Frequency: daily

13.2 Paste/slurry chemistry

- Sampling points: before backfilling

- Frequency: after changes in sources, or every 5 years as per GN. R.634 of 2013
- Variables: constituents of concern identified during the chemical characterisation of the paste

13.3 Surface water (if applicable)

- Sampling points: upstream and downstream of potential impacted area
- Frequency: monthly
- Variables: constituents of concern identified during the chemical characterisation of the paste/slurry, aquatic habitat.

13.4 Groundwater

- Sampling points: upstream and downstream of the direction of flow from the backfilled area
- Frequency: quarterly
- Variables: constituents of concern identified during the chemical characterisation of the paste/slurry and mine void

13.5 Paste placement

Annual survey or report on filled voids to be reported with cumulative volumes of excluded waste used.

14 REPORTING

Reporting to the authorities should include the following:

- Waste Generator:
    - Updated Risk Management Plan to DEA (annually);
    - Reports “arising” from the Risk Management Plan
- User/receiver of material:
    - Volumes/quantities of the material used for backfilling (annually);
    - Independent WUL Audit to DWS (frequency stipulated in WUL);
    - Water monitoring reports to DWS (frequency stipulated in WUL);
    - Independent Performance Assessment to DMR (as stipulated in EMPr);
    - Independent EA Audit to DMR (as stipulated in EA);
    - Survey / report of filled voids to DMR (annually)

15 CONCLUSION

This document gives guidance to proponents of backfilling of mine voids with ash in the form of a slurry, dense slurry or as a pozzolanic paste. Whilst it may have relevance to other applications, it has been prepared with specific reference to the backfilling of coal or gold mines with coal ash produced from combustion or gasification processes. The structure of the document allows all stakeholders interested in pursuing an ash backfill evaluation to understand the technical and regulatory processes that one needs to follow, in order to implement a successful backfilling operation. Given that a backfilling operation requires numerous stakeholders (i.e. different departments within the ash producers and ash receivers namely mines, regulators, community, etc.), the document presents these aspects from a regulatory and technical perspective.

The main concepts discussed in the document include:

- Regulatory requirements both from the perspective of ash producer and receiver
- Net Environmental Benefit (NEB) concept, which is critical in evaluating the total life cycle assessment of each backfilling option (incorporating both questions around ash generation and disposal and questions around mine closure and backfilling) , which is used in assessing the viability of each backfilling option individually and comparatively
- Technical evaluation of backfilling materials in terms of characterization, testing methods, and material behavioural evaluations.
- Risk assessment, mitigation plan, monitoring and reporting which would all be required from a regulatory compliance perspective in evaluating backfilling through the life cycle of the operation

This should be considered a living document, that will require ongoing updates as the science and engineering develop and given the rapidly-evolving regulatory environment.

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