# REFINEMENT OF THE DECISION SUPPORT SYSTEM FOR METALLIFEROUS MINE RESIDUE DISPOSAL FACILITIES

Report to the
Water Research Commission

by

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## EXECUTIVE SUMMARY

The Water Research Commission (WRC) awarded a contract in 2004 to Golder Associates (in partnership with a number of organisations) to develop a first order Decision Support System (DSS) for the sustainable design, operation and closure of mine residue disposal facilities. It was foreseen that this project would represent the first of three phases, with the first phase focussed on the development of a first order DSS.

The first phase of this research programme was completed in 2008 and documented in WRC Research Report No 1551/1/08. The Phase 1 research identified 3 research objectives for phase 2, which was aimed at the refinement of the first order DSS. Phase 3 of the research project was envisaged to be the development of a comprehensive DSS covering all aspects of sustainability.

The research objectives for Phase 2 focussed on the refinement of the DSS and included:

1. Develop a performance demonstration protocol, i.e. procedure or guidance that can be used to demonstrate the acceptability of particular technique, technology or approach;
2. Alignment of the DSS to current legislation;
3. Undertake specialist studies of specific knowledge gaps identified during the development of the first order DSS in order to better understand the aspects and to provide better guidance in the DSS for users. Specialist studies included water and surface stability related studies. The water studies included mine residue disposal facility water balances, depth of oxidation zones, pore water quality evolution and protocols to handle uncertainty in the prediction of mine residue disposal facility impacts. The surface stability studies related to erosion rates and the effectiveness of cover technologies, the effect of slope geometry on surface stability and protocols to monitor surface stability during the post closure phase; and
4. Identify and assess new and promising technologies and approaches that could be used as supporting guidance in the DSS and that could further play a role in managing water resource degradation caused by mine residue disposal facilities.

The second phase of the project was awarded to Golder Associates in association with the same organisations that were involved in the development of the first order DSS. This research report details the outcomes of Phase 2 – Refinement of the first order DSS.

A summary of the outcomes of the various components of the Phase 2 research is provided below:

**Development of a demonstration protocol**

Fundamentally, the DSS is designed to lead to a decision and is captured in final questions that are posed in such a way that if answered, it will lead to a decision higher up in the DSS hierarchy. This final or end-of-line question can either be answered by providing the necessary technical requirements, or comply with said standards, or by following a demonstration protocol in support of answering the question.

A demonstration protocol was developed to provide a mechanism for when a question cannot be answered in the positive using existing knowledge and predictive models, to demonstrate the applicability and acceptability of using a particular technology, approach or technique. The demonstration protocol, although developed for surface stability applications, can also be applied for water related aspects. The demonstration protocol includes guidance to the regulator, the proponent and consultants on:0

- Selecting and prioritising potentially feasible solutions or technologies;
- Comparing the potential solutions to predictive models;
- Undertake appropriately scaled field testing; and
- Documenting the results in support of using the particular technology or technique.

The demonstration protocol will form a key characteristic of the comprehensive DSS.

**Alignment of the DSS with current legislation**

The following bullets summarises the key outcomes of assessing the alignment of the DSS to current legislation which is particularly relevant for the development of the comprehensive DSS:

- The DSS has no legal standing. However, it has been developed to be aligned with the national environmental management principles and to support applications by proponents for current or new mine residue disposal facility schemes.
- The DSS will, based on the preliminary DSS and once developed, provide for the procedure that covers the scope of investigations to define and quantify the environmental risks associated with a current or proposed scheme.
- It is recommended that once the comprehensive DSS is developed that the DSS be converted to guidelines in terms of regulation 73 and/or 74 of Government Notice R385 to the National Environmental Management Act in order to attain official recognition in both the Basic Assessment and Scoping and Environmental Impact Assessment procedures which forms the core vessel for application of the DSS.

It is expected that the development of the comprehensive DSS will include specific legal requirements as recommended by the outcome of the phase 2 study and that it, in principle, will comply with the requirements of Administrative Law and the National Environmental Principles.

**Progress on specialist studies related to water and geochemistry**

Four specialist studies related to water and geochemistry were recommended for phase 2 of the DSS research project, including (1) depth of the oxidised zone, (2) tailings water balances, (3) pore water quality evolution and (4) protocols to handle uncertainty in model predictions.

The aim of the studies were specific to the development of the comprehensive DSS in that it assessed whether enough information/understanding existed to develop the necessary guidance to the user of the DSS to answer a particular water related question in the DSS or not. Should not enough information or understanding be available, the studies had to recommend using either a demonstration protocol, or a research project for Phase 3, to address the particular knowledge gap.

In all four cases, enough information was available to develop guidance on how a particular question can be answered in order to make a decision based on the technical studies conducted in support of the answer to the question. However, in all four cases, although the technology exists to predict future behaviour, there is a requirement to follow a demonstration period in order to calibrate and verify future predictions. Guidance is provided to the regulator on how the monitoring should be done and for how long. Furthermore, since prediction can never be an exact science, guidance was also developed for the assessment, quantification and documenting uncertainty associated with the assessment of the development of the oxidised zone on mine residue disposal facilities, tailings water balances and the evolution of pore water quality in the mine residue disposal facilities. The principles on which these protocols were developed are also applicable for other water and geochemistry related aspects as well as the surface stability aspects.

**Progress on specialist studies related to surface stability**

Surface stability (defined as the stability of the outer surface of the mine residue disposal facility against erosion caused by wind and water) specialist studies focussed on the erosion rate and effectiveness of cover technologies as well as the development of monitoring protocols to monitor and check surface stability during the post closure phase of a mine residue disposal facility.

In the evaluation of erosion rates, slope geometry and engineered erosion mitigation on mine residue disposal facilities were divided into geotechnical and bio-engineering aspects with some overlapping between the two aspects.

In terms of the geotechnical approach, benchmark erosion rates, measured on analogue sites in the Witwatersrand area, were established. Erosion rates are sensitive to slope angle and length, with overall erosion rates increasing linearly with slope angle. Optimum slope angles are proposed and rock cladding is proposed as an effective mitigation measure against erosion.

From a bio-engineering perspective, only the height, slope lengths, slope gradient and slope geometry of the mine residue disposal facilities can be optimised in the design phase which will also be dictated by the type of protection cover and end land-use. The end land-use dictates the first level of cover selection. The second factor determining cover choice is the presence or absence of sulphide minerals in the tailings. The third level of cover selection requires modelling and is dictated by the availability and type of cover materials and the slope length and slope gradient of the mine residue disposal facility. The main knowledge gaps with respect to bio-engineering approach still remain with vegetation issues which are strongly interrelated with the above mentioned support guidance.

In both approaches, monitoring protocols were developed in order to follow a demonstration approach as support for using particular slope geometry design and/or cover technology for a current or proposed mine residue disposal facility.

**Identify new and promising technologies**

The identification of new and promising technologies was addressed largely as part of the specialist studies and included in the specialist reports (appendices to the main research report which appear on the CD found at the back of the report). The approach that was followed in this task was to contact relevant stakeholders/role players (regulators, practitioners, technology providers) and document new and promising technologies. The team engaged with specific technology providers to assess new technologies.

In addition, a separate study focussed largely on a literature review of papers and conference proceedings recently published and categorised technologies in four categories; (1) modelling, (2) process/chemical related, (3) vegetation and natural interventions and (4) laboratory and field trials. Discussions with practitioners also yielded new technologies. Many new and promising technologies were identified and evaluated against criteria that were developed to identify the technologies that should be considered in the future, resulting in seven technologies proposed for further research. The technologies proposed for further research are:

- Natural analogues
- Metallophites and Phytomining
- Apply old technologies with more precision
- Design and construct mine residue disposal facilities with flatter slopes
- Designing scalloped slopes
- Paste rock
- On-site rainfall simulations.

**Conclusions**

In conclusion, the main objectives of Phase 2 (refinement of the first order DSS) of the development of a comprehensive DSS have largely been achieved and incorporated into the current first order DSS. The current DSS is now developed to a point where the methodologies and protocols have been developed and established for the development of the comprehensive DSS (Phase 3).

**Recommendations for Phase 3 of the Research Programme**

As mentioned at the start of this executive summary, Phase 3 of the main research programme is the development of a comprehensive DSS that builds on the experience of the preliminary DSS and the findings of Phase 2. Although Phase 3 is defined as one phase, it will consist of a number of project steps that will lead to the development of the comprehensive DSS. Furthermore, due to the dynamic nature of knowledge developed around the various topics in the DSS, it is envisaged that the DSS guidance components (decision and technical guidance) will change in future as more knowledge becomes available, requiring the DSS to be a dynamic tool. Recommendations are provided for the development of the comprehensive DSS in Phase 3 of the research programme.

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## LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| AMD | Acid mine drainage |
| BACM | Best Available Control Measures |
| BACT | Best Available Control Technology |
| BAT | Best Available Technology |
| BATEA | Best Available Treatment Economically Achievable |
| BCPCT | Best Conventional Pollutant Control Technology |
| BCT | Best Control Technology |
| BDAT | Best Demonstrated Available Technology |
| BDCT | Best Demonstrated Control Technology |
| BDT | Best Demonstrated Technology |
| CM | Chamber of Mines |
| DEAT | Department of Environmental Affairs and Tourism |
| DME | Department of Minerals and Energy |
| DSS | Decision-support system |
| DWAF | Department of Water Affairs and Forestry |
| ECA | Environment Conservation Act No. 73 of 1989 |
| IAPs | Interested and affected parties |
| ISC | Internal steering committee |
| ML | Metal Leaching |
| MPRDA | Minerals and Petroleum Resources Development Act No. 28 of 2002 |
| NEMA | National Environmental Management Act No. 107 of 1998 |
| OSC | Operational steering committee |
| PHD | Pulles Howard and de Lange Incorporated |
| QLD | Queensland |
| RUSLE | Revised Universal Soil Loss Equation |
| TDS | Total dissolved solids |
| UKZN | University of KwaZulu-Natal |
| UP | University of Pretoria |
| US EPA | United States Environmental Protection Agency |
| WRC | Water Research Commission |

# LIST OF TERMS

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| BACT | Best Available Control Technology (BACT): The application of the most advanced methods, systems and techniques for eliminating or minimising discharges and emissions on a case-by-case basis as determined by EPA. BACT represents an emission limit based on the maximum degree of reduction of each pollutant as described in regulations under the CAA. The determination of BACT takes into account energy, environmental, economic effects and other costs (ACAT, 2007). |
| BATEA | Best Available Technology Economically Achievable (BATEA): Originally described under Section 304(b)(2)(B) of the CWA, this level of control is generally described as the best technology currently in use and includes controls on toxic pollutants (ACAT, 2007). |
| BDAT | BDAT, as identified by EPA, is the most effective commercially available means of treating specific types of hazardous waste. The BDATs may change with advances in treatment technologies (US EPA, 2007). |
| BMP | Best Management Practices (BMP): Procedures or controls other than effluent limitations to prevent or reduce pollution of surface water (includes runoff control, spill prevention and operating procedures) (ACAT, 2007). |
| Decision | A decision is defined as an action that must be taken when there is no more time for gathering facts (Moody, 1983:4). |
| Decision-making | The sequence of steps, actions or procedures that result in decisions, at any stage of a scheme (DEAT, 2002:21). |
| Decision-support system | A decision-support system (DSS) is a system that supports decision making by assisting in the organisation of factors and relations between the latter within a rational framework (Sage, 1991:1). |
| Environment | Environment has a number of definitions depending on the context:<br>• environment means the aggregate of surrounding objects, conditions and influences that influence the life and habits of man or any other organism or collection of organisms (ECA, 1989);<br>• environment means the surroundings within which humans exist and that are made up of:-<br>- the land, water and atmosphere of the earth;<br>- micro organisms, plant and animal life;<br>- any part or combination of the afore-mentioned and the interrelationships among and between them; and<br>- the physical, chemical, aesthetic and cultural properties and conditions of the foregoing that influence human health and well-being (NEMA, 1998);<br>• environment means the associated cultural, social, soil, biotic, atmospheric, surface and ground water aspects associated with landfill that are, or could potentially be, impacted on by the landfill (DWAF, 1998:G-4);<br>• or the environment is defined as those parts of the socio-cultural, biophysical and economic environment affected by the scheme (after DEAT, 2002:20). |

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| Environmental impact | An environmental impact is the positive or negative change to the surroundings of a scheme including water, air, land, natural resources, flora, fauna, and their interrelation and which result from aspects associated with a scheme (after DEAT, 2002:20 and SANS 14001, 2005:2). |
| Erosion | Erosion includes a group of processes by which earth materials are entrained and transported across a given surface (Galetovic, 1998:1-1). |
| Fatal flaw | Any problem, issue or conflict (real or perceived) that could result in a scheme being rejected or stopped (DEAT, 2002:21). |
| Hazard | Hazard refers to the capacity of a substance, a structure, an activity or an event to produce an adverse effect on life or property, including health, safety or environment (DME (QLD), 1995). |
| Leaching | Leaching involves removal of minerals from the ground particles by direct contact with solvent, usually a strong acid or alkaline solution depending on the type of ore (Vick, 1883:8). |
| Mine residue | Mine residue includes any debris, discard, tailings, slimes, screenings, slurry, waste rock, foundry sand, beneficiation plant waste, ash and any other waste product derived from or incidental to the operation of a mine or activity and which is stockpiled, stored or accumulated for potential re-use or recycling or which is disposed of (DWAF, 1999:2). |
| Mine residue disposal facility | Mine residue disposal facility includes any dump, tailings impoundment, slimes dam, ash dump, waste rock dump, in-pit deposit and any other heap, pile or accumulation of residue remaining at termination, cancellation or expiry of a prospecting right, mining right, mining permit, exploration right or production right (after MPRDA, 2002). |
| Mine residue stockpile | Mine residue stockpile means any debris, discard, tailings, slimes, screening, slurry, waste rock, foundry sand, beneficiation plant waste, ash or any other product derived from or incidental to a mining operation and which is stockpiled, stored or accumulated for potential re-use, or which is disposed of, by the holder of a mining right, mining permit or production right (MPRDA, 2002). |
| Phreatic surface | The phreatic surface is the level of saturation in the impoundment and the embankment – i.e. the surface along which pressure in the fluid equals atmospheric pressure. In natural systems without flow it is often equal to the water table. |
| Risk | Risk refers to a combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequences of the occurrence. Hazard refers to an attribute or situation that in particular circumstances could lead to harm (DEFRA, 2000). |
| Sediment yield | The sediment yield from a surface is the sum of the soil losses minus deposition in macro-topographic depressions, at the toe of the hill slope, along field boundaries, or in terraces and channels sculpted into the hill slope (Galetovic, 1998:1-1). |
| Significance | Impact magnitude is the measurable change, i.e. intensity, duration and likelihood. Impact significance is the value placed on the change by different affected parties, i.e. level of significance and acceptability. It is an anthropocentric concept, which makes use of value judgements and science-based criteria, i.e. socio-cultural, biophysical and economic. Such judgements reflect the political reality of impact assessment in which significance is translated into public acceptability of impacts (DEAT, 2002:21). |

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| Soil loss | Soil loss is that material actually removed from the particular hill slope or hill slope segment. The soil loss may be less than erosion due to on-site deposition in micro-topographic depressions on the hill slope (Galetovic, 1998:1-1). |
| Sphere of influence | Sphere of influence is the term used in this report to describe the three-dimensional mine residue storage or disposal facility zone of influence within which an effect on the environment is anticipated. This zone is the spatial overlay or sum of the different environmental aspect zones of influence and is also representative of a particular configuration at a specific moment in time. |
| Stakeholders | A subgroup of the public whose interest may be positively or negatively affected by a proposal or activity and/or who are concerned with a scheme or activity and its consequences. The term therefore includes the proponent, authorities and all interested and affected parties (IAPs) (DEAT, 2002:23). |
| Sustainable development | Sustainable development means the integration of social, economic and environmental factors into planning, implementation and decision making so as to ensure that mineral and petroleum resources development serves present and future generations (MPRDA, 2002 and NEMA, 1998). |
| Total dissolved solids | Total dissolved solids (TDS) is a term that expresses the quantity of dissolved material in a sample of water. |
| Vadose zone | Vadose zone is the zone containing water under pressure less than that of the atmosphere, including soil water, intermediate vadose water, and capillary water. This zone is that between the land surface and the surface of the zone of saturation, that is, the water table. |
| Water table | Water table is the surface between the vadose zone and the groundwater, that surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere. |

# 1 INTRODUCTION

The Water Research Commission (WRC) of South Africa developed and published in 2008 a Preliminary Decision Support System (DSS) for the Sustainable Design, Operation and Closure of Mine Residue disposal facilities (WRC Report No. 1551/1/08). This preliminary DSS was the first phase of a research project that was envisaged to be developed over a period of 5-10 years, ultimately leading to the development of a comprehensive DSS.

The aim of the comprehensive DSS is to support regulatory authorities in assessing the acceptability of current or proposed mine residue disposal facilities and to be of equal value to proponents and consultants for the same purpose.

The following phases were envisaged:

- Phase 1: Development of a preliminary DSS making use of available local and international information and identify knowledge gaps that need to be addressed in order to develop and expand the final DSS. The preliminary DSS focused on the Bio-physical aspects, specifically water and surface stability.
- Phase 2: Research and investigate the gaps indentified in Phase 1.
- Phase 3: Develop a comprehensive DSS that builds on the experience with the preliminary DSS and findings of Phase 2.

The outcome of Phase 1 was documented in WRC report No 1551/1/08. The WRC appointed Golder Associates in association with Frazer Alexander, the University of Witwatersrand and the University of Pretoria, in 2008 to conduct Phase 2 of the research. The outcome of Phase 2 is documented in this research report and recommendations for Phase 3 are provided in Section 0 of this report.

## 1.1 Research Aims and Approach

The WRC's terms of reference for the second phase of the DSS research project had three main objectives:

1. Develop a performance demonstration protocol, i.e. procedure or guidance that can be used to demonstrate the acceptability of a particular technique, technology or approach;
2. Undertake specialist studies of specific knowledge gaps identified during the development of the first order DSS in order to better understand the aspects and to provide better guidance in the DSS for users; and
3. Identify and assess new and promising technologies and approaches that could be used as support guidance in the DSS and that could further play a role in managing water resource degradation caused by mine residue disposal facilities.

The specific aims and research approach for each of these objectives are discussed in more detail below.

### 1.1.1 Research inception report

The first task in the refinement of the DSS (Phase 2) was to develop an Inception Report (WRC report No 1551/1/08, and Appendix J). The key objective of the inception report was to develop a work plan for the various tasks in Phase 2 of the research. More specifically the aim of the Inception Report was to:

- Act as internal document to record the understanding of the project requirements;
- Assist the team to understand the brief;

- Define the objectives, methodologies, tasks, knowledge gaps, deliverables and anticipated outcomes of the research to be undertaken;
- Provide background information relevant to the project; and
- Consolidate supporting information.

### 1.1.2 Performance demonstration protocol

The aim of developing a performance demonstration protocol was to provide guidance for proponents/regulators on the acceptability of a technology, technique or approach for solving a potential or actual problem.

The approach and methodology that was followed in the research tasks included:

1. Literature review.
2. Reviewing similar approaches applied elsewhere in the world such as the United States Environmental Protection Agency's (US EPA) Best Demonstrated Available Technology (BDAT) approach.
3. Extracting the essence and understanding the underlying philosophy of developing, applying and implementing BDAT approaches. Decision making systems or processes allowing the use of a BDAT approach provide (usually proponents) with the opportunity to demonstrate what is being done (or proposed) meets certain criteria or is acceptable even though the underlying science and mechanisms are not fully understood at present.
4. Selective communication with agencies (government authorities) implementing and following this approach.
5. Distributing the developed protocol to key role players and decision makers within South Africa to obtain comments and input into the process.

Items 1 to 3 have been completed as part of Phase 2. Items 4 and 5 will be completed in Phase 3.

The need for an evaluation of how the final DSS should be aligned with legislative requirements in context of the authorisation of a particular mine residue disposal facility scheme, was identified during the development of the first order DSS. The scope of work therefore included research to assess some key questions related to the legal standing of the DSS and how the DSS can be aligned with the various legislative and authorisation requirements for mine residue disposal facility schemes.
Golder Associates subcontracted Cameron Cross Inc., attorneys specialising in environmental, health and safety law, to assist in the evaluation. The question "Does the DSS have any legal standing?" was evaluated in terms of general administrative legal principles and alignment with national environmental management principles. Furthermore, the question "Can the DSS be aligned with legislation?" was evaluated in terms of regulatory procedure and material regulatory requirements.

### 1.1.3 Specialist studies of identified knowledge gaps

There were seven specialist knowledge gaps that were identified in the first phase of the project. These are grouped as follows:

- Water related topics;
  - Depth of the oxidised zone;
  - Tailing water balances;
  - Modelling of pore water quality evolution; and

- Development of protocols to handle uncertainty in models.

- Surface stability topics;
  - Erosion rates and effectiveness of cover technologies;
  - Effects of slope geometry on mine residue disposal facility stability; and
  - Develop protocols and techniques to check surface stability after closure.

The general approach and methodology that was applied in the research of these topics is summarised as follows:

- Specific project team members led in the specialist studies, supported by students who primarily assisted in the literature reviews and documentation;
- Specialist studies were primarily desktop studies. However, in certain selected instances experimental and testing work as well as site inspections were conducted;
- Project team members provided the necessary context for the literature reviews and were also responsible for documenting the study findings in a format that could be integrated into the DSS; and
- The approach and methodology was specific for each of the components and the details were provided in the report.

In general, the aims of each of the proposed specialist studies were:

a. To explain the relevance of the particular knowledge gap in the DSS and how better knowledge in this area would allow/support decision making using the DSS. This could be related to answering specific questions in the DSS or to provide guidance on how to go about in answering the questions and what protocol to follow;
b. To document the state of the art knowledge on the particular knowledge gap based on local and international releases and science;
c. Should the current knowledge provide enough guidance for decision making in the DSS, proceed to f;
d. Should the current knowledge not provide enough guidance for decision making in the DSS, define what the key knowledge gaps were that needed to be addressed to enable the use of this knowledge in the DSS;
e. Determine whether the above knowledge gap could be addressed by the South African research community and write the detailed scope of work/research methodology to address the particular knowledge gap; and
f. Extract from the current knowledge gap guidance for the DSS system and document it in a format that can be incorporated into the DSS system.

### 1.1.4 New and promising technologies

The aim of this task was to ensure that the first order DSS benefits from experience, intellectual capital and current innovation generated by the global community and to prevent the duplication of research initiatives.

This was addressed largely as part of the specialist studies and were included in their reports. The approach that was followed in this task was to contact relevant stakeholders/role players (regulators, practitioners, technology providers) and document new and promising technologies. The team engaged with specific technology providers to assess new technologies.

In addition to this, a separate study focussed largely on a literature review of papers and conference proceedings recently published and categorised technologies in four categories; (1) modelling, (2) process/chemical related, (3) vegetation and natural interventions and (4) laboratory and field trials.

Discussions with practitioners also yielded new technologies. Many new and promising technologies were identified and evaluated against criteria that were developed to identify the technologies that should be considered in the future.

### 1.2 Document structure

The research tasks for phase II of the development of a comprehensive DSS consisted predominantly of specialist studies which were documented in specialist research reports. In order to provide context for these specialist studies, an over arching research report was prepared with the following objectives that also forms the structure of the report:

1. Background information on the DSS development research project (Section 1);
2. Provide the research aims, objectives and approach followed in the Phase 2 research project (Section 1);
3. Provide summaries of the outcome from each of the research tasks that constitute the phase 2 research projects. These summaries are provided for the three focused areas of the phase 2 research project, including performance demonstration protocol (Section 0), water and geochemistry aspects (Section 3) and surface stability aspects (Section 4);
4. To discuss the research progress in the context of how the phase 2 research tasks supports the development of the final comprehensive DSS (Section 5);
5. Provide recommendations for the development of the comprehensive DSS (phase 3) research tasks (Section 0).

The full research was broken up into the three focus areas, described in Section 1.1.2 and 1.1.3 – performance demonstration protocols and legal assessment, water and geochemistry related topics, and surface stability aspects.

A key initiative of the research is the transfer of knowledge to those that previously could not benefit from research such as this. Section 0 describes the capacity building that formed part of this project.

## 2 PERFORMANCE DEMONSTRATION PROTOCOLS (INCLUDES LEGAL ASPECTS)

The terms of reference for the second phase of DSS development project included three main objectives. This section addresses the objective- the development of a performance demonstration protocol that can be used to demonstrate the acceptability of a particular technique, technology, solution or approach. In addition to this, the DSS was aligned with legislative requirements in context of the authorisation of a particular mine residue disposal facility scheme.

The specialist report on the Performance Demonstration Protocol is provided in Appendix A. The assessment of the legal status of the DSS and its alignment with authorisation procedures and requirements are provided in Appendix B.

### 2.1 Development of PDP protocols (Appendix A)

The first phase of the project identified the following two key issues that typically prevented authorities from approving proposed mine residue disposal schemes from mining companies:

- Long term erosional stability of sloping surfaces and;
- Long term groundwater related impacts with particular reference to geochemical outcomes.

The Phase 1 report (Rademeyer et al., 1997) recommended that, where the above uncertainties were cause for too much uncertainty, mining companies be permitted to run field scale demonstrations of their proposed mitigation schemes. The recommendation went further to suggest that a performance demonstration protocol be developed in Phase 2 to guide mining proponents and authorities through the process of design of suitable demonstration trials, monitoring thereof and reporting of the results in such a manner as to facilitate decision making. This section summarises the performance demonstration protocol that has been developed.

The main steps in the recommended performance demonstration protocol are:

- Selecting and prioritising potentially feasible solutions or technologies;
- Comparing the potential solutions through predictive modelling;
- Undertaking appropriately scaled field testing;
    - documenting experimental field test results;
    - interpreting results; and
- Checking if the results meet the criteria.

The results of the field trials will provide the basis for proponents to substantiate their proposals. In order to do so it was however essential that the field trials are conducted in such a manner as to produce incontrovertible evidence that the uncertainties that would normally be cause for rejection of proposals have been eliminated. The demonstration must therefore be scientifically designed and carried out.

## 2.2 Implementability of the DSS for Mine Residue Disposal Facilities in a Legal Context (Appendix B)

Decision making within the DSS must comply with two key aspects – namely the rules of decision making in a legal context, and related hereto, the required scope of investigations to sufficiently define environmental risks associated with mine residue disposal facilities and associated mitigating measures.

The preliminary DSS provides for a procedure that covers the required scope of investigations to define the environmental risks, provided that the research gaps related hereto are sufficiently resolved through further work. However, the ability of the DSS to comply with the rules of decision making from the Regulator's perspective also requires validation.

The implementability of the DSS in a legal context and from the Regulator's point of view was assessed and gaps for consideration in the further refinement of the DSS to resolve the difficulty of obtaining approvals for mine residue disposal facilities were identified.

The DSS in its current form pursues the overall objectives of environmental law which, broadly speaking, is to protect the environment. In this context it does not serve as a vehicle for interaction with the Regulator within a specific procedural arrangement and therefore requires enhancement in this area with specific reference to the Administrative Law and the Constitution of South Africa.

It is against this background that the implementability of the DSS has been evaluated.

The assessment philosophy that was therefore followed in this study revolves around:

i) The realisation of the limitations inherently part of the decisions associated with future impacts that may results from present decisions;

ii) The requirements of the law that governs decision making by the Regulator and by persons whose actions, in the context of mine residue disposal facilities, may affect the environment; and

iii) The fact that mine residue disposal facilities approvals vests in more than one Department due to the fact that the impacts as caused by mine residue disposal facilities relate to different departmental mandates.

Based on the assessment it was concluded that the DSS clearly presents immediate benefits to enhanced regulatory decision making in respect of mine residue disposal facility applications.

Of equal importance however is recognising the fact that any potential Achilles heel of the DSS in its current form is concealed in what the DSS omits rather than in the first-rate tool it offers. This from a legal administrative point of view could unfairly (although lawfully) distract from its real potential.

In this context it is concluded that both the direct (Table 1 and 2 in the Report) and implied recommendations (i.e. various statements made in the Report) should be assessed for implementation, starting with those legal elements that have been omitted from the DSS and proceeding with aspects that will result in a distinct further improvement in the implementability of the DSS.

## 2.3 Is the DSS aligned with relevant legislative requirements? (Appendix C)

The scope of work for the second phase of the DSS development project included an evaluation of how the final DSS should be aligned with legislative requirements in context of the authorisation of a particular mine residue disposal facility scheme.

The need for this evaluation was identified during the development of the first order DSS and the terms of reference developed from various Steering Committee meetings. As per the Inception Report (WRC report No 1551/1/08, and Appendix J), this assessment arrived at assessing some key questions related to the *legal standing of the DSS* and *how the DSS can be aligned with the various legislative and authorisation requirements* for mine residue disposal facility schemes. These questions are answered in this section.

Golder Associates subcontracted Cameron Cross Inc., attorneys specialising in environmental, health and safety law, to conduct the evaluation. The specific questions developed for this assessment and the answers based on the specialist report received from Cameron Cross Inc., is summarised below:

The full text is included in Appendix C, which includes the report by Cameron Cross Inc.

### 2.3.1 Does the DSS have any legal standing?

General Administrative Legal Principles

From a general administrative legal principle perspective, the DSS generally underscores and enhances the legal principles of administrative decision making by, amongst others:

- Minimising the potential for inclusion of irrelevant considerations in the regulatory decision making process;
- Minimising the potential undue adherence to fixed principles in the regulatory decision making process;

- Supporting the pursuance of common sense where appropriate and offers opportunities for a reasonable departure from the DSS and guidelines;
- Securing a rational connection between the regulatory decision and the motivation therefore; and
- Securing a rational decision trail which is essential to both regulators and applicants in instances where the outcome of a decision is legally challenged.

It is of course essential that the principles involved be based on sound science and/or best practice. Early disclosure of the methodology of the DSS within the application process is also essential. Failing to disclose the DSS methodology and rationale either directly or by publication of the DSS as official policy may result in the eventual decision being vulnerable to legal challenge on various procedural legal grounds, but predominantly on the basis that the decision making process was not procedurally fair.

<u>Alignment with National Environmental Management Principles</u>

It is important that the DSS incorporate waste minimisation or the avoidance of waste in principle. This aspect however cannot be evaluated from a water and surface stability module perspective (which assumes that waste already exits), and must form part of the final DSS in due course.

The uncertainty control mechanisms in the DSS appear to deal with the uncertainty principle elegantly, assuming that proper criteria and guidelines are compiled. The same applies to the Best Practicable Environmental Option principle and lifecycle management.

The DSS itself is also a baseline approach for proper inter governmental coordination from a material perspective. Although not the primary purpose, the schematic review will also seek to establish a baseline approach for proper procedural inter governmental coordination.

### 2.3.2 Can the DSS be aligned with legislation?

<u>Regulatory procedure</u>

From a regulatory procedural perspective, the NEMA process is critically important in the assessment of mine residue disposal facilities for various reasons set out in this assessment. It is recommended that the DSS once fully developed, be converted to guidelines in terms of regulation 73 and/or 74 of Government Notice R 385 to the NEMA in order to attain official recognition in both the Basic Assessment and Scoping and Environmental Impact Assessment procedures which forms the core vessel for application of the DSS. The DSS however also guides the decisions of the DWAF and DME during the integrated authorisation processes.

The DSS must be applied where the final statutory discretion is applied as conferred by law to the various decision makers. These points are respectively at:

- Section 39(4) MPRDA (DME);or
- Section 43 of the MPRDA (DME);
- Regulation 35(1) of Government Notice R 385 of the NEMA (Relevant Authority); and
- Sections 41 and 42 of the National Water Act – implied (DWAF or Catchment Management Authority).

The process leading up to the application of the DSS however differs under different scenarios.

Material regulatory requirements

It is not evident that the DSS will, in all instances of application, ensure compliance with certain material legal requirements such as material requirements for impact assessment as set out in the MPRDA. It is also likely that the logic applied in these peremptory legal requirements is not entirely compatible or aligned with the methodology of the DSS. While many if not most of the DSS principles and requirements are to be enhanced by further criteria and guidelines in due course, it is likely that some material legal requirements will not find its way into this methodology automatically through this process.

Other than the need to incorporate specific legal requirements with the DSS where appropriate, the DSS in principle, its objectives and methodology complies with the requirements Administrative Law and National Environmental Principles. The DSS would in our view ad benefit to both the decision making as well as application process from a flow, process and justification perspective. It is of course essential that the current policies of the DWAF in the consideration of water use license applications also be considered upon finalisation of DSS criteria and guidelines. Generally, comprehensive consultation and buy-in by the three key regulators cannot be over-emphasised.

# 3 WATER AND GEOCHEMISTRY RELATED TOPICS

Water quality impacts from mine residue disposal facilities are arguably the most critical aspects that need to be considered in the life cycle of a mine residue disposal facility. The water quality impacts typically relate to contaminated seepage emanating from the base of the mine residue disposal facility, entering the downstream receiving groundwater and potentially surface water resources. The contaminated seepage typically contains elevated salinity and metal concentration levels and can also be acidic.

Mine residue could have an acid mine drainage (AMD) and/or metal leaching (ML) potential that, once set in, is very difficult to control and will prevail long after closure resulting in potentially significant downstream water (salinity and metal) water quality impacts.

Although protocols and guidelines exist today to characterise the AMD and ML potential of mine residues, very few protocols and standardised modelling methodology are in place to predict the AMD and ML from mine residue under site conditions. This results in designers finding it difficult to incorporate AMD and ML issues. Protocols for the handling of uncertainty in model predictions are not well developed making it difficult for regulators and decision makers to interpret modelled impacts.

Significant uncertainty still exists in the prediction of pore water quality evolution in a mine residue disposal facility, especially during the decommissioning and closure phase. These uncertainties make it difficult to accurately predict impacts and propose/motivate mitigation measures further making it difficult to assess the viability of a particular mine residue disposal facility.

The approach and methodology followed in each of these tasks are discussed in more detail below.

## 3.1 Depth of the Oxidised Zone (Appendix D)

This study addressed the specialist study related to the development of oxidation zones. A summary of the research is presented here and the specialist report in Appendix D.

The physical manifestation of an oxidised cap (identifiable through red or yellow staining) indicates the progressively decreasing rate of oxygen ingress that occurs through a mine residue disposal facility profile. Rapid oxidation only typically occurs in the top 1 to 2 metres of a profile, depending on the physical and geochemical characteristics of the tailings. Reaction rates then decrease significantly as the oxygen diffusion distance increases and would thus be expected to result in a lower impact, depending on the rate of contaminant flushing through process water and rainfall recharge during the operational and post closure periods.

The Acid Rock Drainage (ARD) processes that occur through sulphide oxidation result in acidity, which may or may not be neutralised through reactions with neutralising minerals in the tailings. Regardless of whether ARD is neutralised or not, the process mobilises salinity and toxic trace elements, some of which can result in downstream impacts, depending on the final pH and redox conditions of the seepage water and the flow path that a pollution plume follows. Impacts under acidic conditions are typically much more accentuated due to the mobilisation of metals and trace metals and their consequential aquatic toxicity. An understanding of when drainage from a mine residue disposal facility will turn acidic is therefore import in the quantification and mitigation of water quality impacts.

Taking the above considerations into account, it is clear that an appropriate assessment of the development of oxidation zones from ARD processes associated with tailings is required to determine operation and a post closure water quality impacts as well as to assess the effect of mitigation measures proposed.

A comprehensive discussion of the current state of knowledge regarding the development of oxidation zones on tailings is provided in Section 4 of the full research report (Appendix D).

Decision support guidance is provided in Section 5 of the report and takes account of the following parameters:

- Guidance on when and how oxidation zone formation needs to be assessed relative to mine life cycle;
- Guidance on technical aspects that should be considered in the assessment of oxidation zone formation;
- Guidance on the relevance of oxidation zone formation relative to mineral commodity; and
- Guidance on the key questions to ask in determining if oxidative zone assessment is required as part of answering the relevant question in the DSS.

The decision support flow diagram is provided in Figure 1. Guidance to answer the questions is provided in Section 5 of the full research report (Appendix D).

The current methodologies for assessing oxygen transport in tailings are based on both empirical and theoretical models, which are supported by field and laboratory data. The methodologies in use provide a sufficient basis to evaluate the development of the oxidised zone for the purposes of making the decision in the DSS that relates to the development of oxidation zones on mine residue disposal facilities. Verification of predicted oxidation rates is required by conducting prescribed field measurements. Although much research can still be done to understand all the mechanisms that determine sulphide oxidation in mine residue disposal facilities and modelling tools can be substantially refined to simulate sulphide oxidation better, it is not considered necessary to conduct further research for the purpose of decision support.

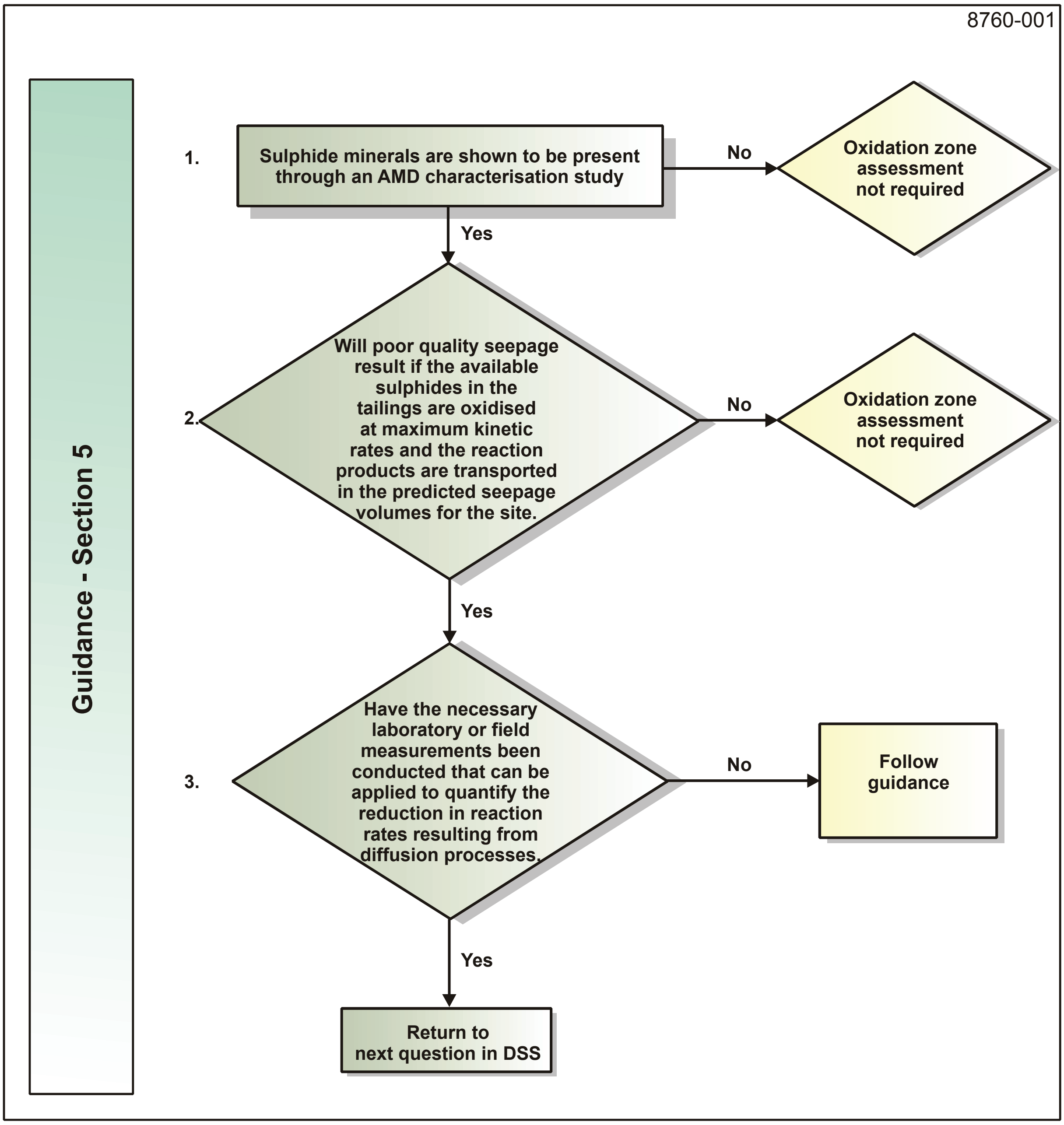


**Figure 1: Decision support flow diagram**

### 3.2 Tailings Water Balances (Appendix E)

This study assessed the water balance of mine residue disposal facilities during their operational and post-closure phases. A summary of the research is presented here and the specialist report in Appendix E.

It is abundantly clear from the practical examples of water balances for both operational hydraulic fill mine residue disposal facilities or a closed dry dump that water balances cannot be calculated with reliable accuracy if the necessary waste properties are not known. A "generic" knowledge of these properties is insufficient; the properties must be measured for the specific waste and the specific method of operation of the storage. It must also be borne in mind that the properties of the waste being deposited will be variable from hour to hour, day to day, year to year and decade to decade. It may be, and often is necessary to use generic properties for the waste at the design stage. However, once the storage has been commissioned, the actual parameters for the waste must be determined. Measurements must not only be made once when the waste storage is commissioned, but monitoring of properties and adjustment of the storage operation must be ongoing throughout its operating life and when it is finally being rehabilitated.

The study concludes that it is difficult to obtain good information associated with the components of the water balance for an operational hydraulic fill mine residue disposal facility. The innate variability of available data of these components presents challenges in using this data. Because the slurry density represents the quantities of both solids and water being deposited, it is truly the driving variable of the water balance. A satisfactory representation of the water balance is not possible without accurate data on slurry density.

Recession of the phreatic surface after ceasing deposition takes place mainly by seepage into the foundation strata. The rate of recession can be estimated by applying D'arcy's law to the system of storage plus foundation. Interstitial water will also reduce as the recession occurs, but fine grained tailings will remain saturated until the suction in the tailings exceeds the air entry value.

It was shown that evaporation from a wet surface is very similar to that from an apparently dry surface and also that the effects of evaporation extend for several metres below the surface.

Once operations have ceased, the important components of the water balance change, and the climatic variables of rain infiltration, evaporation or evapotranspiration from the surface and recharge, i.e. seepage into the foundation, become important. The research describes methods for measuring infiltration and for estimating and also measuring evaporation (refer to Appendix E for full research text). A further example of transferability of principles from one type of waste deposit to another is the recommended use of the method of estimating evaporation from A-pan measurements, which is now in use for municipal solid waste landfills.

For the Regulator to be satisfied that a proposal is technically and practically adequate, it is suggested that the proponent may be asked to undertake a performance demonstration procedure. The performance demonstration procedure should be required to satisfy the Regulator on the following points regarding part(s) or the whole of the proposal.

- What result or procedure should be regarded as acceptable and why?
- What parameters need to be measured, and how should they be measured?
- Over what time period should the measurements extend?
- In what form should the performance demonstration procedure be presented in order to be satisfactory?

## 3.3 Modelling of pore water quality evolution (Appendix F)

This research addresses the specialist study related to the modelling of pore water quality evolution. A summary of the research is presented here and the specialist report in Appendix F. The aim of this study is to develop a protocol and guideline on methods to assess pore water quality evolution and report it in a mine residue disposal facility water quality impact prediction and assessment study.

The importance of the concept of pore water quality evolution in the DSS for sustainable design, operation and closure of mine residue disposal facilities, relates to the difficulty of predicting future water impacts from the mine residue disposal facility. These future water (typically quality) impacts often require mitigation measures or define future liability. If the future impacts are not well understood because pore water evolution is not well predicted, regulators (and proponents) will find it difficult to make decisions where liability is transferred (or responsibility accepted). It is often due to lack of knowledge on best practice in pore water quality predictions and assessments, how pore water quality evolution should be quantified and expressed; and how to make risk-based decisions.

The characterisation of a mine residue disposal facility, in terms of its potential to impact on water resources, is directly related to the tailings life cycle. The three phases include:

- Operational phase, during which most of the mine residue disposal facility is dominated by saturated conditions. Unsaturated conditions are limited to wall and dry beach areas;
- Decommissioning or initial post-closure phase, during which the phreatic surface recedes and an oxidised condition develops in the upper, unsaturated portion of the tailings. These conditions are also characteristic of the walls of the mine residue disposal facility during the operational phase; and
- Closure phase, during which the tailings are dominated by unsaturated conditions as the phreatic surface recedes to the base of the mine residue disposal facility.

A variety of geochemical processes dictate the pore water quality during each phase, depending on the degree of saturation and oxidation of the tailings. Typical influences on pore water quality include:

- Moisture content;
- Mineralogy;
- Weathering of primary minerals, including sulphides, carbonates and silicates;
- Precipitation and dissolution of secondary minerals; and
- Oxygen diffusion.

The current state of the art with regard to the prediction of pore water quality evolution includes the following steps:

- Characterisation of the system through a programme of sampling and laboratory analysis;
- Conceptualisation of the system to identify key geochemical and flow processes that may influence pore water quality at different stages in the mine residue disposal facility life cycle; and
- Modelling of the system components using a range of modelling tools whose outputs are integrated to develop the pore water quality prediction.

The prediction of pore water quality evolution lacks a single "Black Box" into which initial conditions can be input and which will provide an output quality over time. Rather, current state of the art places several "black box" models in series with output from one providing input to the next. The entire series is managed by the experts who shepherd data through the process, making simplifying assumptions as needed to obtain output. It is difficult, if not impossible, to develop a procedure to allow a regulator with limited technical background to make an informed decision on whether the pore water prediction is appropriate. Therefore, this report suggests that the approach in the Best Practice Guidelines (BPG) for Water Management in Mining published by the South African Department of Water Affairs and Forestry (DWAF, 2008) be adopted in the DSS.

The BPG G4 process assigns responsibility for technical review to a third party reviewer. The reviewer's role is to ensure that the assessment of pore water quality evolution has been undertaken in a scientifically valid manner, that all assumptions that were made are reasonable and defensible and that all pertinent information (negative or positive) that could influence a regulator's decision is contained in the project documentation. The regulator applying the DSS would merely need to confirm that the pore water quality prediction has satisfied the reviewer's technical appraisal. The DSS can therefore be limited to guidance on whether the process of assessing pore water quality evolution has been conducted appropriately and not on whether the pore water quality assessment is technically robust (Figure 2).

Box 4 incorporates several further questions which the regulator will need the input from the reviewer to answer. It is strongly recommended that the reviewer's input be provided in the form of a written document and in person to the regulator applying the DSS.

A predictive model is only the first step in managing tailings pore water quality impacts. Considerable uncertainty exists in the prediction of pore water quality. Given this uncertainty, it would be inappropriate to allow model predictions to guide the management of a mine residue disposal facility throughout its operational life and into the post-closure phase.

The predictive model(s) must be calibrated by the collection of monitoring data. Based on the data, the predictive pore water quality model should be modified and refined as necessary to reduce uncertainty and support decisions with regard to long-term management of the tailings. This demonstration protocol needs to be included as part of the predictive model and its presence confirmed by the DSS (Figure 2).

Once the regulator has been assured by the reviewer that the modelling of pore water quality has been conducted to an acceptable level and that a demonstration protocol is in place to confirm the pore water quality prediction over time, the regulator can move to the next module of the DSS.


**Figure 2: Guidance for the DSS regarding pore water quality assessment**

### 3.3.1 Development of protocols to handle uncertainty in models (Appendix G)

This study develops protocols to handle uncertainty in model prediction related to the long-term behaviour of a proposed or current mine residue deposit. The specialist study is included in Appendix G. The importance of the concept of uncertainty in the DSS, relates to the challenge that regulators (and proponents) often do not know how to identify uncertainties in predictions and assessments, how to quantify and express uncertainties and they do not have proper guidance on how to make risk based decisions on the presented predictions.

There is a large amount of literature available on the subjects of uncertainty analysis, risk assessment and risk based decision making, but there is not much guidance on how to bring all the concepts together when making a final decision, especially where liability transfer is intended. An attempt was made to bring these concepts together in the development of protocols to handle uncertainty in model predictions and to provide guidance on how to make appropriate decisions based on the uncertainty.

The numerous sources of uncertainty in model predictions are divided between uncertainty in measurement, uncertainty in models and uncertainty in interpretations. Guidelines are given on how to reduce uncertainty in the various sources of uncertainty. For risk assessment and therefore better decision making, it is very important to report uncertainties at all stages of assessment, however, this is often neglected. A diagrammatic illustration of uncertainty propagation is shown in Figure 3.

Practical guidelines are given for:

- Analysing and reporting uncertainty in model predictions
- Specific guidance for the DSS
  - Assessment of the procedure followed
  - Guidance on decision making.

These guidelines for decision making with uncertainty were aimed at regulators when a full risk assessment with stakeholders and interested parties is not feasible. The guidelines include options to follow when risk levels are not acceptable. The various sources of uncertainty, the risks associated with them and final decision making for closure and transfer of liability is presented by example of a mine residue disposal facility and the impact that it may have on water resources after closure.

The proposed decision making process with the different options to follow is also illustrated schematically in Figure 4.

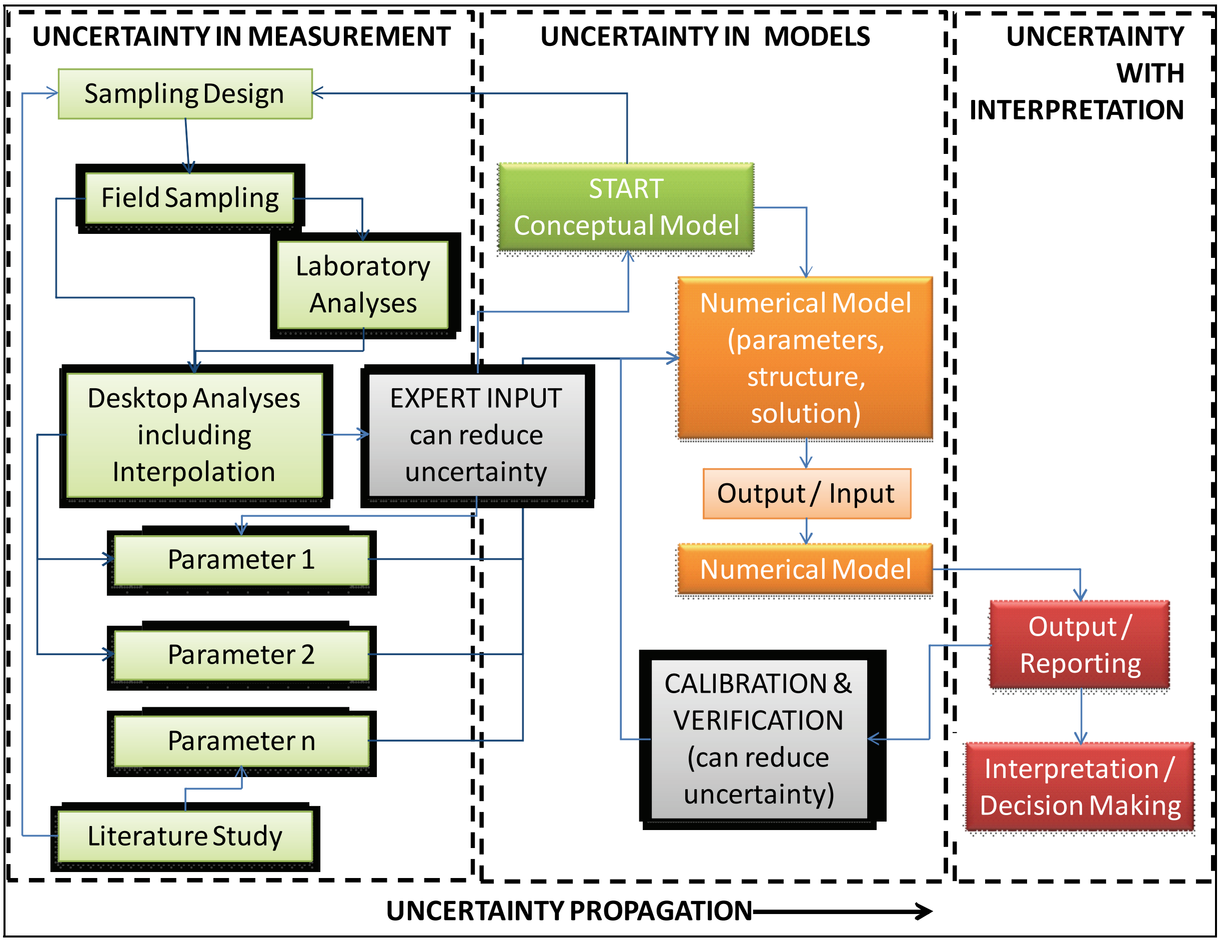


**Figure 3: A diagrammatic illustration of uncertainty propagation**

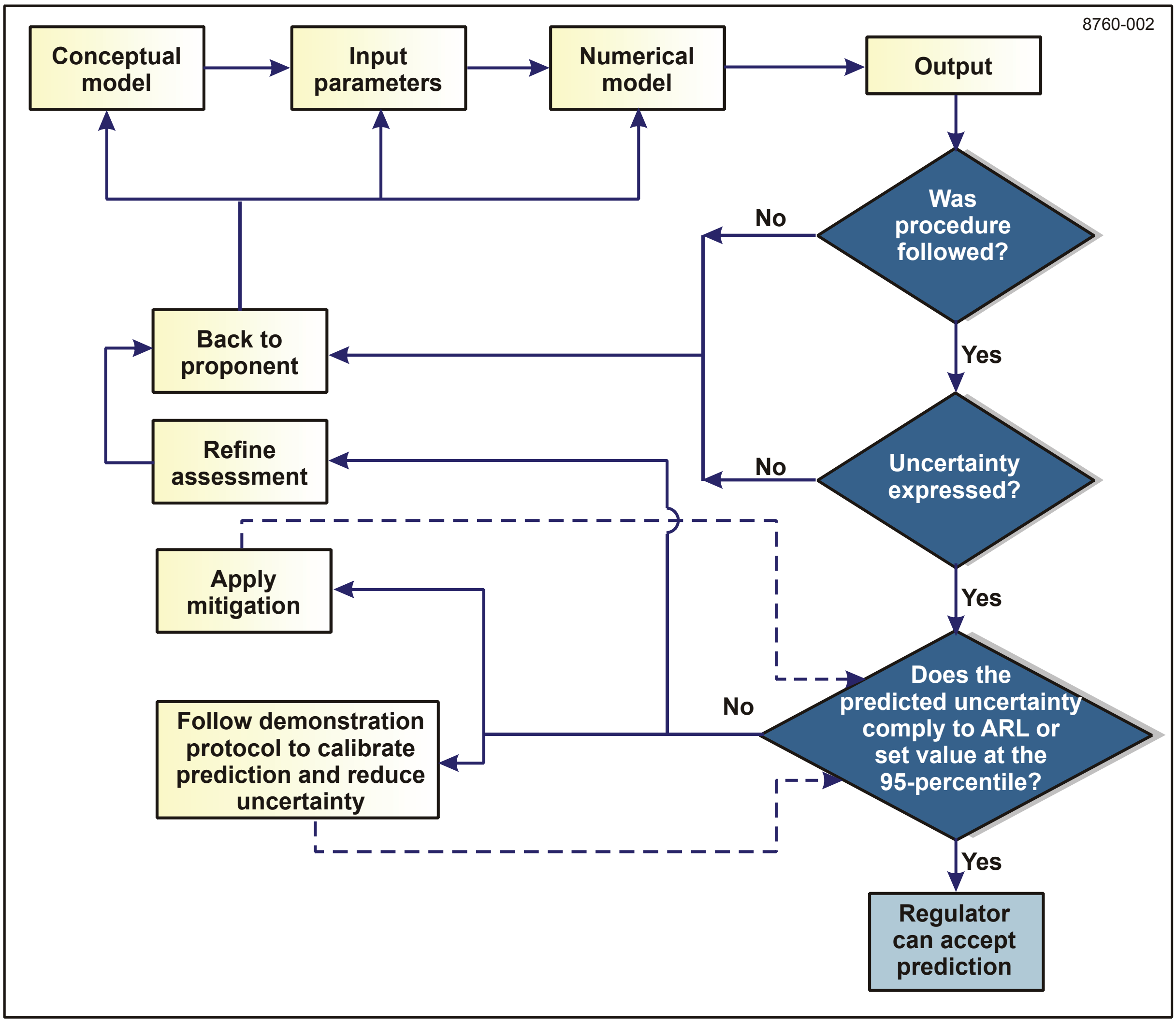


**Figure 4: Proposed decision making process**

## 4 SURFACE STABILITY ASPECTS (Appendix H)

This research addresses the specialist study related to surface stability aspects of a mine residue disposal facility. A summary of the research is presented here and the specialist report in Appendix H. Surface stability in the context of this project refers to the stability of the outer surface or cover of a mine residue disposal facility against erosion caused by wind and water. It is not the overall large scale geotechnical slope stability.

The problem arises primarily because mine residues are usually fine grained non cohesive silts and sands. For both water and wind erosion the transported materials may be deposited both in and outside the footprint. The surface stability of the mine residue disposal facility affects both the off-site impact on receiving environment as well as the integrity of the facility itself. The surface stability of the outer top surface and side slopes of mine residue disposal facilities is one of the key considerations in assessing the impact of these facilities on the environment. Models exist for determining the quantity and distribution of particles eroded by wind. Similarly models such as the Revised Universal Soil Loss Equation (RUSLE) also exist to calculate surface runoff and erosion due to water. However, these models are not well defined yet and calibrated nor has acceptable criteria been defined. Nevertheless, sufficient information exists to develop a workable water erosion surface stability module.

A primary decision tree structure has been developed to assess surface stability of a proposed mine residue disposal facility during the various stages of its life in Phase 1 of the project. This study included an evaluation of the state of the art knowledge and addressed information gaps of key processes affecting surface stability. Key aspects addressed included the impact of the mine residue disposal facility on the sediment load within and outside the footprint.

## 4.1 Erosion Rate and Effectiveness of Cover Technologies

Surface stability (and instability) of mine residue disposal facilities is a highly diversified subject with many facets with respect to the specific causes, factors contributing to potential instability and mitigation measures. Precautionary and proactive mitigation measures could be divided into geotechnical and bio-engineering aspects with some overlapping between the two aspects. It was decided to keep the two aspects separate to ensure the necessary emphasis of the two aspects. The original proposed task on Erosion rate and effectiveness of cover technologies and task on Effect of slope geometry on mine residue disposal facility surface stability were merged into one report Erosion Rates, Slope Geometry and Engineered Erosion Protection of Tailings Dams Slopes but with two distinct parts, i.e. A) Geotechnical Approach and B) Bio-engineering Approach.

### 4.1.1 Part A: The Geotechnical approach

Two distinct approaches to surface stability and erosion protection of mine residue disposal facilities slopes developed in South Africa from the two early Chamber of Mines of South Africa “Handbook of Guidelines for Environmental Protection, 1979, Volume 1, The Design, Operation and Closure of Residue Deposits and Volume 2, The Vegetation of Residue Deposits Against Water and Wind Erosion.” The first and main part of this report deals with the more widespread approach that has grown out of Volume 2 and which is widely applied by horticulturally orientated commercial successors to the original Chamber of Mines Vegetation Unit. This report, which supports the main report, deals with the geotechnical approach that developed out of Volume 1 and which has been applied mainly by geotechnically orientated commercial practitioners. The supporting report, included in Appendix H summarises this approach.

1. Measurements on natural soil slopes in the Witwatersrand region of South Africa have shown that they erode at a rate of 5 to 50 T/ha/y. When attempting to reduce the rate of erosion of tailings slopes, this range of erosion rates should be considered the target to be aimed for. Erosion rates for unprotected slopes of gold mine residue disposal facilities in the Witwatersrand and Free State gold mining areas have been measured at up to 500 T/ha/y. There is therefore a pressing need to implement measures to protect the surfaces of mine residue disposal facilities against erosion.

2. Studies have shown that rates of erosion of unprotected slopes of gold tailings depend mainly on the angle of the slope and its length. The maximum rate of erosion occurs at slope angles of 31 to 37$^{o}$, and decreases as the slope angle decreases. Flat and horizontal slopes erode very little. The overall rate of erosion of slopes increases roughly linearly with slope length.

3. The total erosion of a tailings slope is made up of components due to water and wind. Erosion by water predominates in the wet season of a year, and wind erosion predominates in the dry season. Limited studies on the Witwatersrand show that more erosion from gold tailings slopes is caused by wind than by water.

4. Considering the requirement that the storage capacity for tailings solids of a given site must be maximised, together with the requirements for overall shear stability and the requirement to limit rates of surface erosion, as well as the practical advantage of a slope that can be worked mechanically, an

acceptable slope angle for tailings slopes appears to lie in the range of 15-20º. A round figure of 1 vertical on 3 horizontal or 18º appears to be a good compromise.

5. Berms, step-ins and ramps are necessary to provide access to the slopes of a mine residue disposal facility during its operational phase, as well as after decommissioning and closure. They should be carefully pre-planned and be located, designed and constructed to maximise their functionality. They should be easily accessible to motor vehicles, and traversable in both directions between at least two entry and exit points. A suitable height between berms of 8.5m in an 18º slope will limit slope length to an acceptable value to reduce erosion.

6. A number of physical (non-biological) means of preventing erosion have been devised, experimented with and applied on a full scale with reasonable success. These include gravel mulching of surfaces with flat (0-10º) inclinations, rock cladding for steeper slopes and rock armouring, in which the surface texture of a natural vegetated slope is simulated. Various forms of rock cladding have been shown experimentally (Doornkop experiment) to reduce erosion rates to 20% of the erosion rate for an untreated slope. Only limited measurements exist for gravel-mulched or rock armoured surfaces. Various forms of rock cladding have been shown by the FS S6 experiment to reduce cumulative surface runoff to 5% of cumulative rainfall, whereas cumulative runoff from the untreated control section was 25% of cumulative rainfall. The 80% reduction of runoff is the probable main reason for the effectiveness of rock cladding in reducing rates of erosion. A full scale trial of rock cladding at the Cooke L1 mine residue disposal facility showed that even on relatively steep (25º) slopes, rock cladding is effective in reducing erosion rates to 80T/ha/y.

7. Earlier (1980s) work on stabilising the surfaces of tailings slopes with cement or lime showed promise and should be revisited at least to investigate current potential costs in situations where waste rock is either not available, or could more profitably be used as concrete aggregate. The problem experienced with attack by salt crystallization could be investigated further if current cost estimates prove promising.

### 4.1.2 Part B: The Bio-engineering approach

In the early days of rehabilitation of mine residue deposits, it was not possible to stabilise mine residue deposit surfaces by physical means, and the early pioneers in mine rehabilitation turned to vegetation for this purpose. The establishment of a permanent cover of vegetation involves not merely growing plants. It necessitates establishing a plant community that will maintain itself indefinitely with limited attention or artificial aid. This aim has seldom been achieved although vegetation establishment is still the accepted form of mine residue disposal facility rehabilitation in South Africa. The performance of an established vegetation cover is measured in terms of ecological criteria and not in terms of its effectiveness to reduce erosion or it's landscape functionality, i.e. erosion protection and surface stability.

Erosion rates as high as 500 t/ha/year was measured from mine residue disposal facility without a surface cover and rates as high as 200 t/ha/year under a vegetation cover. Other covers such as rock cladding had yield erosion rates as low as 15 t/ha/year. The measured erosion rates provide an indication of the severity of the problem but the factors that influence erosion (erosivity, erodibility, slope length, slope gradient, slope geometry and cover characteristics) were not described properly. If the rehabilitation industry had used an accepted erosion model, factors influencing erosion would be properly characterised and their influence been quantified. New cover technologies can now only be evaluated through trails and not by simulation.

The DSS allow proponents through the use of a Best Demonstrated Available Technology (BDAT) approach, with the opportunity to demonstrate that what is being done (or proposed) meets certain criteria or is acceptable even though the underlying science and mechanisms are not fully understand at present. According to the USDA-ARS National Sedimentation Laboratory, the Revised Universal Soil Loss Equation

(RUSLE) is used by numerous government agencies, private businesses, and individuals to assess the magnitude of rill erosion, to pin point where erosion is serious, and to guide development of plans to control soil erosion. According to the National Sedimentation Laboratory, RUSLE is the BDAT for erosion prediction from specific field sites. In addition, the equation combines interrelated physical and management parameters such as soil type, rainfall pattern, and topography that influence the rate of erosion. These parameters are represented through RUSLE's five factors whose site-specific values can be expressed mathematically.

Erosion is a natural process and erosion processes and factors influencing erosion on mine residue disposal facilities are similar to that in the natural environment. However, certain erosion processes and factors influencing erosion are accentuated more on mine residue disposal facilities.

An overview of erosion processes and factors influencing erosion is the topic of section 3 of the specialist report (Appendix H). Soil erosion by water is a three-phase process involving; 1) detachment of individual particles from the soil mass, 2) transport by impacting raindrops and running water, and 3) deposition when sufficient energy is no longer available to transport the particles. The detachment and transport of water is by rain-splash and overland flow. Erosion by water is manifest as; interrill or sheet erosion, rill erosion, gully erosion, ephemeral gully erosion, bank gully erosion, and pipe/subsurface erosion. The factors influencing erosion are; rainfall erosivity, soil erodibility, slope length, slope gradient, surface cover and land management practices.

The RUSLE and MUSLE erosion models that can be used to estimate erosion rates. The RUSLE equation was developed to estimate average annual sediment loss from agricultural fields. The full equation is: A=RKLSCP, where:

R is the rainfall-runoff erosivity factor,

K is a soil erodibility factor,

LS is a slope length and steepness factor,

C is a cover management factor,

P is a conservation support factor, and

A is estimated soil loss (t/ha/year).

The RUSLE equation can be modified to allow for the prediction of sediment directly and is applicable for individual storm events. This modification is termed MUSLE where the rainfall erosivity factor is replaced with a stormflow factor (product of amount of runoff and the peak discharge). The erosion parameters in RUSLE and MUSLE can be adapted for mine residue disposal facilities.

It is only a rock cladding cover that did not have a vegetation cover. For a rock amour cover the vegetation cover is not the primary surface stability component. For hydraulic barrier and store and release covers the vegetation can act as the primary surface stability factor but more important, the vegetation cover act as an evapotranspiration control mechanism.

Decision support guidance for surface stability in terms of mining phases, assessments and cover selection is provided in section 3 of the specialist report. Only the height, slope lengths, slope gradient and slope geometry of the mine residue disposal facility can be optimised in the design phase which will also be dictated by the type of protection cover and end land-use. The end land-use dictates the first level of cover selection. The second factor determining cover choice is the presence or absence of sulphide minerals in the tailings. The third level of cover selection requires modelling and is dictated by the availability and type of cover materials and the slope length and slope gradient of the mine residue disposal facility. The main knowledge gaps with respect to bio-engineering approach still remain with vegetation issues which are strongly interrelated with the above mentioned support guidance.

## 4.2 Monitoring Protocols and Techniques to Monitor Surface Stability Post Closure

The research relating to monitoring protocols and techniques to check surface stability post closure are included in the surface stability report (Appendix H).

Monitoring and maintenance programs should be developed for individual cover types to comply with legislative requirements and to ensure proper management. The purpose of maintenance programs are to ensure the stability of the slopes and if neglected. If the integrity of the slope fails, side effect like surface water pollution and soil erosion and pollution become a problem.

Two key questions regarding monitoring are:

- Whether monitoring data and performance assessment results provide confidence in total surface stability within acceptable norms and threshold values in the long term (>30 years or > 100 years)?
- Can quality be maintained with a simple and cost effective maintenance program?

The monitoring data which can be used in the evaluation phase could be the following:

- Collecting data, e.g. erosion sediment transport;
- Predictive modelling undertaken with field verification, e.g. erosion models and silt traps; and
- Analogue data.

If possible two or more data sets should be used, e.g. analogue, predictive modelling and field verification. The main concern is still the period of monitoring and data collecting. In the case of rock cladding it seems as if three years is enough; rock armour is five years but vegetation is much more dynamic and subject to major changes in relative short periods. Field observations of a 4 year old rock armour cover at Daggafontein seems to be acceptable, the only signs of unacceptable erosion is associated with old deep gully and donga erosion which were not properly filled and compacted prior to the placing of the rock armour. A fourteen year old rock cladding project at Doornkop and twelve years at FS6S in the Free State are all in a good condition with rock armour cover. Both these sites were monitored annually for a period of four years after construction and stability has been proven within one to two years. Other sites with a ± 35 year old vegetation cover which were visited recently are Fleurhof and Chamdor East. Except for a few major dongas on Chamdor East, they are both in a stabilised condition. The dongas on Chamdor East are associated with poor vegetation cover at the toe of the bottom slope. Keeping in mind that no maintenance was done over the last 25 years on these two dams, they are in a good condition.

Surface stability assessment and simulation guidance was given on the assumption that rehabilitation and closure planning happens early in the mine residue disposal facility life. The Strategic Framework for Mine Closure (ANZMEC, 2000) suggest that closure planning should include a commitment to concurrent (progressive) rehabilitation, the development of a more detailed closure plan and implementation of the plan over the life of the mine. According to Mackenzie *et al.,* (2006), the benefits of planned mine closure includes:

- Identification of high risk priorities for research or rehabilitation;
- Reduction of ongoing environmental liabilities by concurrent rehabilitation;

- Distribution of rehabilitation and closure cost during the productive phase of mining rather than deferral to the end of the project;
- Ongoing feedback, through monitoring, of the effectiveness of rehabilitation designs;
- Anticipated closure outcomes are more reliable as they are the product of considered decisions;
- Early estimation of rehabilitation and closure cost so that sufficient financial and material resources can be set aside; and
- Reduced, post-closure monitoring and maintenance period for areas rehabilitated earlier during the life of mine.

# 5 DISCUSSION OF RESEARCH PROGRESS AND CONCLUSION

## 5.1 Overall research context

The ultimate aim of the overall research project is to develop a comprehensive DSS that can be used primarily to aid regulating authorities in assessing the acceptability of current or proposed mine residue disposal facilities. The DSS can be of equal value to proponents and consultants for the same purpose. The following overall DSS framework objectives were formulated at the beginning of the research project:

- To develop a DSS which will rationally address key issues pertaining to a mine residue disposal facility resulting in a decision of the type that the scheme is either acceptable or unacceptable.
- To provide decision-makers with sufficient information and guidance when considering mine residue disposal facilities during the phase under consideration to make consistent and transparent informed decisions.
- To assist with decision-making at the key points in the stages of the life of a mine residue disposal facility:
  - conceptualisation, planning and site choice in order to continue with feasibility studies;
  - planning and design in order to consider whether a scheme can continue into the operational phase; and
  - closure planning and design to seek approval of the closure plan.

It was originally envisaged that the DSS will be developed in phases over a period of 5-10 years, including:

| | |
|---|---|
| Phase 1: | Develop a preliminary DSS making optimal use of available local and international information and identify knowledge gaps that need to be addressed in order to develop an expanded final DSS. |
| **Phase 2:** | **Research and investigate the gaps identified during Phase 1.** |
| Phase 3: | Develop a comprehensive DSS that builds on the experience with the preliminary DSS and the findings of Phase 2. |

Phase 1 is complete and is documented in Rademeyer et al., 1997.This research report is the outcome of the second phase (Phase 2) of the research programme. Recommendations for Phase 3, development of the comprehensive DSS, are provided in the next chapter.

The following sections provide a discussion on the research progress made in Phase 1 and 2, and how it positions the research for the development of the comprehensive DSS in Phase 3.

### 5.2 Phase 1 Progress

Phase 1 included the development of a preliminary DSS to a point where it could be used to guide decision making. The following key outcomes from the development of the preliminary DSS are relevant to the development of the comprehensive DSS:

- Defining the DSS in terms of its objectives, its scope, its technical framework and its intended user group.
- Development of a hierarchical rational framework for the DSS that encompasses social-cultural, biophysical and economic considerations in assessing the acceptability of a new or existing mine residue disposal facility scheme.
- Development of the hierarchical questions for the Water and Soil and Landform components of the Biophysical aspects to consider

The preliminary DSS was developed with existing knowledge and information and necessitated the use of the precautionary principle and conservative assumptions to satisfy environmental concerns and compliances.

The development of the preliminary DSS therefore set the framework, principles and protocols for the development of the comprehensive DSS.

### 5.3 Phase 2 Progress

The preliminary DSS was developed and designed to support decision making based on the utilisation of various models, tools and techniques. Application of these models, tools and techniques require guidance and resulted in recommendations for phase 2 of the research project, including the development of a demonstration protocol, evaluation of the alignment of the DSS to current legislation, a number of specialist type studies to provide guidance in the answering of various technical questions in the DSS and the evaluation of new and promising technologies.

The following provides a summary of the progress made on the various components of the phase 2 research that is relevant to the development of the comprehensive DSS.

#### 5.3.1 Development of a demonstration protocol:

Fundamentally, the DSS is designed to lead to a decision and is captured in final questions that are posed in such a way that if answered, it will lead to a decision higher up in the DSS hierarchy. This final or end-of-line question can either be answered by providing the necessary technical requirements or complying with said standards or by following a demonstration protocol in support of answering the question.

A demonstration protocol was developed to provide a mechanism for when a question cannot be answered in the positive using existing knowledge and predictive models, to demonstrate the applicability and acceptability of using a particular technology, approach or technique. The demonstration protocol, although developed for surface stability applications, can also be applied for water related aspects. The demonstration protocol includes guidance to the regulator, the proponent and consultants on:

- Selecting and prioritising potentially feasible solutions or technologies;
- Comparing the potential solutions to predictive models;
- Undertake appropriately scaled field testing; and
- Documenting the results in support of using the particular technology or technique.

The demonstration protocol will form a key characteristic of the comprehensive DSS.

### 5.3.2 Alignment of the DSS with current legislation:

The following bullets summarises the key outcomes of assessing the alignment of the DSS to current legislation which is particularly relevant for the development of the comprehensive DSS:

- The DSS has no legal standing, however, is developed to be aligned with the national environmental management principles and support applications by proponents for current or new mine residue disposal facility schemes.
- The DSS will, based on the preliminary DSS and once developed, provide for the procedure that covers the scope of investigations to define and quantify the environmental risks associated with a current or proposed scheme.
- It is recommended that once the comprehensive DSS is developed that the DSS be converted to guidelines in terms of regulation 73 and/or74 of Government Notice R385 to the Nation Environmental Management Act in order to attain official recognition in both the Basic Assessment and Scoping and Environmental Impact Assessment procedures which forms the core vessel for application of the DSS

It is expected that the development of the comprehensive DSS will include specific legal requirements as recommended by the outcome of the phase 2 study and that it, in principle, will comply with the requirements of Administrative Law and the National Environmental Principles.

### 5.3.3 Progress on specialist studies related to water and geochemistry

Four specialist studies related to water and geochemistry were recommended for phase 2 of the DSS research project, including (1)depth of the oxidised zone, (2)tailings water balances, (3)pore water quality evolution and (3)protocols to handle uncertainty in model predictions.

The aim of the studies were specific to the development of the comprehensive DSS in that it assessed whether enough information/understanding existed to develop the necessary guidance to the user of the DSS to answer a particular water related question in the DSS or not. Should not enough information or understanding be available, the studies had to recommend using either a demonstration protocol, or a research project for Phase 3, to address the particular knowledge gap.

In all four cases, enough information was available to develop guidance on how a particular question can be answered in order to make a decision based on the technical studies conducted in support of the answer to the question. However, in all four cases, although the technology exists to predict future behaviour, there is a requirement to follow a demonstration period in order to calibrate and verify future predictions. Guidance is provided to the regulator on how the monitoring should be done and for how long. Furthermore, since prediction can never be an exact science, guidance was also develop for the assessment, quantification and documenting uncertainty associated with the assessment of the development of the oxidised zone on mine residue disposal facilities, tailings water balances and the evolution of pore water quality in the mine residue disposal facilities. The principles on which these protocols were developed are also applicable for other water and geochemistry related aspects as well as the surface stability aspects.

### 5.3.4 Progress on specialist studies related to surface stability

Surface stability (defined for the purposes as the stability of the outer surface of the mine residue disposal facility against erosion caused by wind and water) specialist studies focussed on the erosion rate and effectiveness of cover technologies as well as the development of monitoring protocols to monitor and check surface stability during the post closure phase of a mine residue disposal facility.

In the evaluation of erosion rates, slope geometry and engineered erosion mitigation on mine residue disposal facilities were divided into geotechnical and bio-engineering aspects with some overlapping between the two aspects.

In terms of the geotechnical approach, benchmark erosion rates, measured on analogue sites in the Witwatersrand area, were established. Erosion rates are sensitive to slope angle and length, with overall erosion rates increasing linearly with slope angle. Optimum slope angles are proposed and rock cladding is proposed as an effective mitigation measure against erosion.

From a bio-engineering perspective, only the height, slope lengths, slope gradient and slope geometry of the mine residue disposal facilities can be optimised in the design phase which will also be dictated by the type of protection cover and end land-use. The end land-use dictates the first level of cover selection. The second factor determining cover choice is the presence or absence of sulphide minerals in the tailings. The third level of cover selection requires modelling and is dictated by the availability and type of cover materials and the slope length and slope gradient of the mine residue disposal facilities. The main knowledge gaps with respect to bio-engineering approach still remain with vegetation issues which are strongly interrelated with the above mentioned support guidance.

In both approaches, monitoring protocols were developed in order to follow a demonstration approach as support for using particular slope geometry design and/or cover technology.

### 5.3.5 Progress on Identifying new and promising technologies

The identification of new and promising technologies was addressed largely as part of the specialist studies and included in the reports.

The separate study that focussed largely on a literature review of papers and conference proceedings and discussions with practitioners also yielded new technologies. Many new and promising technologies were identified and evaluated against criteria that were developed to identify the technologies that should be considered in the future, resulting in seven technologies proposed for further research. The criteria for identification of new and promising technology to be researched further were:

1. Will the technology address one or more of the key issues identified in the research project?
2. Will the technology resolve a problem encountered frequently in South Africa?
3. Is the probability of successful full implementation at least moderate?
4. Can the technology be proven within the financial and resource constraints normally applicable to South African conditions?
5. Will the time frame for proving the technology be less than 10 years?
6. Is this something new and worthy of competing for limited research funds?

These technologies, along with possible benefits to be gained from them are listed in Table 1.

**Table 1: New and promising technologies**

| Technology | Possible benefit |
|---|---|
| Natural analogues | Benefits include improved slope geometry and resultant landscapes, and reduced cover erosion. |
| Metallophites and Phytomining | Reduced metal loads emanating from mine residue deposits and resultant decreased ground and surface water quality pollution. |
| Apply old technologies with more precision | Using already proven technologies, but using greater precision to extract more benefits from these technologies. This is particularly beneficial in vegetating mine residue deposits. |
| Design and construct mine residue disposal facilities with flatter slopes | This has potential surface stability benefits, reducing closure liabilities. |
| Designing scalloped slopes | This has potential surface stability benefits, reducing closure liabilities. |
| Paste rock | It is reported that the following benefits are gained:<br>• Significant stability gains over conventional mine residue disposal facilities are achieved. This can result in smaller footprints used, compared to conventional mine residue disposal facilities;<br>• The tailings limit oxygen ingress into the mixture, reducing oxidation processes;<br>• The permeability of the mixture is reported to be very low ($10^{-8}$m/s); and<br>• The mixture is reported to have high water storage capacity. |
| On site rainfall simulations | More representative experimental results can be achieved, thus increasing the chance of successful implementation of a particular technology. |

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## 5.4 Conclusions

In conclusion, the main objectives of Phase 2 in the development of a comprehensive DSS were:

1. Develop a performance demonstration protocol, i.e. procedure or guidance that can be used to demonstrate the acceptability of particular technique, technology or approach.
2. Undertake specialist studies of specific knowledge gaps identified during the development of the first order DSS in order to better understand the aspects and to provide better guidance in the DSS for users.
3. Identify and assess new and promising technologies and approaches that could be used as supporting guidance in the DSS and that could further play a role in managing water resource degradation caused by mine residue disposal facilities.

These objectives have largely been achieved and incorporated into the DSS. The current DSS is now developed to a point where the methodologies and protocols have been developed and established for the development of the comprehensive DSS (Phase 3).

# 6 CAPACITY BUILDING

## 6.1 Project bursaries

The project allowed for R300 000 as scholarships to students. The initial intent was to provide five students with partial support. However, the search for post graduate students proved difficult as bursaries were competing financially with employment opportunities. Students preferred work opportunities over receiving a bursary. It was agreed by the WRC (inception meeting No 3 held on 4 June 2008) to reduce the number of students to two with a R150,000-00 bursary each.

Two suitably qualified students at a Master's level were identified. The bursary amount was made available to each student over a two-year contract period and should be sufficient to cover most of the student's costs during this study period.

The project team was able to attract MSc student Ms Karen van Rensburg, studying under Professor Eben Rust at the University of Pretoria and who has been involved in the specialist study on the development of protocols to handle/report uncertainty in modelling predictions (Section 3.3.1).

The project team also approached 9 tertiary institutions (8 universities and 1 university of technology) and advertised the bursary in appropriate faculties. Eleven students were identified and put through a screening process by the project team. Honours student Thandikhaya Mxinwa, studying under Professor Bruce Cairncross (University of Johannesburg) was selected. Thandikaya will study towards a Masters degree in Environmental Geology. Professor Cairncross supports the project initiative.

Thandikhaya was contracted towards the end of the project and therefore was not afforded the opportunity to contribute directly to the project. However, to ensure capacity building, Thandikhaya has accompanied Professor Geoff Blight, Piet van Deventer and Johan Hatting on site inspections as part of project. The project team members have all agreed to be available to Thandikhaya in some capacity after the project to provide further capacity building.

Thandikhaya's bursary has been postponed until he starts his Masters degree in 2011. He was supposed to start his Masters in 2010, but a family tragedy late in 2009 resulted in him not passing one of his second semester courses. He has to redo the course in the second semester of 2010, after which he will continue with his Masters. Thandikhaya's selection of his masters topic and future career path has been influenced by the project scope.

## 6.2 Internal capacity building

A number of internal previously disadvantaged Golder staff members have benefitted from the project:

- Shareen Khamisa has gained significant project administration and technical support experience;
- Catherin Ngobo has gained additional project administration experience;
- Passy Goga has gained technical experience in the field of Geochemistry;
- Talita Germishuyse has gained additional technical experience in the field of Geochemistry and numerical modelling; and
- Koovila Govender has gained technical experience in the field of Geochemistry.

# 7 RECOMMENDATIONS FOR PHASE 3 OF THE RESEARCH PROGRAMME

As mentioned in Section 5.1, Phase 3 of the main research programme is the development of a comprehensive DSS that builds on the experience of the preliminary DSS and the findings of Phase 2. Although Phase 3 is defined as one phase, it will consist of a number of project steps that will lead to the development of the comprehensive DSS. Furthermore, due to the dynamic nature of knowledge developed around the various topics in the DSS, it is envisaged that the DSS guidance components (decision and technical guidance) will change in future as more knowledge becomes available, requiring the DSS to be a dynamic tool.

The following process steps and associated methodologies are proposed for the development of the comprehensive DSS (Phase 3):

1. Develop first order DSS for the “Economic” and “Social-cultural” components of the DSS.

   The first order DSS developed in the Phase 1 of the research programme focussed on the water and soil and landform components of the “Biophysical” component (air, water, soil and landform, fauna and flora) of the overarching DSS. It is recommended that a first order DSS be developed for the “Economic” component and “Social” component (people, visual, heritage and land-use) of the DSS that specifically includes mechanisms for the weighting of the three components given the specific context of a current and proposed mine residue disposal facility.

Figure 5 provides a schematic of the comprehensive DSS indicating the components for which a first order has been developed.

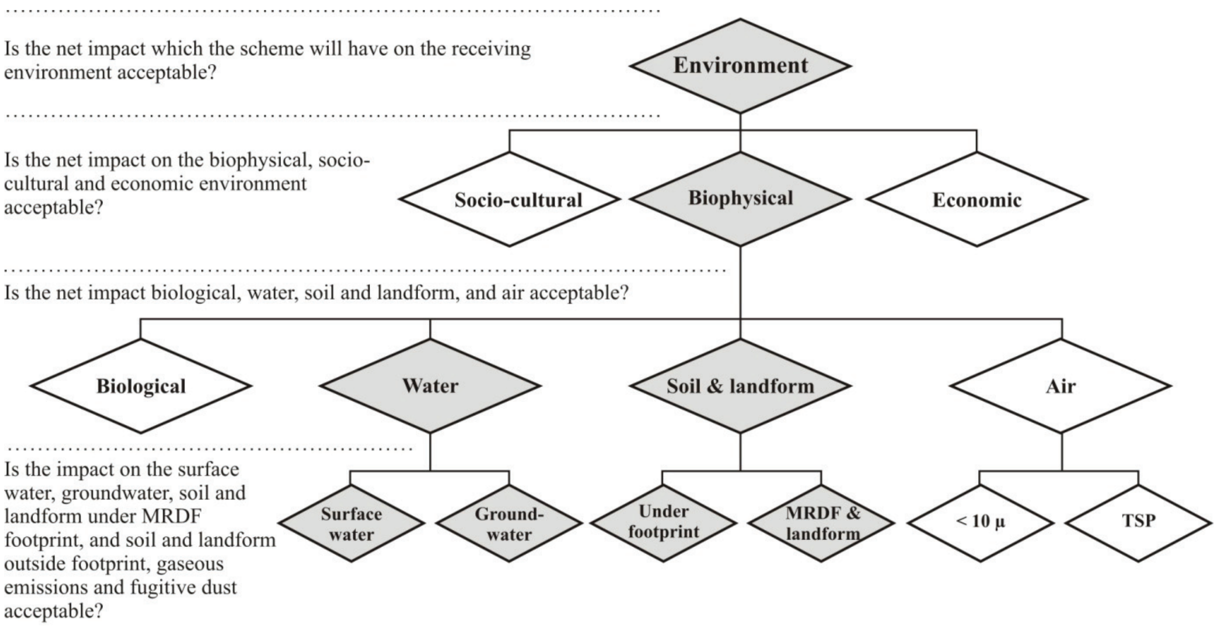


**Figure 5: Hierarchy of questions developed for the DSS**

2. Develop first order DSS for the biological and air components of the “Biophysical” component of the DSS.

   As with step 1, it is recommended that the first order DSS be developed for the biological and air aspects of the “Biophysical” component of the DSS.

3. Develop the regulatory guidance and technical standards/requirements to answer key questions in the DSS.

   Once the overall DSS has been developed, the specific guidance to the regulator should be developed for key question in the DSS. Furthermore, technical standards or requirements should be defined for each of the key questions in the DSS. It is also recommended to have a broad stakeholder engagement process in this step to encourage buy-in from mining companies and the regulating authorities as well as benefit from the collective experience of experts in the various discipline fields in the DSS.

4. Develop a web based application for the DSS that will allow for regular updating of the DSS and information related to the questions in the DSS.

   It is recommended that the DSS be converted to a web application, specifically a Wiki format, which will have the following benefits:

- Easier access and use for stakeholders in South Africa and the rest of the world (particularly the African continent);
- The ability to leave comments and suggestions by users to improve the DSS and specifically its guidance components;
- The ability to keep the DSS updated without having to re-distribute documentation.

5. Promote the use of the DSS

   An important success factor in the development of the comprehensive DSS is when stakeholders are using the DSS for decision support about current or proposed mine residue disposal facilities. It is important that the DSS do not remain in the research domain indefinitely and should become part of the regulators toolbox in regulating the design, operation and closure of mine residue disposal facilities. It is recommended, that once the DSS Wiki is established, that the use of the DSS be promoted by conducting training sessions and information sessions on the DSS at local conferences and related events.

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