# TABLE OF CONTENTS

## TABLE OF CONTENTS

**RISK ASSESSMENT HANDBOOK FOR SHUT DOWN AND ABANDONED MINE SITES IN NAMIBIA**

### FOREWORD

### LIST OF ACRONYMS

### GLOSSARY

### 1. INTRODUCTION

1.1 Background  
1.2 Objectives of this Handbook  
1.3 Scope of this Handbook

#### 1.3.1 Type of Mining and Associated Process

#### 1.3.2 Mining Site Status

#### 1.3.3 Components of a Shut Down or Abandoned Mine Site

1.4 Basic Risk Concepts

#### 1.4.1 Risk of contamination

#### 1.4.2 Risk to safety

### 2. RISK ASSESSMENT METHODOLOGY FOR SD/AMS

2.1 Stages of Risk Assessment and Prioritization of SD/AMS

#### 2.1.1 Identification of Hazard Scenarios

#### 2.1.2 Identification of Receptors

#### 2.1.3 Assessing the Likelihood of Occurrence

#### 2.1.4 Assessing the Severity of Consequences

#### 2.1.5 Applying the Risk Matrix

#### 2.1.6 Indications for Conducting a Detailed Risk Assessment, DRA

#### 2.1.7 Risk Assessment due to the Proximity of other Sites

#### 2.1.8 Classification of MEL and Non-MEL Sites

### 2.2 SD/AMS Risk Assessment Approach

### 2.3 Suggestions for the Assessor

### 3. PREPARING THE ASSESSMENT AND FIELD VISIT

#### 3.1 General Aspects

#### 3.2 Stages in Preparing the Assessment
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2.1 Information Gathering</td>
<td>3-2</td>
</tr>
<tr>
<td>3.2.2 Map Preparation</td>
<td>3-3</td>
</tr>
<tr>
<td>3.2.3 Definition of the Area Study</td>
<td>3-5</td>
</tr>
<tr>
<td>3.2.4 Descriptions of Receptors in the Area of Study</td>
<td></td>
</tr>
<tr>
<td>3.2.4.1 People</td>
<td>3-8</td>
</tr>
<tr>
<td>3.2.4.2 The Environment</td>
<td>3-10</td>
</tr>
<tr>
<td>3.2.4.3 Economic Activities</td>
<td>3-12</td>
</tr>
<tr>
<td>3.2.5 Preparing the Field Visit</td>
<td></td>
</tr>
<tr>
<td>3.2.6 Summary of Assessment Preparation Stage</td>
<td>3-16</td>
</tr>
<tr>
<td>3.3 Field Visit</td>
<td></td>
</tr>
<tr>
<td>3.3.1 Identification and Description</td>
<td>3-16</td>
</tr>
<tr>
<td>3.3.1.1 Identification of Installations, Deposits and Works</td>
<td>3-17</td>
</tr>
<tr>
<td>3.3.1.2 Description of Installations, Deposits and Works</td>
<td></td>
</tr>
<tr>
<td>3.3.2 Identification of Hazard Scenarios for each Installation, Deposit or Work</td>
<td>3-18</td>
</tr>
<tr>
<td>3.3.3 Drawing the Boundaries of the Area of Study</td>
<td>3-18</td>
</tr>
<tr>
<td>3.3.4 Characterization of Receptors for each Hazard Scenario</td>
<td>3-19</td>
</tr>
<tr>
<td>3.3.5 Field Information required to Determine the Likelihood of Occurrence of each Hazard Scenario</td>
<td>3-19</td>
</tr>
<tr>
<td>3.3.6 Field Information required to Determine the Severity of the Consequences for each Hazard Scenario</td>
<td>3-19</td>
</tr>
<tr>
<td>3.3.7 Final Review of Field Inspection</td>
<td>3-20</td>
</tr>
<tr>
<td>4. SIMPLIFIED RISK ASSESSMENT</td>
<td>4-1</td>
</tr>
<tr>
<td>4.1 Simplified Risk Assessment for Safety</td>
<td>4-1</td>
</tr>
<tr>
<td>4.1.1 General Aspects</td>
<td>4-1</td>
</tr>
<tr>
<td>4.1.2 SRA process for Safety Risks</td>
<td>4-2</td>
</tr>
<tr>
<td>4.1.2.1 STEP 1: Identification of Hazard Scenarios</td>
<td>4-3</td>
</tr>
<tr>
<td>4.1.2.2 STEP 2: Assessing the Likelihood of Occurrence (Probability)</td>
<td>4-17</td>
</tr>
<tr>
<td>4.1.2.3 STEP 3: Estimating the Severity of the Consequences</td>
<td>4-18</td>
</tr>
<tr>
<td>4.1.2.4 STEP 4: Assessing the Magnitude of Risk</td>
<td>4-22</td>
</tr>
<tr>
<td>4.1.3 Results of the Simplified Risk Assessment for Safety</td>
<td>4-22</td>
</tr>
<tr>
<td>4.2 Simplified Risk Assessment for Contamination</td>
<td>4-23</td>
</tr>
<tr>
<td>4.2.1 General Aspects</td>
<td>4-23</td>
</tr>
<tr>
<td>4.2.2 SRA Process for Contamination</td>
<td>4-24</td>
</tr>
<tr>
<td>4.2.2.1 STEP 1: Formulation of the Problem</td>
<td>4-25</td>
</tr>
<tr>
<td>4.2.2.2 STEP 2: Identification of Hazard Scenarios</td>
<td>4-26</td>
</tr>
</tbody>
</table>
4.2.2.3 STEP 3: Estimating the Probability Index (PI) 4-39
4.2.2.4 STEP 4: Estimating the Severity of Consequences 4-41
4.2.2.5 STEP 5: Assessing the Magnitude of Risk 4-45
4.2.3 Result of the Risk Assessment for Chemical Contamination 4-46
4.3 Summary of Risk Assessment for SD/AMS 4-47
4.4 Cumulative Risk Assessment 4-48
4.4.1 Need for a Cumulative Risk Assessment 4-48
4.5 Need to perform a Detailed Risk Assessment 4-49
4.5.1 General Aspects 4-49
4.5.2 Process to Determine the Need for a DRA 4-50

5. DETAILED RISK ASSESSMENT FOR SAFETY 5-1
5.1 Subsidence Study 5-3
5.1.1 Field Studies 5-4
5.1.2 Laboratory Analysis 5-4
5.1.3 Analysis and Modelling 5-5
5.1.4 Content of Subsidence Reports 5-6
5.1.5 Bibliographic References 5-6
5.2 Slope Stability assessment 5-6
5.2.1 Slope Stability Study 5-7
5.2.1.1 Laboratory Test Related to Stability 5-9
5.2.1.2 Data Analysis and Modelling 5-9
5.2.2 Considerations Related to the Water Table 5-11
5.2.3 Mitigation of Risk 5-11
5.2.4 References and Programmes Available for Slope Stability Analysis 5-12
5.3 Tailing Dams and Impoundments 5-12
5.3.1 Field Investigations of Tailings Storage Facilities 5-14
5.3.1.1 Sloughing and Slope Stability 5-14
5.3.1.2 Freeboard 5-14
5.3.1.3 Rates of Rise 5-14
5.3.1.4 Seepage and Drains 5-14
5.3.1.5 Phreatic Surface 5-15
5.3.1.6 Penstock Inlets 5-16
5.3.1.7 Groundwater 5-16
5.3.1.8 Tailings Dam Inspections and Safety Observations 5-16
5.3.2 Bibliographic References Related Tailings and Impoundments 5-17

6. DETAILED RISK ASSESSMENT FOR CONTAMINATION 6-1
6.1 Methodology Background 6-1
## TABLE OF CONTENTS

### 6.2 DRA Process for Contamination
- 6-3

### 6.3 STEP 1 – Formulate the Problem
- 6-3
  - 6.3.1 Study Approach
- 6-3
  - 6.3.2 Assessment of Sources of Contamination
  - 6.3.3 Preliminary Identification of Chemicals of Potential Concern
  - 6.3.4 Preliminary Identification of Receptors and Exposure Pathways
  - 6.3.5 Designing a Conceptual Model
  - 6.3.6 Requirements for Additional Studies and Sampling

### 6.4 STEP 2 – Collect Supplementary Information
- 6-9
  - 6.4.1 Visit to the SD/AMS
  - 6.4.2 Collection and Analysis of Supplementary Samples
    - 6.4.2.1 Selection of Sampling Points and Sample Size
    - 6.4.2.2 Sampling Methodology
    - 6.4.2.3 Laboratory Analysis
    - 6.4.2.4 Statistical Analysis of the Results
    - 6.4.2.5 Quality Assurance and Quality Control of Sampling (QA/QC)

### 6.5 STEP 3 – Assessment of Chemicals of Potential Concern
- 6-27

### 6.6 STEP 4 – Risk Assessment
- 6-27
  - 6.6.1 Quantitative Human Health Risk Assessment
    - 6.6.1.1 Introduction
    - 6.6.1.2 Dose-Response Assessment (Toxicological Assessment for Humans)
    - 6.6.1.3 Exposure Assessment
    - 6.6.1.4 Characterization of Human Health Risks
    - 6.6.1.5 Analysis of Uncertainties
  - 6.6.2 Ecological Risk Assessment
    - 6.6.2.1 Introduction to Quantitative Ecological Risk Assessment
    - 6.6.2.2 Stressor-Response Assessment for Ecological Receptors
    - 6.6.2.3 Exposure Assessment
    - 6.6.2.4 Quantification of Ecological Risks
    - 6.6.2.5 Analysis of Uncertainties

### 6.7 STEP 5 - Risk Statement
- 6-51
  - 6.7.1 Human Health Risk Assessment
  - 6.7.2 Ecological Risk Assessment
  - 6.7.3 Assessment of Severity of Consequences
TABLE OF CONTENTS

6.8 Peer Review of Detailed Risk Assessment Reports 6-57
6.9 Calculating Site Specific Target Levels 6-58

7 CLASSIFICATION AND PRIORITIZATION OF SD/AMS ACCORDING TO RISKS 7-1
7.1 Classification of SD/AMS 7-1
7.2 Prioritization of SD/AMS 7-1
    7.2.1 Prioritization of Class I SD/AMS (MEL) 7-1
    7.2.2 Prioritization of Class II SD/AMS (non-MEL) 7-3
7.3 Periodic Review of Class II SD/AMS Risk Assessment 7-4

TABLES

Table 1-1: Components of a SD/AMS .............................................................. 1-7
Table 2-1: Criteria for Defining the Severity of Consequences ........................................ 2-5
Table 2-2: Risk Matrix ....................................................................................... 2-5
Table 2-3: Significant and Non-significant Risk .................................................. 2-6
Table 2-4: Classes of SD/AMS ........................................................................... 2-8
Table 4-1: Characterization of Site Components .................................................... 4-5
Table 4-2: Sample Information Identifying and Describing the Installations, Deposits and Works of a SD/AMS .............................................................. 4-6
Table 4-3: Safety-related Hazard Scenarios ...................................................... 4-7
Table 4-4: Sample Record of Safety Hazard Scenarios ........................................ 4-16
Table 4-5: Sample record of SHS Probability Indices ............................................. 4-18
Table 4-6: Severity of Consequences Scale – Safety Hazard Scenarios ......................... 4-19
Table 4-7: Severity of Consequences Rating for People ......................................... 4-20
Table 4-8: Severity of Consequences Rating for Terrestrial Fauna and Flora ................ 4-21
Table 4-9: Sample Record of Safety Risks .......................................................... 4-23
Table 4-10: Contamination Hazard Scenarios .................................................... 4-28
Table 4-11: Sample Record of Contamination Hazard Scenarios for Site 'X' ................. 4-39
Table 4-12: Sample Record of CHS Probability Indices .......................................... 4-41
Table 4-13: Receptors for Risk Assessment ...................................................... 4-41
Table 4-14: Severity of the Consequences in the SRA due to Chemical Contamination .................................................. 4-43
Table 4-15: Severity of Consequences for People ............................................... 4-45
Table 4-16: Sample Risk Matrix for Contamination Risk ....................................... 4-47
Table 4-17: Sample Risk Assessment for Safety and Contamination of a SD/AMS ......... 4-47
Table 4-18: Identification Codes for Risk Matrix cells ............................................ 4-50
Table 5-1: Safety Hazard Scenarios for which a DRA is indicated .......................... 5-1
Table 5-2: Recommended Borehole Positions ................................................... 5-8
Table 6-1: Potential Sources of Contamination and Media Susceptible to Contamination .................. 6-6
Table 6-2: Types of Minerals and Main Chemicals of Potential Concern ...................... 6-7
Table 6-3: Conceptual Sampling Plan for Media Susceptible to Contamination .............. 6-14
TABLE OF CONTENTS

Table 6-4: Exposure Pathways to Consider in Assessing Exposure ................................................. 6-31
Table 6-5: ERA – Possible Exposure Pathways by Media Susceptible to Contamination ............. 6-44
Table 6-6: Example of a Probability Index Rating Scheme .................................................. 6-51
Table 6-7: Classification Criteria for Hazardous Categories of Carcinogens ......................... 6-52
Table 6-8: Probability Index versus Ecological Risk Value or Hazard Quotient .................. 6-53
Table 6-9: Example of a Severity of Consequences Index Rating .......................................... 6-54
Table 7-1: Cell identification Codes in the Risk Matrix .................................................. 7-2

FIGURES

Figure 1-1: Abandoned/Dormant Mines in Namibia .......................................................... 1-4
Figure 1-2: Abandoned/Dormant Mines in the Tsuseb-Otavi-Grootfontein Area ............... 1-5
Figure 1-3: Abandoned/Dormant Mines in the Erongo Region ........................................... 1-6
Figure 2-1: Schematic Diagram of Risk Assessment Process for SD/AMS ......................... 2-2
Figure 2-2: SD/AMS Risk Assessment Process ........................................................... 2-10
Figure 4-1: SRA Process for Safety Risks .......................................................... 4-3
Figure 4-2: SRA Process for Chemical Contamination .................................................. 4-25
Figure 4-3: Contamination Model Scheme .......................................................... 4-27
Figure 4-4: Classifying a SD/AMS based on Risk .................................................... 4-51
Figure 5-1: Defining the Area in Danger of Subsidence for Underground Mine Works with Slope less than 30° .............................................................. 5-5
Figure 6-1: Flowchart for Detailed Risk Assessment for Contamination ...................... 6-2
Figure 6-2: Steps in the Detailed Risk Assessment ................................................... 6-4
Figure 6-3: Statistical Analysis of Laboratory Results .................................................... 6-22
Figure 6-4: Example of Pathway-Receptor Integration Diagram .......................................... 6-33
Figure 7-1: Example of MEL prioritization ............................................................ 7-3
# ANNEXURES

## ANNEX A: COMPLEMENTARY INFORMATION FOR THE SIMPLIFIED RISK ASSESSMENT FOR SAFETY

A1: Guide for Estimating each Hazard Scenario Safety Index  
A2: Supporting Material for the Simplified Risk Assessment for Safety

## ANNEX B: COMPLEMENTARY INFORMATION FOR THE SIMPLIFIED RISK ASSESSMENT FOR CONTAMINATION

B1: Guides to Estimate the Probability Index for each Contamination Hazard Scenario  
B2: Supporting Material for the Simplified Contamination Risk Area

## ANNEX C: COMPLEMENTARY INFORMATION FOR THE DETAILED RISK ASSESSMENT FOR CONTAMINATION

C1: Guideline Concentrations for Assessment of Chemicals of Potential Concern in Environmental Media  
C2: Basic Considerations for Reviewing Studies in the Detailed Risk Assessment for Contamination

## ANNEX D: COMPLEMENTARY INFORMATION FOR THE DETAILED RISK ASSESSMENT FOR SAFETY

D1: Basic Considerations for Reviewing Studies in a Detailed Risk Assessment for Safety

## ANNEX E: RISK ASSESSMENT RECORD FORMS

## ANNEX F: FIELD GUIDE

## ANNEX G: SHUT DOWN AND ABANDONED MINE SITE INVENTORY DATA SHEET