Assessment of Cover Design, Construction and Aging on Percolation, Oxygen Ingress and Acid Mine Drainage for Coal Discard Facilities for Mpumalanga Highveld

Part B
Best Practice Guideline on Soil Covers to Mitigate Acid Mine Drainage and Seepage Impact

Technical report to the
Water Research Commission

by

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This report forms part of a set of two reports. The other report is *Assessment of Cover Design, Construction and Aging on Percolation, Oxygen Ingress and Acid Mine Drainage for Coal Discard Facilities for Mpumalanga Highveld. Part A. Soil Covers Assessment and Modelling*. (WRC Report No. 2759/1/22)

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EXECUTIVE SUMMARY

Well-designed and constructed soil covers can provide cost-effective, source-directed and mainly passive-management measures to minimise Acid Mine Drainage (AMD) from rehabilitated discard dumps. Current South African standards and guidelines do not effectively address procedures or provide tools for a risk-based approach to quantitatively assess the likelihood and extent that acceptable environmental limits (AELs) can be met in the receiving (ground)water with a soil cover (residual risk), and the latent (long-term) risk of coal discard with well-designed and constructed soil covers. No systematic study on the effects of cover aging on material properties have been conducted in South Africa.

Part B of the report addressed the following study aim:

- To develop a Technical Best Practice Guideline (BPG) for the design and construction of soil covers to minimise rainwater and oxygen ingress, AMD production and seepage loads, all to achieve acceptable environmental limits in the receiving (ground)water.

Guidelines for the planning, design, construction and post rehabilitation care of soil covers were developed internationally with the aim to minimise rainwater- and oxygen ingress, AMD production and seepage loads from waste and mine residue facilities. The BPG was developed to integrate with relevant components of the BPG on Impact Prediction for Water Resource Protection in the South African Mining Industry, the Land Rehabilitation Guidelines for Surface Coal Mines, and international BPGs on soil covers. This BPG promotes integration of risk-based predictive framework with good practice Source Pathway Receptor (SPR) modelling and economically viable cover designs.

The BPG provides a means to determine the probability that AELs in (ground)water can be met with a cover constructed from materials available on site, residual risks and need for additional measures if AELs cannot be met. It also provides a means to predict long-term post-closure cover performance on AMD production and seepage loads and to determine the latent risk of discard facilities on the receiving (ground)water.

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1 INTRODUCTION

The purpose of this technical Best Practice Guideline (BPG) on soil covers (Cover-BPG) is to provide guidance on good practices to those involved in the planning, assessment, design, construction, care and monitoring of soil covers to mitigate acid mine drainage (AMD) and seepage impacts from discard facilities for the Mpumalanga Highveld coalfield. The BPG constitutes *Part B* of the project funded by the Water Research Commission (WRC). Part A of the study focussed on analysing associated research, measuring performance characteristics of existing mature soil covers and identifying knowledge and data gaps.

1.1 Motivation for guideline

Infiltrated rain that seeps through the soil cover into coal discard during periods where daily rain significantly exceeds daily potential evaporation leads to the oxidation of sulphide-containing residue that produces AMD and leachate containing CoCs while oxygen is available in the discard. Important factors that influence the ingress of infiltrated rain (rainwater ingress) into coal discard include the water retention and permeability of cover materials, cover water storage capacity, root depth and development, and plant transpiration rates. This emphasises the importance of optimising soil cover- and vegetation characteristics to minimise rainwater ingress and reduce oxygen ingress into coal discard to mitigate AMD and CoCs seepage into the receiving (ground)water.

The mine water management hierarchy for evaluation and decision-taking by Department of Water and Sanitation (DWS) in potential seepage impacts sets a priority order where pollution prevention options are first implemented before water reuse, reclamation and treatment are considered (DWAF, 2008). Soil covers relate to the *pollution prevention strategy* of the hierarchy as a *source-directed measure* that mitigates the generation and seepage of AMD from mine residues by reducing rainwater- and oxygen ingress into it. It is also a *passive-management measure* where the need for ongoing intervention and active mine water management could be minimal. According to the G5-BPG, source-directed and passive management systems are preferred due to their generally more robust nature and tend to be more effective in pollution prevention as they address the source of contamination (e.g. acid-generating discard) before it migrates into water resources. Source-directed, passive management systems also often have a lower risk of failure.

Soil covers have become an *integral component in mine rehabilitation, closure and post-closure management* of mine residue facilities of the Mpumalanga Highveld (Land Rehabilitation Society of Southern Africa, Coaltech, Minerals Council of South Africa (LaRSSA *et al.*), 2019). It is, therefore, important to provide guidance on the appropriate planning, assessment, design, and construction of soil covers, and to highlight care and monitoring requirements of soil covers to minimise AMD production and seepage of CoCs to ensure that defined rehabilitation-, closure- and post closure objectives are met for discard facilities in the short- and long-term.

Appropriately designed and constructed soil covers to achieve above-mentioned objectives plays a pivotal role in managing the risks originating from the impact that coal discard facilities have on the receiving (ground)water quality, and in limiting associated liabilities. To control latent and residual environmental impact risks on AMD and CoCs seepage, planned management actions, such as to appropriately design and construct soil covers and concurrent rehabilitation of the coal discard facility, should be implemented during the mining life cycle, through to mine-closure and thereafter (LaRSSA *et al.*, 2019; INAP, 2017).

The pollution prevention strategy is essentially a rational planning and design process where options, such as soil covers, are evaluated to identify pollution control measures that offer the optimal degree of pollution mitigation and require the least amount of active long-term interventions (DWAF, 2007). According to INAP (2017, 2009), soil covers most often provide the most *viable and cost-effective means to mitigate seepage impacts from mine residue facilities* in arid, semi-arid and sub-humid climates and have traditionally been preferred as final covers for mine residue facilities due to the large areas that need to be covered. It is therefore important that good practices, such as those included in this guideline, are presented that can be utilised to assess, design, construct and care for soil covers to be implemented as part of pollution mitigation strategy.

According to NEMWA, Section 3 in GN R.632, dated 24 July 2015 (as amended), a risk-based assessment can be followed in the assessment of impacts and analysis of risks relating to the management of mine residue stockpiles and residue deposits (MRSRDs). The cover design component of the guideline relies on risk analysis and cover designs to optimise performance of soil covers that aim to mitigate seepage impacts to acceptable environmental limits or targets. The *risk analysis of this BPG focusses on residual risks of seepage impacts* that are likely to be evident shortly after rehabilitation and mine closure. The *risk-based design- and SPR impact prediction approaches* of the guideline is consistent with principles and approaches included in the G4, G5, A2 and A5 BPGs on mine water impact assessment and management. This includes the application of appropriate unsaturated flow (hydrological), geohydrological and geochemical assessment techniques to appropriately design covers for rehabilitated discard facilities that will minimise long-term pollution risks cost-effectively.

According to LaRSSA *et al.* (2019), predictive modelling has become a preferred option to *determine the long-term outcomes of rehabilitation projects* since long-term measured site data and reliable case studies are usually lacking. Predictive modelling of covers is particularly useful to *analyse and compare seepage impacts and risks, and to assess potential cost-benefit analyses of cover options*, or against the collection and treatment of mine effluent.

Predictive modelling allows the assessment of cost-benefits between different, feasible, cover option(s) or between cover materials with different (hydraulic) properties and enables the designer to modify those aspects of the cover design that present unacceptable levels of risk. Predictive modelling allows for timeous actions when target results are not achieved and reduces the risk of unwanted post-rehabilitation and closure mining-related environmental impacts. Soil cover design decisions are based on the modelled predictions of how rainwater ingress can be limited, and oxygen ingress reduced, to mitigate AMD and seepage impacts to acceptable environmental targets. Predictive modelling will also inform appropriate water treatment and management strategies, if required.

1.2 Guideline development

The technical guideline was developed to align with various existing guidelines.

The series of *Best Practice Guidelines for Water Resource Protection in the South African Mining Industry* was largely integrated into this document. This series includes (in decreasing order of relevance and integration into this guideline):

- G4: Impact Prediction (G4-BPG; DWAF, 2008a);
- G5: Water Management Aspects for Mine Closure (G5-BPG; DWAF, 2008b);
- A2: Water Management for Mine Residue Deposits (A2-BPG; DWAF, 2007a);
- H2: Pollution Prevention and Minimization of Impacts (H2-BPG; DWAF, 2007b).

Other guidelines, where sections were integrated into this guideline, include; G3: Water Monitoring Systems (DWAF, 2008c) and H1: Integrated Mine Water Management (DWAF, 2008d).

In addition to the guideline series published by DWAF, components of a Decision Support System for oxygen diffusion and pore water quality evolution modelling (Bezuidenhout and Randell, 2010) were also integrated with this guideline.

Several documents that deal with land rehabilitation of coal mining sites have been published in South Africa. The most recent guideline is the *Land Rehabilitation Guidelines for Surface Coal Mines* (Rehab-BPG) that was published by the LaRSSA *et al.,* 2019. The Rehab-BPG includes several good practices on landform design, soil stripping, stockpiling, placement, and amelioration, revegetation, monitoring and site relinquishment that are important to soil covers. This guideline is, therefore, linked to, and integrated with the Rehab-BPG.

Recent International Guidelines for the planning, design, construction, care and monitoring of soil covers provide information on measures to *inter alia* minimise rainwater ingress and reduce (atmospheric) oxygen ingress into facilities and mitigate associated AMD and seepage impacts from mine residue and waste facilities (International Network for Acid Protection (INAP 2017; 2009); Waste Management Association of Australia (WMAA, 2011); Albright, Benson, and Waugh, 2010). A gap analysis was conducted on South African guidelines, compared against International Guidelines. Important aspects that were not addressed in previous South African guidelines are included in this guideline.

This guideline integrates with existing South African guidelines, fills gaps in these documents, and links with international soil cover guidelines to meet the specific needs of soil covers that mitigate seepage impacts from discard facilities with a focus on the Mpumalanga Highveld coalfields (Figure 1-1).

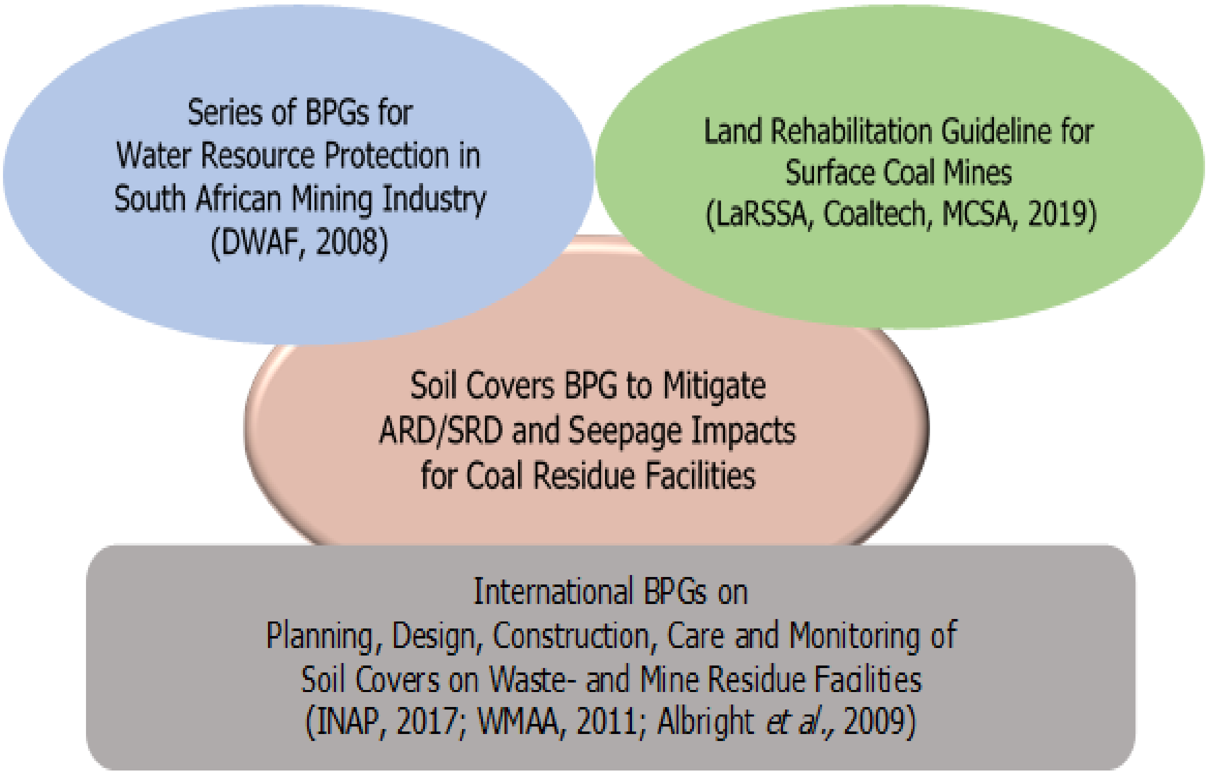

Figure 1-1: Integration of South African and international guidelines in developing guideline.

1.3 Purpose of guideline

The purpose of this *technical* guideline is to provide guidance on good practices to those involved in the planning, assessment, design, construction, care and monitoring of soil covers on coal discard facilities that mitigate:

- Rainwater and oxygen ingress into coal discard;
- Production of AMD in the coal discard;
- AMD and CoCs seepage from coal discard facilities; and
- Achieve statutory and regulatory compliance.

The guideline was developed with a focus on the Mpumalanga Highveld coalfields. Most of the approaches, concepts, principles, methods and (modelling) tools can also apply to other coalfields in semi-arid regions of South Africa

1.4 Disclaimer

This soil cover-BPG for coal discard facilities was funded by the WRC as part of a larger research project that also assessed mature soil covers in the Mpumalanga Highveld coalfields (Section A of this report).

While reasonable efforts were made to ensure that information contained in this guideline is correct, the Water Research Commission, Terrasim CC and the collaborating organisations and individuals can provide no warranties on the completeness or accuracy of information of this BPG, and shall not be held liable for any loss or damage that may occur directly or indirectly through using, or relying on, the contents of this guideline.

This guideline is an accumulation of knowledge and information relevant to soil covers, and the design thereof, at the time of completion of this guideline. Users should consider the guideline to be a reference guide on accepted good practice at the time of publication. The guideline is not intended to replace the need for professional advice on individual discard facilities. The guideline should be reviewed and revised, so that new ideas can be incorporated, and gaps filled as more information becomes available.

The guideline has no legal standing. It has, however, been developed to support and align with the statutory provisions of water and environmental legislation. Immediate benefits would include augmented good practice and detailed information that should support and facilitate regulatory decision making in respect of the planning, assessment, design, construction, care and monitoring of soil covers that aim to mitigate seepage impacts from backfilled pits or discard facilities.

2 PLANNING

Soil cover planning aimed to provide:

- *Cover goals and objectives* that are align with regulatory requirements and the facility and mine's rehabilitation and closure objectives;
- *Cover performance objectives and criteria* to monitor cover performance against, and that provide a basis to determine site relinquishment criteria;
- *Viable cover options and high-level risks and knowledge gaps on cover options* that are identified from a screening level risk assessment.

The process to plan for covers will generally follow the process indicated in the flow-chart shown in Figure 2-1.

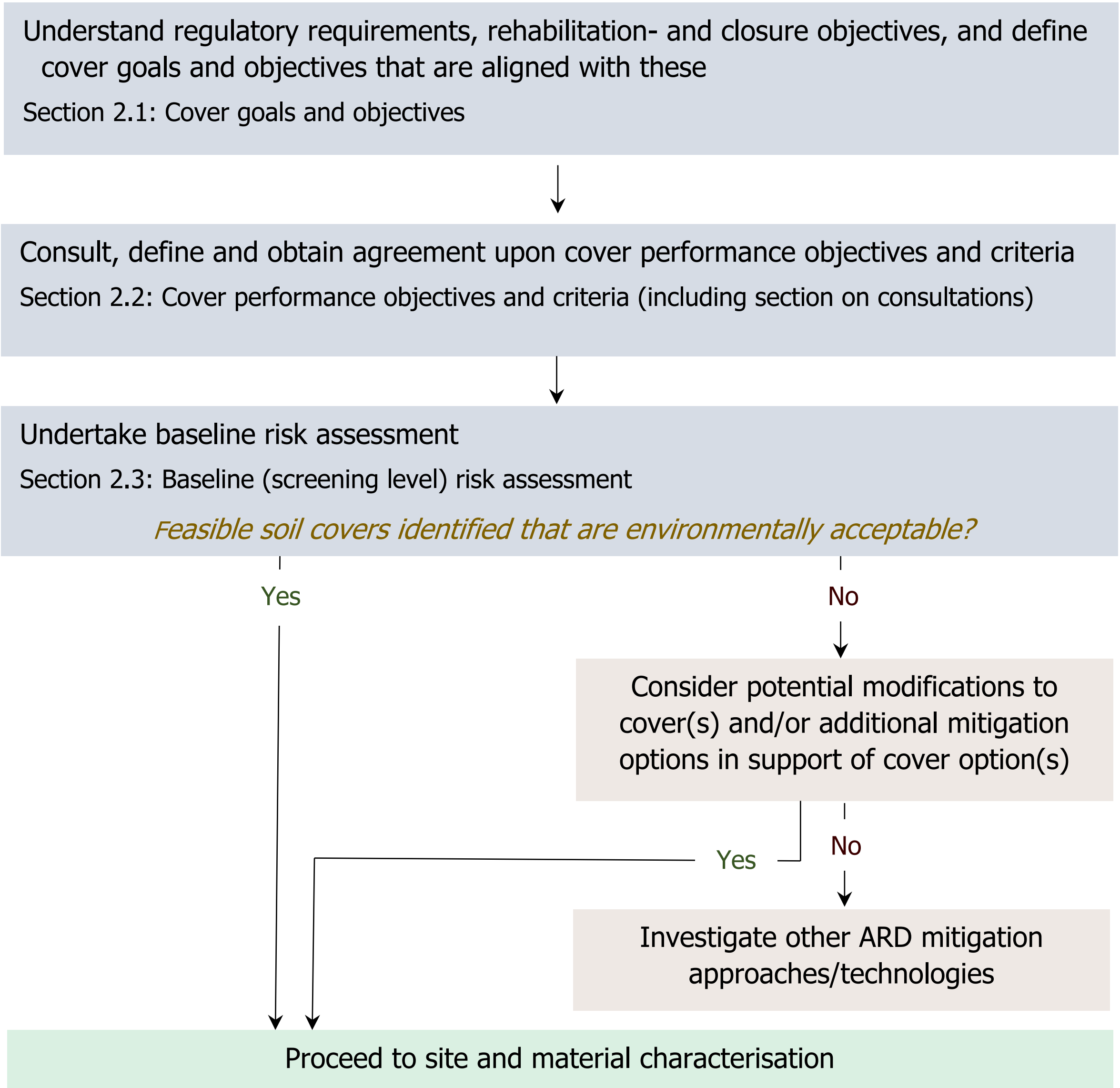

Figure 2-1: Process for planning for covers.

2.1 Cover goals and objectives

The first step is to become familiar and understand the regulatory requirements and the goals and objectives of the facility/mine's land rehabilitation-, final land use-, and closure plans to ensure that the covers design meets these overall goals and objectives. If the land rehabilitation and closure plans do not yet exist, then it will be necessary to consult the closure objectives in the applicable legislation.

The focus of this guideline relates to the following rehabilitation and closure goals:

- Meet regulatory requirements;
- Provide a soil cover that has the specific functions of:
  - Minimising rainwater ingress into the discard,
  - Reduce (atmospheric) oxygen ingress into the discard, and
  - Minimise pyrite oxidation and related AMD production in the discard (by minimising rainwater ingress and reduce oxygen ingress);
- Provide covers that will achieve the above-mentioned objectives, and that are:
  - Provide a growth medium to establish vegetation to achieve stated end land use,
  - Cost-effective to construct and maintain, and are
  - Robust and stable in the long-term (decades), while supporting the approved end land use.

Additional information

According to INAP (2017), arid- and semi-arid climates are too dry for soil covers to limit oxygen ingress, but the ingress can be reduced. Consequently, an oxygen-limiting cover should not be included as a cover goal for the coalfields in South Africa.

According to the Land Rehabilitation Guidelines for Surface Coal Mines (LaRSSA *et al.*, 2019), a rehabilitation goal is a high-level post-mining target vision of the desired final land state at site relinquishment. Cover (and rehabilitation) goals should be realistic, based on the site's physical, environmental and socio-economic assets as defined by available site data and knowledge. It should also provide enough detail to serve as a clear target against which measurable relinquishment criteria can be set.

Rehabilitation of mined land can include goals related to:

- Securing suitable land capabilities for food production;
- Ensuring local and regional catchment and water resource integrity by limiting water resource contamination and improving recharge to affected aquifers;
- Reinstating and improving ecosystem goods, services and functionality; and
- Creating alternative livelihoods for communities, whilst ensuring that the post-mining land use opportunities identified are sustainable (LaRSSA *et al.*, 2019).

Considerations when setting goals for soil covers include:

- *Discard chemical reactivity*. The level of reactivity and buffering capacity of the coal discard needs to be considered. As a general rule, the more reactive the discard, the more stringent the cover specifications will need to be to mitigate seepage impacts from discard facilities to AELs;
- *End land use*. The end land use must be kept in mind in setting cover goals and when developing cover designs, to ensure that the outcome is aligned with the end land use in the closure plan;

- *Landform stability*. The erosional stability of landforms needs to be considered to ensure that constructed cover surfaces are stable (regarding erosion), especially during periods of low vegetation cover or when there are long slopes that are too steep. The actual landform geometries also need to be considered, as steeper side slopes and sharp edges in the geometry will promote erosion, while flatter side slopes will allow more surface infiltration into the soil covers. Consequently, the overall landform erosional stability needs to be designed to be in equilibrium with the net water ingress into the facilities; and
- *Surface stability*. In addition to erosion, the stability of the cover surfaces towards the development of surface seals and crusts is also important, as this can result in increased erosion and reduced germination and plant growth. The use of the Orthic A- and Apedal B-soil horizons as growth mediua should provide stable surfaces in terms of erosion, seals and crusts. The use of subsoil horizons, such as plinthic B, subsoils and soft (completely weathered) overburden could result in a considerable increase in erodibility, surface sealing and crusting, erosion damage, gullying, and reducing germination success and overall growth and vigour of the vegetation cover.

2.1.1 Regulatory requirements

The regulatory requirements for the planning, design and management of Mine Residue Stockpiles and Residue Deposits (MRSRD), such as coal discard facilities, have evolved significantly in recent years.

MRSRDs should be designed and managed according to the relevant legislation and best practice in order to reduce pollution of the receiving environment, particularly water resources (LaRSSA *et al.*, 2019). The design of MRSRDs form part of the Water Use Licence applications which must be submitted to the Department of Water and Sanitation for review and approval.

The Rehab-BPG (LaRSSA *et al.*, 2019) summarised (in Chapter 2 and Appendix B) the legal obligations in terms of practical procedures, operations and performance standards regarding land rehabilitation and closure. It highlights the key areas of South African legislation that should inform the development of a mine site's rehabilitation and closure plan, and the factors that must be taken into consideration.

The more important legislation and regulations that are applicable to the soil covers include:

- 'Duty of Care' principle requires everyone to take all reasonable measures to avoid/prevent pollution of the environment and water resources, or, where they cannot be avoided, they are minimised and remedied:
  - Constitution of the Republic of South Africa (Act No. 108 of 1996), Section 24,
  - National Environmental Management Act (NEMA) (Act No. 107 of 1998), Section 2(4)(a)(ii) and Section 28, and
  - National Water Act (NWA), No. 36 of 1998;
- Protection of water resources through the inclusion of measures to prevent water containing waste (leachate) or pollutants (CoCs) from seeping into the groundwater:
  - NWA, Regulation 7 contained in Government Gazette No. 7(4) (GN704) of 1999;
- With the design of final cover/capping, it must be realised that the cap (final cover) works in conjunction with the liner by limiting the long-term generation of leachate. This is presented in the context of best practice based on the legal principle of Best Practical Environmental Option:

  - Minimum Requirements for Waste Disposal by Landfill (DWAF, 1998), section on the design of final cover/capping (primarily applies to landfills but sometimes used for MRSRDs);
- Other design considerations for MRSRDs include a capping (cover) layer to prevent the generation and mobilisation of CoCs:
  - NWA, Regulation 7 contained in Government Gazette No. 7(4) (GN704) of 1999, and
  - NEMA, Section 24N. Environmental management program; subsection 2 (a)(i) planning and design;
- Risk-based assessment can be followed in the assessment of impacts and analysis of risks relating to the management of MRSRDs. This provides an opportunity to introduce risk assessment as a scientific and legally defensible basis for statutory conformance of pollution barriers regarding soil covers. However, the onus is on the applicant to show that the overall performance of the proposed alternative option, such as proposed soil covers as a cost-effective alternative, will not exceed acceptable environmental impact limits, such as the Acceptable Water Quality Objective;
- The investigation and assessment of MRSRDs must be included in the environmental management plan and programme, which must include inter alia the requirements for design, construction, operation, decommissioning, closure and post-closure maintenance, and details of rehabilitation of the MRSRDs:
  - NEMA, Section 24N. Environmental management program; subsection 2 (a)(i) planning and design;
- The design of a MRSDSs must take into account all phases of the life cycle of the MRSRD, from construction through to post closure:
  - GNR 527 of 27 March 2020: Mineral and Petroleum, Social and Environmental Regulations: Section 56 - Principles for mine closure: (a) the closure of a prospecting or mining operation incorporates a process which must start at the commencement of the operation and continue throughout the life of the operation;
- The decommissioning, closure and post closure management of MRSRDs must be addressed in the closure plan, which must include inter alia record of consultation with interested and affected parties, closure objectives, final land use, conceptual description and details for closure and post-closure management, and the residual impacts, monitoring and requirements to obtain mine closure in terms of the Act:
  - Mineral and Petroleum Resources Development Act (MPRDA), No. 28 of 2002, Section 62 of GN R. 527 of 2020, Mineral and Petroleum Resources Development Regulations;
- Information for operational rehabilitation and closure planning to determine the costs associated with the management, rehabilitation and remediation of any potential environmental impacts arising from mining and related activities. This includes financial provision for closure at the operation’s envisaged end of life, as well as for any operation-related residual environmental impacts that may become known in future (post-closure):
  - NEMA General Notice Regulation (GNR) 1147 of 2015 (last draft for comments published on 17 May 2019) on the regulations pertaining to the financial provision for rehabilitation and closure; and

- Environmental risk report that includes post closure residual- and latent risk:
  - NEMA General Notice Regulation (GNR) 1147 of 2015 on the regulations pertaining to the financial provision for rehabilitation and closure.

No promulgated norms and standards currently exist for soil cover designs, such as WB covers, to reduce seepage impacts to acceptable levels. The aim of this BPG is to provide the processes, methodologies and tools needed to appropriately plan, design, construct and care for soil covers to meet this objective.

2.1.2 Consultations

Permits to carry out mining activities in South Africa rely considerably on the results of Environmental Impact Assessments (EIAs) carried out in terms of the National Environmental Management Act (NEMA). An important function of the EIA process is the establishment of a social impact, which equates to an implicit agreement between stakeholders to cooperate towards a defined sustainable environmental condition at the end of mining operations. Soil covers are important in establishing surface conditions that are suitable for planned final land use but are also instrumental in achieving AELs.

EIAs must include mechanisms for widespread consultation, and the findings must be presented to interested and affected parties through a public review process. Failure to manage the impacts of mining on water resources (surface and groundwater) in an acceptable manner will result in the mining industry finding it increasingly difficult to obtain community and government support for existing and future projects (DWAF, 2008).

The key consultations are those with stakeholders who have a direct interest in covers design, construction, management, site ownership and regulations. Early communication with the regulator is particularly important to obtain support for the cover objectives, performance criteria, cover performance assessment approach and acceptable level of risk for cover designs (WMMA, 2011).

2.2 Cover performance objectives and criteria

Well-defined and measurable cover performance objectives and criteria, over a specific timeframe, are pivotal to assess the success of a cover design and the construction thereof. According to the G5-BPG, the performance assessment timeframe can be determined from the results of the numerical modelling if the timeframe is not provided by the regulator.

The cover performance objectives should provide the basis to define performance criteria with regards to a soil cover against which the monitored cover performance can be assessed to determine when site relinquishment can be obtained (INAP, 2017). It is imperative that cover performance objectives and criteria are established that specify target acceptable environmental limit values (AELs), both in terms of location and timeframes. This emphasises the need to ensure that cover performance objectives and criteria are drafted carefully to make them both measurable and achievable, and to allow for sign-off by the decision-making Authorities.

According to INAP (2017), cover performance criteria that were set during the planning phase can be refined when more detailed information and data obtained from the risk analysis and numerical impact predictions provides more realistic criteria. The cover performance objective and criteria for a cover may consist of the Water Quality Objectives for a receptor(s) (points of compliance) that is approved by DWS and specified in a Water Use Licence (WUL) over a specific timeframe. If Water Quality Objectives were not specified, the quality standards included in the water quality guidelines that were published by DWAF for either surface or groundwater as specified by the various water users (namely ecological, industrial, agricultural, domestic and recreational users) can be used.

Performance objectives and criteria may also, in addition to water quality criteria, consist of acceptable rainwater ingress rates (also referred to as net percolation rates or rain recharge), for example, to minimise toe seepage from a rehabilitated discard facility; or minimise the volume of seepage for treatment after rehabilitation and closure.

It is imperative that AELs are established that specify target values, both in terms of location and time. It is possible that latent environmental risks, though present, will only manifest after an extended period, because it might take time for the CoCs to be transported through the vadose zone.

Other cover performance objectives that should be addressed include:

- Meeting legal requirements and approved end land use;
- Providing covers that are robust and cost-effective to construct and maintain during post closure; and
- Establishing resilient covers with an erosionally stable landform, as well as a physically and chemically stable growth medium to achieve the primary cover performance objectives in the long-term (decades) by ensuring that there are adequate plans and procedures in place to meet a long-term sustainable end land use.

Additional information

According to LaRSSA *et al.* (2019), cover performance criteria (rehabilitation objective and site relinquishment criteria) should be:

- Specific: It details exactly what needs to be done;
- Measurable: Achievement or progress can be measured;
- Achievable and realistic: It can be attainable within the resource and timeframe constraints;
- Time-bound: Time period against which achievement of the objective can be measured.

The more specific, measurable and achievable the performance criteria are defined, the easier it is to clearly define relinquishment criteria against which rehabilitation success can be evaluated and approved by decision-makers.

The advantages of using AELs as cover performance criteria are that the following aspects can be *clearly defined (specified), are measurable, can be cost-effective to monitor, and are simple and understandable to everyone*:

- The constituent(s) that needs to be monitored (monitoring indicator) can be defined;
- Monitoring (performance) point/s should be fixed spatially and over time;
- Period of monitoring;
- Frequency of monitoring;
- Method and procedure of sample collection and analysis; and
- Interpretation of monitoring results.

2.3 Baseline risk assessment

The aim of the baseline risk assessment is to provide a low-cost screening of potential risks prior to committing to more detailed cover designs. The baseline risk assessment includes two components:

- Screening level (qualitative) risk assessment to identify *potentially suitable covers* to meet defined cover performance for water ingress and/or seepage impacts AELs considering:
  - Coal discard geochemistry (AMD potential), and
  - Volume of potential suitable cover materials available at site or identified in potential borrow area(s); and
- Preliminary site conceptual models that identify data gaps and provide focus on data collection for subsequent cover designs.

2.3.1 Screening level (qualitative) risk assessment

The aim of the screening level risk assessment is to reduce the number of potentially suitable covers in order to provide focus on those with a more realistic expected/projected performance considering site-specific conditions.

INAP (2017) and WMAA (2011) indicated that the most important sources of risk to be considered in a screening level risk assessment include:

- Legal obligations, and more specifically to reduce seepage impacts to acceptable levels (AELs);
- Site and facility related factors:
  - Whether the defined AELs *or* Department of Water Affairs and Sanitation (DWA) approved water quality criteria for the receiving groundwater are likely to be exceeded for the proposed cover design/s for the discard facility, and
  - AMD potential and CoCs of the coal discard, and whether the CoCs are prone to leaching as determined from static geochemical tests;
- Cover materials:
  - Availability of growth medium materials,
  - Availability of potentially suitable cover materials, such as for water retention layers,
  - Whether the growth media and potentially suitable cover material(s) have unfavourable properties, and
  - If unfavourable properties exist whether these can cost effectively be ameliorated;
- End land use and vegetation, especially if the planned revegetation and land use and objectives can be achieved during the rehabilitation process.

The qualitative rating of potentially suitable covers, and the identification of those that require further detailed analysis. If the qualitative risk assessment indicates that covers are suitable- or marginally suitable with regard to the mitigation of seepage impacts, then those cover designs can be taken forward to be processed.

Additional information

The climate of the Mpumalanga Highveld can be regarded as suitable for soil covers for the baseline risk assessment as the mean annual precipitation exceeds the mean annual potential evaporation by more than two times, and the rainy season is characterised typically by drier periods between significant rain events or periods of consecutive rainy days. Consequently, a qualitative assessment to determine if soil covers are suitable covers for the Mpumalanga Highveld climate, such as included in the guideline by INAP (2017), will not be required.

The screening level risk assessment presented in this BPG is applicable when seepage impacts from discard dumps has been identified as a residual- and/or latent risk in other (qualitative) risks assessments, most notably the rehabilitation-risk assessment presented in the Rehab-BPG (LaRSSA *et al.,* 2019). The focus of the screening level risk assessment in this BPG is on the application and identification of soil covers as seepage mitigation measures (rehabilitation actions), where they are feasible to be implemented.

3 SITE AND MATERIAL CHARACTERISATION

SPR modelling must account for the interaction between site-specific climate, available cover materials, vegetation, site geohydrology, and geochemistry of the discard.

Site and material characterisation aimed to provide:

- *Geochemistry and reactivity of the discard*, which determines how stringent a cover design needed to be to meet performance criteria;
- *Site conceptual model* that describes the most significant receptor(s), important processes to be simulated and integration of modelling components;
- *Site characteristics* that provide vital inputs for SPR modelling; and
- *Availability and properties of suitable cover materials at site* to gain an understanding of viable cover options and potential cover thickness.

The process of site and cover material characterisation will generally follow the process indicated in the flow-chart shown in Figure 3-1.

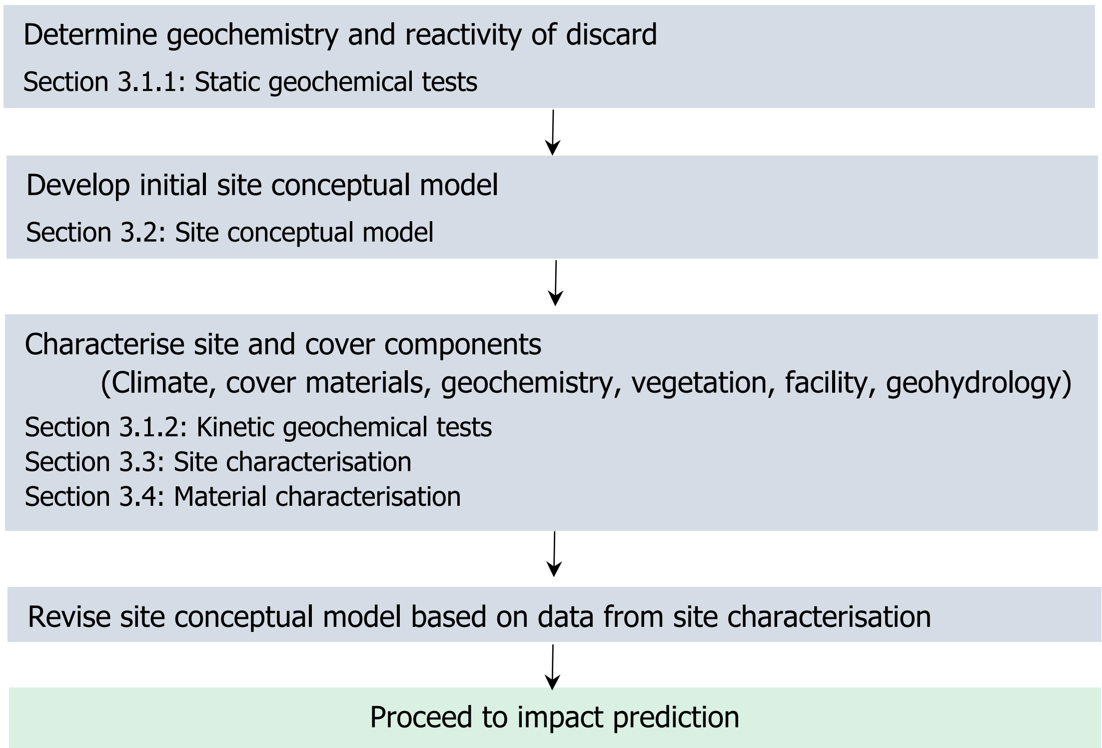

Figure 3-1: Process of site and material characterisation.

3.1 Geochemistry

The geochemistry and reactivity of the discard are an integral part of cover design, as it primarily determines how stringent cover designs should be in order to meet performance criteria on seepage impacts (INAP, 2017). According to DWAF (2008a), the mineralogy and leaching potential, acid generation and neutralisation potential, and reaction kinetics must be determined to assess risks and impacts that seepage will have on water resources. Geochemical aspects, analyses and modelling are described in G4-BPG.

According to DWAF (2008a), geochemical analyses can, in general, be divided into two categories, namely:

- *Static tests* which should be conducted for the screening level (qualitative) risk assessment; and
- *Kinetic tests* which should be conducted for the geochemical component of the numerical model (quantitative risk assessment).

3.1.1 Static geochemical tests

Static tests should be conducted for the screening level (qualitative) risk assessment to provide an indication of the reactivity and acid-base accounting of the backfill or discard. Static tests do not consider the effects of time and changes in the (micro)climates in a facility (such as changes in moisture content and oxygen levels). Therefore, kinetic tests should be conducted for geochemical predictive modelling. The static tests are discussed in the G4-BPG.

3.1.2 Kinetic geochemical tests

Kinetic tests should be conducted to provide the function of the geochemical reaction rate over time in order to predict the behaviour of the discard over time. Kinetic tests are laboratory tests that attempt to simulate field conditions. Humidity cells are frequently used, but column leach tests could also be conducted. Kinetic tests provide only an indication of the kinetic behaviour of the discard itself. It does not account for site-specific climate conditions, seasonal variability in rainwater ingress and water contents of the discard, and effect of covers thereon, which requires geochemical modelling.

The G4-BPG stipulates that geochemical analysis should be conducted by laboratories that have a quality assurance and quality control programme. The level of confidence in the data must also be assessed. The data sets must be reviewed and the reviewer must agree that the data sets are appropriate for the project, are representative of the backfill or discard, with the desired level of confidence.

3.2 Site conceptual model

A critical component of seepage impact risk modelling is to develop a conceptual site model for the source, pathway, and receptor (SPR) analysis, which is defined and clearly described. The development of conceptual site models is documented in the G4-BPG.

The framework for a site conceptual model for impact prediction includes:

- Determine the most significant receptor, e.g. groundwater user down-gradient of the discard facility;
- Draw conceptualised cross section through the discard facility, soil cover and aquifer(s) that indicates the key (must have) and important processes and factors to provide a focus for numerical modelling;
- Specify processes for integration of the various SPR numerical modelling components;
- Determine data requirements (for numerical modelling);
- Determine available data, data that are readily available and data gaps (according to data importance rating), potential sources of information for filling data gaps;
- Determine sampling, laboratory tests and analysis required, which may include soil surveys, test pits, in-field tests, geohydrological census and potential boreholes.

Examples of a site conceptual model for a rehabilitated discard facility are shown in the G5-BPG (DWAF, 2008b).

Important processes to consider for seepage impact modelling are:

- *Source component:*
  - *Water gains* such as rainfall,
  - *Water losses* such as runoff, evaporation, plant transpiration and rain interception, and toe seepage,
  - *Water retention* and water storage within the cover and discard,
  - Retarded flow through the discard,
  - Oxygen diffusion into and in the discard,
  - Oxidation of sulphide containing minerals,
  - Mineral dissolution reactions;
- *Pathway component:* Saturated flow through aquifer(s), groundwater level response, seepage down-gradient of discard facility, and CoCs transport, dispersion, advection and attenuation through the aquifers;
- *Receptor:* Location of the most significant (key) receptor in relation to the discard facility, and the CoCs to be monitored at the receptor.

The G4-BPG stipulates that the initial site conceptual model identifies critical receptor(s), and a methodology for sampling and analysis needs to be reviewed, refined, and accepted by affected parties. DWS should be approached to evaluate and approve the conceptual model and the identified critical receptor(s). An initial conceptual model must be updated with any improved understanding of site and cover materials characterisation or availability.

3.3 Site characterisation

3.3.1 Precipitation

Daily rainfall is the most important input for a soil cover design. Daily time series of rainfall that represents the site long-term rainfall (e.g. ≥50 years) on the site should be used. According to the G5-BPG, time series of daily rainfall depths may be stochastically generated if the rainfall record period is less than 50 years.

The Mpumalanga Highveld experiences several days where precipitation from small rain events (i.e. ≤5 mm) evaporate and is intercepted by vegetation, resulting in little effect on seepage. Seepage will mostly occur during larger rain events that exceed evapotranspiration and vegetation interception.

Rainfall averages, such as MAP, are insufficient as model input since it could result in a considerable over-prediction of cover performance (INAP, 2017), and must be considered as an unacceptable modelling practice. Periods with consecutive days (e.g. >5 days) where daily rain significantly exceeds potential evaporation, are critical model inputs, and should be reflected in the rainfall dataset. This scenario does not allow enough time between events for evapotranspiration to remove adequate water from the covers, which could result in considerable increase in seepage rates during that period.

3.3.2 Climate

Daily climate data that is representative of the study site is important as model input. Climate data allows the calculation of water losses that result from soil evaporation and plant transpiration (evapotranspiration) (INAP, 2017). Unsaturated flow models require daily data on temperature, evaporation (reference evapotranspiration), relative humidity and wind speed. In addition, data on daily solar radiation is preferred.

Reference evapotranspiration (Et_0) calculated from equations such as the Penman-Monteith equation (FAO, 1998), should be used for model input. Reference evapotranspiration (Et_0) represents the atmospheric evaporation demand from soil and vegetated surfaces, which is more applicable to soil covers. Potential evaporation recorded from water surfaces such as from an A-pan or S-pan, over-estimates potential evaporation from soil and vegetation.

Additional information

The mean annual potential evaporation for the Mpumalanga Highveld exceeds the mean annual precipitation by more than a factor of 2.2. The rainy season also occurs during the warm to hot months, with thunderstorms typically commencing late in the afternoon, providing sufficient time for evapotranspiration to occur between rain events. Consequently, soil covers are suitable covers for the Mpumalanga Highveld climate.

3.3.3 Vegetation

Transpiration is the main mechanism by which infiltrated rain is removed from soil covers for the coalfields in SA. Good (vigorous) vegetation growth, combined with higher vegetation cover, and well-developed root system are key to the performance of soil covers. The transpiration potential of grasses is usually lower than for shrubs, woody species and crops with high biomass production. Direct measurement of transpiration is mostly limited to research studies. Numerical models usually predict transpiration from photosynthetically active (green) leaf area indices (LAIs) (Albright *et al.,* 2010), which is the ratio of the area of leaves per unit surface area (1 m^2).

Revegetated grasses on rehabilitated mine land invariably have lower LAIs and transpiration potential than natural grassland (veld). Literature values on LAIs for natural grassland must therefore be adjusted for numerical modelling. Revegetation of rehabilitated land with grasses should include species with higher transpiration potential if native grass species cannot provide the required transpiration rates to meet cover performance criteria (WMAA, 2011; Albright *et al.,* 2010). Revegetation of discard facilities with woody species is often discouraged, due to the apparent risk of exposing discard (with higher ARD potential) to the atmosphere when a tree dies or is uprooted by wind.

Root distribution studies conducted by Schoeman (2001) and Versfeld *et al.* (1998) on rehabilitated coal mine land showed that root penetration depth was mostly determined by the presence of a compacted layer. Methods and equipment used to place soil must be selected to minimise compaction during the placement of cover materials. This is important for store and release cover performance since root depth for plant water uptake and subsequent transpiration must be optimised to minimise rainwater ingress into discard.

The design of soil covers requires the selection of a vegetation mix to maximise cover water losses through high plant transpiration rates, in addition to those closure objectives related to biodiversity, ecological succession and erosion control. It is recommended that the selection of appropriate plant species should be done through collaboration between a vegetation specialist and the cover designer (WMAA, 2011).

3.3.4 Geohydrology

The geohydrology should be determined for the area around the discard facility since the groundwater model must account for the geohydrological migration of CoCs. The regional geohydrological setting includes physical hydraulic processes (recharge and discharge rates), volumes and rates of water movement, CoCs loads and transport, and CoCs migration pathways. The geohydrological characterisation relates to the groundwater depth-, flow- and quality characteristics and the use of ground- and surface water. Geohydrological modelling aspects are described in the G4-BPG.

Identifying faults and fractures as preferential flow paths in the geology is important, as they provide pathways for the rapid mass transport of CoCs from the facility to the surrounding groundwater (DWAF, 2008a).

Covers and the effects of concurrent rehabilitation are of key importance to groundwater modelling, as this influences several factors and, therefore, model input which groundwater models are based on. These factors include the extent that water- and oxygen ingress are reduced with soil covers, resultant reduction in discard oxidation and AMD production, and seepage of CoCs into groundwater.

Groundwater modelling also allows soil cover designers to evaluate how the rehabilitated discard facility may alter the groundwater regime and whether proposed soil covers will result in achieving groundwater AELs. Furthermore, it is important to understand how groundwater processes will evolve post-mining as the groundwater system reaches a new equilibrium. It is also more advantageous to understand the hydrogeological setting of the facility site and incorporate the geohydrology into cover designs, rather than incurring substantial costs in large-scale earthworks and structures (INAP, 2017).

3.4 Cover material

3.4.1 Materials balance

Available cover material and haul distances are key factors that influence optimal cover design and cost. Transport and placement costs are usually evaluated against the benefits of using more desirable cover materials from further distances (INAP, 2017).

An appraisal of the *type and volumes of cover material* available on site is required to gain an understanding of potential cover thickness for viable cover options. This includes information from a soil survey that is conducted as part of the EIA/EMP to define site-specific material balances for rehabilitation. Soil surveys are described in the Rehab-BPG.

For the Mpumalanga Highveld, suitable cover materials characteristically include soils of the arable land capability, and excludes soils of the wetland land capability. Soils of the grazing land capability could be suitable for soil covers if the coarse fragments (gravel, rock) content is less than 35% and it has an apedal soil structure.

A soil survey provides information on suitable soils for the cover growth medium (topsoil). A survey often does not consider subsoils (e.g. saprolite, unconsolidated C-horizons) or weathered overburden that can also be used for cover material. The volume available of cover material (other than growth medium) on site should be investigated if a soil survey indicates a shortage of soil to construct a cover to the required thickness.

Materials with moderate to strong structure are not suitable cover material if rainwater ingress, AMD and seepage impacts have to be minimised. These materials are characterised by preferential flow paths for rainwater and oxygen through the (desiccation) cracks.

The type of cover materials for which material volumes should be determined are discussed in subsequent paragraphs.

Growth medium is the surface (1st) layer of a soil cover, which must sustain vegetation growth. Suitable materials for growth mediums include the A- and apedal B-soil horizons for the Mpumalanga Highveld coalfield.

Water retention layer is included below a growth medium (2nd cover layer), if the thickness of a growth medium is insufficient to achieve cover performance criteria for rainwater ingress. Water retention layers typically have a high fines fraction (silt, clay and very fine sand).

Compacted clay layer is included below a thin (i.e. 20-30 cm) growth medium (2nd layer) of a rain-shedding cover (also referred to as clay caps) to limit rainwater ingress through increased runoff. The compacted clay layer must function as a flow limiting (barrier) layer.

Capillary breaker layer is included below a water retention layer (3rd layer) should a water balance cover design indicate that further reduction in rainwater ingress is required, or the upward movement of acid and salt into the root zone must be mitigated. The coarse-textured (coarse/medium sand) capillary breaker layer must always be overlain by a fine-textured (silty/clayey) water retention layer to create a capillary break effect.

Low permeable layer is included below a water retention layer (3rd layer) if water balance cover designs indicate that further reduction in rainwater ingress is required. A low permeable layer is not flow limiting, but have a lower permeability than a water retention layer to limit temporal deep percolation through it during (very) wet periods.

3.4.2 Tests and analyses

Material hydraulic properties are key input for unsaturated flow (soil water balance) modelling to predict rainwater ingress. The tests required is discussed below.

Water retention curve: For a conceptual cover design, pedo-transfer functions (statistical equations) can be applied to predict a water retention curve from particle sizes and/or bulk density. For a final cover design, a water retention curve should be determined from at least 5-6 pressures, which include the low suction range (e.g. 2-10 kPa; 20-100 cm H_2O). A water retention curve should preferably be determined on intact material to account for the effect of soil (micro)structure and densities.

Saturated hydraulic conductivity (K_{sat}): For a conceptual cover design, pedo-transfer functions can be applied to predict K_{sat} from particle sizes and/or bulk density. For a final cover design and a constructed cover, K_{sat} of the growth medium, and water retention or compacted clay layer should be determined from an in-field infiltrometer or permeability test, or from a laboratory permeability test conducted on an intact sample if an in-field test is not practically feasible. An in-field infiltrometer or permeability test is particularly important for gravel and structured materials.

Important *soil physical properties* for a cover are particle size distribution, gravel content, (dry) bulk density, soil structure and plasticity index. *Particle size distribution (PSD)* analyses should include the clay, silt, very fine, fine, medium and coarse sand, fine gravel (2.0-4.75 mm), and the gravel (>4.75 mm) fractions. Alternatively, a *foundation indicator test* can be conducted, which has the advantage that Atterberg limits are often included. PSD analyses or indicator tests that do not include the silt and clay fractions (e.g. road indicator test) must *not* be conducted for a cover as the silt and clay fractions considerably affects material hydraulic properties which are of key importance to a cover. *Plasticity index* must also be determined from Atterberg limits.

Bulk density must be determined on oven-dried samples of known volume. *Gravimetric water contents* can be determined from the difference between the mass of the sample before and after drying. *Volumetric water contents* can be calculated from the (dry) bulk density and gravimetric water contents.

Soil fertility of the growth medium plays an essential role in vegetation establishment and sustainable plant growth. Soil fertility, soil sampling and analyses to determine fertiliser demands are described in the Rehab-BPG.

3.4.3 Cover material evaluation

In practice, the ideal cover material may not be available on site. Consequently, available materials should be used sensibly to optimise the functionality of the soil cover design so as to cost-effectively meet cover performance objectives and criteria. Material suitability can be qualitatively rated for the following:

- Growth medium;
- Cover layer to limit rainwater ingress:
  - Water retention layer,
  - Flow limiting layer, and
  - Capillary breaker layer;
- Risks to long-term cover functioning; and
- Cover resilience.

The suitability of the materials can be qualitatively rated as suitable, marginally suitable and poorly suitable based on the extent that the material has favourable properties for the specified cover layer, and if simple and inexpensive measures can be applied to create favourable conditions for the material to perform at expected standard. Material properties that should be considered in the suitability rating and selection of materials for these cover layers are listed in Appendix A.

Material properties on cover resilience and long-term functioning: Sustainable function of a cover and cover resilience is important to ensure that performance criteria are met in the short-term and over the long-term (decades). Material properties that can be used to identify potential risks to long-term cover function includes erodibility, susceptibility to surface sealing and crusting, risk for desiccation cracks, and risk for salinisation and acidification of the root zone due to upward movement of salts and acids from discard through capillary flow in thin covers. Signs of surface sealing and crusting, erosion and desiccation cracks should be recorded for each soil horizon in areas where cover materials will be stripped.

4 IMPACT PREDICTION

Numerical modelling is an important component of cover design, as it provides a means to provide predictions of the potential future impact on the water resource, which are fundamental to environmental risk/impact assessment and management. Modelling also provides the ability to optimise cover performance to limit seepage impacts. This may include modifications (optimisation) of covers, cover layers and thicknesses, improving material properties, selecting grass species to increase plant transpiration, as well as many other strategies. According to DWAF, 2008b, numerical modelling is typically the most difficult part of the risk assessment process to undertake, and costly decisions will be made based on prediction results. It is important to ensure that the numerical modelling is done correctly.

The risk assessment approach that is followed in this guideline allows for risks of AMD and related seepage impacts to be identified and evaluated systematically. Numerical modelling provides the ability to *optimise cover performance* to limit rainwater ingress and reduce oxygen ingress and related seepage impacts, to meet defined performance criteria. This may include modifying aspects of the cover that include, cover layer and thickness, cover material properties, vegetation with higher transpiration demand, and other strategies. The optimised cover design can then become a powerful tool for conveying closure objectives and strategies to mitigate seepage impacts (INAP, 2017).

Impact prediction for soil covers aims to:

- Assess the effect of soil cover option(s) on the likely rainwater and oxygen ingress into the discard;
- Optimise cover components (materials, vegetation, cover properties) to minimise rainwater ingress and mitigate seepage impacts to AELs;
- Determine the likely post-rehabilitation seepage from a discard facility;
- Determine the need for additional seepage mitigation measures if the (optimised) cover options cannot meet AELs, and provide information on the likely duration of mitigation;
- Provide details on the cover, cover material and vegetation properties for input to the cover design.

The process of impact prediction will generally follow the process indicated in the flow-chart shown in Figure 4-1.

4.1 Source-pathway-receptor modelling

The Source-pathway-receptor (SPR) approach is an established risk assessment methodology that can be applied for water resource protection in the mining industry (DWAF, 2008a). According to BPG-G4, the most basic risk assessment methodology is based on defining and understanding the three basic components of risk, namely; the source of the risk, the pathway along which the risk propagates and the target that experiences the risk (receptor).

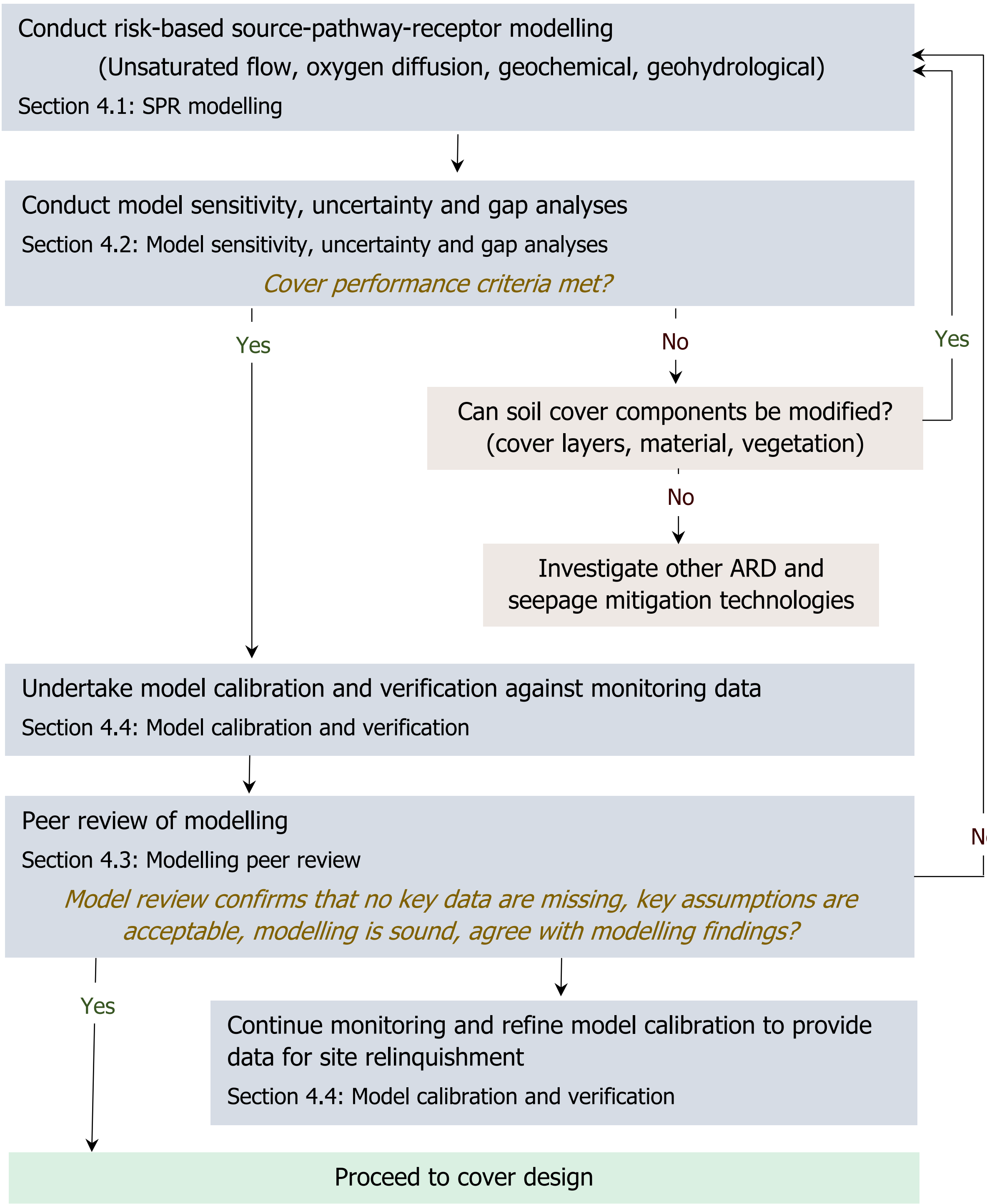

Figure 4-1: Process of impact prediction.

The SPR modelling includes the following components:

- *Source-term (source),* which relates to the coal discard for the purposes of this BPG. It includes the following models:
  - *Unsaturated flow model* (soil water balance model) to predict net percolation (rainwater ingress) into the discard,
  - *Oxygen diffusion model* to predict atmospheric oxygen diffusion (ingress) into the discard and resultant sulphide minerals (pyrite) oxidation,
  - *Geochemical reaction model* to predict leachate qualities from the coal discard, and
  - *Determined CoCs seepage loads* seeping into the vadose zone or elevated groundwater levels below the facility;
- *Pathway*, which relates to the unsaturated zone below the coal discard facility (vertical pathway) and the groundwater (horizontal pathway) through which CoCs travel to the defined receptor. The pathway involves geohydrological (groundwater) modelling;
- *Receptor:* It is good practice to include two sets of receptors, namely:
  - Receptor as defined in the BPG-G4 guideline that is the critical groundwater user or water feature down-gradient which could be affected by the seepage impacts,
  - A theoretical 'receptor' at the receiving groundwater below the discard facility that represents maximum CoCs concentrations in the groundwater prior to any advective and dispersive transport and dilution in the surrounding aquifer.

Numerical modelling starts with *unsaturated flow* and *oxygen diffusion modelling* to predict rainwater and oxygen ingress rates through the cover and into the discard. These rates serve as input into *geochemical reactive modelling*, which predicts the rate of AMD production and associated interstitial/pore water (leachate) qualities in the discard. Rainwater ingress rates and interstitial water qualities define the seepage volumes and concentrations of CoCs that will seep into the receiving groundwater.

Geohydrological modelling uses the seepage volumes and CoC concentrations of a rehabilitated discard facility to predict how groundwater plumes for CoCs are likely to develop into the future.

Model output of impact modelling is typically presented as time series graphs that show how seepage volumes, CoCs leachate qualities/loads or the receiving groundwater quality vary into the future (Figure 4-2). The graphs also show the extent and duration that additional seepage mitigation or water treatment will be required.

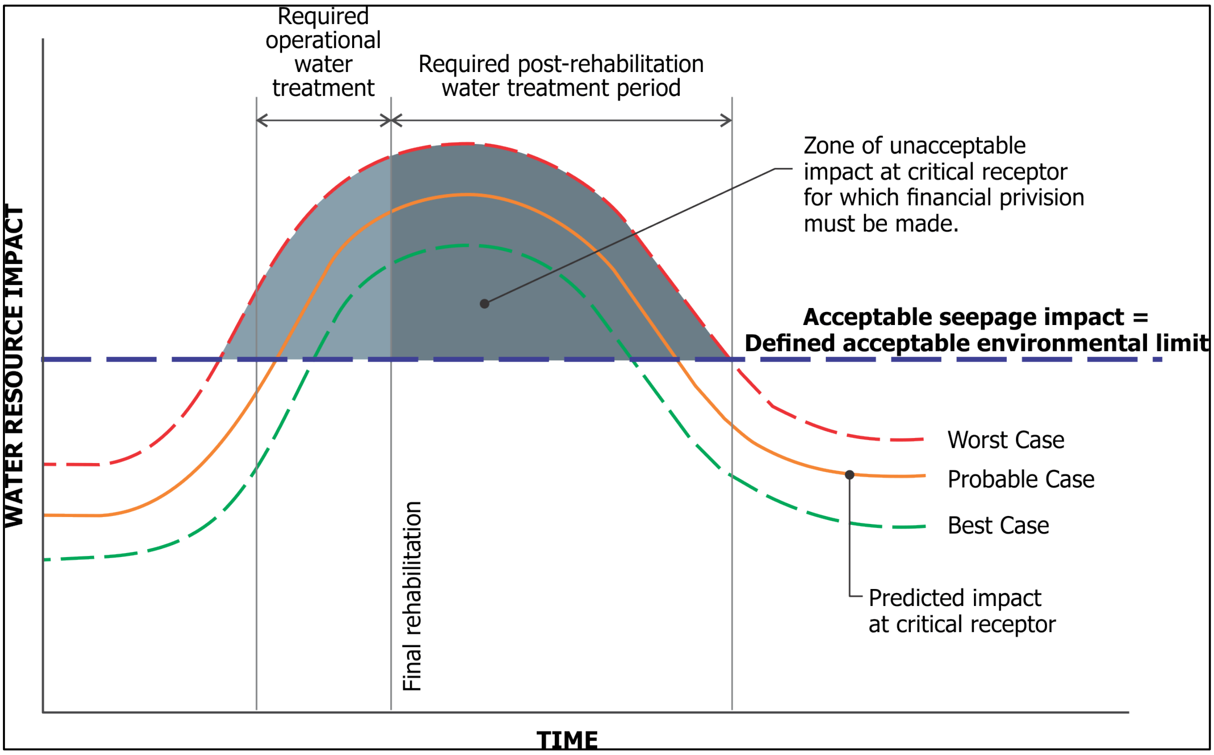

Figure 4-2: Illustration of modelling output graph (DWAF, 2008b).

4.1.1 Unsaturated flow modelling

Unsaturated flow modelling is a key component in designing soil covers to minimise rainwater ingress as a cost-effective seepage mitigation measure. Predicted net percolation (rainwater ingress) allow designers to modify aspects of a cover to mitigate seepage impacts to defined cover performance criteria and to optimise closure strategies (INAP, 2017; WMAA, 2011).

Unsaturated flow modelling is required to predict:

- *Net percolation* from a cover and the *water ingress rates* into the coal discard;
- *Varying water conditions* (content) of a soil cover and discard which is required for the oxygen diffusion (ingress) modelling; and
- *Seepage volumes* from discard facilities to predict CoCs loads seeping into the receiving vadose zone and groundwater.

Predicted *net percolation* represents the drainage from a cover and the net infiltration or rainwater ingress into the discard after rain interception of vegetation, runoff, rain infiltration, evaporation, plant transpiration and changes in cover water storage were accounted for.

Unsaturated flow models should be applied that have the ability to simulate the following processes:

- Simulate the interaction between site precipitation and climate, cover material hydraulic properties, vegetation characteristics and cover configuration (cover layers and thicknesses);
- *Runoff* and *rain infiltration* during a rain event;
- *Actual evaporation* (as opposed to potential evaporation) from the interaction between climate and material hydraulic properties;
- *Actual plant transpiration* from the interaction between climate, vegetation characteristics and root zone soil water content;
- Reduction in actual evaporation and transpiration as the cover dries between rain events, as opposed to the use of potential evaporation;
- Apply a *hydraulic conductivity function* to reflect a continuum of the material's hydraulic conductivity from saturated to dry conditions rather than using a single K_{sat} value;
- Apply a *water retention curve* that define the water storage capacity, capillary potential and desaturation rate of a material; and
- *Water redistribution and budgeting* of covers between rain events;
- Account for *capillary effect* in material and *capillary break effect* at the interface of materials with contrasting hydraulic properties created by marked textural- and density differences.

Unsaturated flow modelling is, in various literature sources, also referred to as soil water balance, hydraulic or unsaturated (geo)hydrologic modelling. Various unsaturated flow modelling software are available to predict net percolation. According to WMAA (2011), one- and two-dimensional models will provide sufficient precision for most cover designs.

4.1.2 Oxygen diffusion modelling

The availability of oxygen in discard largely affects the reaction kinetics of sulphide oxidation, which is the primary factor that determines the rate and extent of AMD from a facility. Predicting the rate and depth of oxygen ingress into the discard is key to predict residual seepage impacts from discard facilities, since oxygen ingress primarily dictates the rate and extent of pyrite oxidation and AMD production (INAP, 2017; DWAF, 2008a).

Oxygen diffusion modelling should account for the following processes:

- Kinetic rate of oxygen consumption associated with sulphide (pyrite) oxidation;
- Development of an oxygen concentration gradient in the discard due to depletion of oxygen;
- Depth of oxidation within the (unsaturated) discard;
- Oxygen diffusion flux through covers and in the discard as affected by the (air) diffusion coefficient, pyrite content and pyrite oxidation rates; and
- The effect of porosity and degree of (water) saturation on the oxygen diffusion coefficient, which determines the rate and depth of oxygen diffusion within the discard as affected by cover designs and seasonal water contents.

4.1.3 Geochemical/interstitial (pore) water quality modelling

In addition to the seepage impacts of AMD from coal discard facilities, water quality aspects are pertinent, such as seepage loads of sulphate, metals and salinity from the facilities. It is therefore important that seepage impact prediction modelling can provide information on the impacts of CoCs on the groundwater, in addition to AMD (DWAF, 2008a).

According to the G4-BPG, predicting residual (and latent) risks requires geochemical modelling as geochemical analyses do not consider temporal scales, nor do they provide sufficient information on when the source would become acidic, for how long acidic conditions would continue and when the release of other CoCs would become evident. Numerical kinetic and transport modelling is required to model the reactions between the discard ingressed rainwater and oxygen to determine the extent of acidification and CoC leachate composition, and to predict changes over time.

The prediction of interstitial (pore) water quality requires integration of various geochemical processes that include:

- Rainwater- and oxygen ingress rates (and seasonal variability thereof) and pyrite oxidation;
- Acid production from pyrite and neutralising potential from e.g. calcium carbonate minerals and reactions;
- Mineral- and metal precipitation and dissolution based on equilibrated solid- and solution phases;
- Eh (redox)- and Eh-pH reactions;
- Ion exchange based on a chemical's distribution between solution- and adsorbing phases and the number and nature of exchange sites; and
- Microbial activity (Bezuidenhout and Randell, 2010).

Geochemical modelling and its application in predicting seepage impacts that inform the detailed quantitative risk assessment, are well documented in the G4-BPG.

4.1.4 Vadose zone modelling

The vadose zone, also termed unsaturated zone, is the zone between the base of the discard facility and the groundwater table. For facilities where the discard is more than 5-10 meters above the groundwater level, vadose zone modelling can be an advantage as less conservative seepage impact results can be predicted. This is especially the case for concurrent rehabilitation, where the facility has been covered with a vegetated soil cover. However, the advantage of a less conservative result must be considered against the additional resources (cost and time) required for the modelling.

4.1.5 Geohydrological modelling

Once CoCs enter the groundwater, lateral transport through the groundwater will occur. According to the G4-BPG, the impact of AMD and CoCs seepage loads on the groundwater qualities must be predicted at the defined (critical) receptor, by developing:

- Time graphs for 100 years after (final) rehabilitation (or longer should it be required) to quantify the seepage impacts; and
- Scenarios for alternative seepage impact mitigation, which include:
  - Base case scenario of uncovered backfill or discard, or a prescribed cover design,
  - Soil cover options as cost-effective seepage mitigation measures.

Hydrogeological models, modelling methodologies and impact prediction are well documented in the G4-BPG.

4.1.6 Receptor

The receptor(s) is the final component of SPR modelling. In the context of the risk assessment of seepage impacts from discard facilities, the receptor could include:

- Groundwater monitoring borehole(s) down-gradient of the facility;

- Potential groundwater users down-gradient of the facility; and
- Water courses that are connected with the groundwater down-gradient of the facility and associated water users such as:
  - Potential water users abstracting water from an impacted watercourse, and
  - Aquatic fauna and flora in a receiving impacted watercourse.

According to DWAF (2008a), it is generally impractical and unnecessary to consider the full range of potential receptors that may be impacted by any particular source-term (discard facility). Therefore, the critical receptor that could be impacted by the seepage from the discard facility, should be determined and defined. DWS officials and other water users should be involved where appropriate, while reaching an agreement regarding the critical receptor. Acceptable water quality objectives could include:

- Water use criterium, such as specified in Water Use Licenses; or
- Receiving groundwater objectives, for example the Water Quality Guidelines published by DWAF (1996).

According to the BPG-G4, the common approach in water resources risk assessments is to use published or regulatory water quality criteria for the receptor (user) of interest. It would therefore be appropriate to use the series of water quality guidelines published by DWAF (1996) for domestic use, livestock watering and irrigation purposes, unless the water quality objectives were set for a critical receptor identified for a mine risk assessment.

4.2 Model sensitivity, uncertainty and gap analysis

Sensitivity analysis is conducted to determine how numerical modelling results (e.g. rainwater ingress, seepage- or groundwater quality) are impacted by the uncertainty or variability of model parameters. Sensitivity analysis is conducted to ensure that the level of uncertainty within the numerical modelling results is defined and to ensure that the most critical data inputs and variables are identified and included in the model calibration and validation monitoring programme (DWAF, 2008b). Sensitivity analysis is also known as the "What-if" analysis.

The G4-BPG discussed two approaches to sensitivity analysis for seepage impacts predictions, namely:

- *Repeatedly rerunning a (deterministic) model with changed parameter values:* This approach involves where the prediction calculations are repeated where all parameters remain constant except for one which is then varied around the average value. Repeating this exercise for several key input parameters will identify variables that have the biggest effect on predictions;
- *Creating a probabilistic or stochastic framework:* Uncertainty in predictions is defined by mathematical modelling within a probabilistic or stochastic framework (e.g. Monte Carlo modelling). Values are randomly selected from a known distribution of values for each parameter. This provides results as an average (likely) value with confidence limits showing upper and lower boundary values. The mathematical modelling must realistically represent the response of a biophysical environment to changes in a parameter (factor).

Examples of sensitivity analysis on cover performance includes:

- Wetter and drier years;
- Effect of periods of consecutive rainy days (e.g. >5 days) where rain significantly exceeds evapotranspiration;
- Thinner and thicker covers;

- Sandier and more clayey cover material; and
- Sub-optimal plant growth or poor vegetation establishment (INAP, 2017; Albright *et al.,* 2010).

Uncertainty is inherent in any cover design and seepage impacts prediction exercise since the analysis is based on assumptions about future conditions (e.g. rainfall, climate, rehabilitation success). Uncertainty is also created by modelling tools that attempt to describe natural processes as mathematical formulae. While it is accepted that uncertainty is inherent in any prediction, the modelling specialist must be able to describe and define the uncertainty in the prediction, and confidence levels that can be placed on the predictions.

Results of model sensitivity and uncertainty analyses are usually described in terms of the probability (likelihood) performance criteria for cover design and that seepage impacts predictions will be exceeded (Albright *et al.,* 2010; DWAF, 2008b). Confidence limits indicate the probability that the end result will fall outside boundaries defined in the impact predictions. A 90% confidence limit, for example, means that the chance of the real-world situation being outside the predicted boundaries is 10% (i.e. 10% chance that performance criterion will be exceeded). The sensitivity analysis provides an indication of the effect of uncertainty in model input data and spatial and temporal uncertainties in the cover design (Albright *et al.,* 2010).

The sources of uncertainty that can be encountered with seepage impacts predictions are documented in the G4-BPG.

4.3 Model calibration and validation

Prediction models have some degree of uncertainty. Model inaccuracy (due to misrepresentation of aspects of the biophysical system) and uncertainty increases when poor model input was used and proper model calibration has not been undertaken. Predictive models should therefore be subjected to calibration and verification, which form an integral part of a monitoring programme (DWAF, 2008c).

Model calibration is a process of refining model input data and parameters. Calibration will progressively reduce uncertainties until the model accurately represents the relevant processes of the modelled system (e.g. rainwater ingress, geochemical reactions, site geohydrology).

Model validity is reached when model calibration has demonstrated the model results are accurate enough for the intended use of the model. This point is reached when model predictions agree with monitored data, producing credible information on the system, its performance, water qualities downgradient of the discard facility and underpinning parameters. Model validity is vital at the time for obtaining approval from the Competent Authorities for site relinquishment. If pre-agreed model validity criteria are not met, calibration should be repeated by review and adjustment of previously calibrated model parameters.

Assumption validity will be both proactive (when developing the model) and reactive (during the verification stage) to improve model accuracy once real data becomes available from a (concurrently) rehabilitated discard facility. Typical aspects that will be subjected to validity assessment in order to optimise assumption accuracy include spatial and material representativeness, material hydraulic properties, geochemical controls, and declining source-term for soil covers.

4.3.1 Cover percolation (rainwater ingress)

An unsaturated flow model can be calibrated from:

- Field plot monitoring, which includes:
  - Directly determine percolation rates with lysimeters during cover performance monitoring trials,
  - Determine cover percolation indirectly by monitoring field water contents of the cover;
- Large scale field monitoring, which includes:
  - Determine cover percolation indirectly by monitoring field water contents and the cover water balance components along a hillslope, and
  - Monitored groundwater levels.

Percolation rates from a soil cover (into the discard) can be determined with *lysimeters that are installed for cover performance monitoring trials*. A lysimeter is a large box constructed below a soil cover that has a sump and system to collect and measure water draining from the base of the soil cover. Such a trial was conducted for the Kilbarchan research study where the effect of various soil cover options over fine coal discard was studied by Vermaak *et al.* (2004), and discussed in Part A of the study report. A similar study was conducted for vermiculite covers on waste rock and tailings facilities at Phalaborwa (McDonald and Lorentz, 2018). To date (2020), such a project was not initiated in the Mpumalanga Highveld coalfield.

The primary advantage of a lysimeter is that a direct measurement of percolation rate is obtained. No inferences are required and measurement can be made with high precision. The primary disadvantages are the cost and effort associated with constructing and operating a lysimeter. Lysimeters also have the ability to detect preferential flow and quantify percolation due to both matrix- and preferential flow (Albright *et al.,* 2010). The construction and instrumentation of a lysimeter requires expertise and thorough planning, and can be costly. The use of lysimeter should only be considered if there is a commitment for human resources to dedicatedly operate the monitoring equipment, assess the quality of monitoring data immediately after data was downloaded, and the equipment (including data loggers) is regularly maintained, especially during the rainy season. The construction, instrumentation and operation of lysimeters are discussed by Albright *et al.* (2010), INAP (2017) and WMAA (2011).

The *indirect approach in determining percolation rates from monitored water contents* at various depths in the cover as a function of time, involves inferring percolation rates from modelling results on the relationship between percolation and water contents or the water contents using a calculation based on Darcy's Law (Albright *et al.,* 2010). Indirect methods to determine cover percolation for model calibration provide less accurate data for calibration, and may not be appropriate where cover performance (percolation rates) is expected to be several millimetres per year. Indirect methods to determine cover percolation, however, are easier and less expensive.

The calibration approach from monitored groundwater levels is based on the calibration of an unsaturated flow model and verification of predicted water ingress rates from rain recharge that is determined from the groundwater levels at the discard facility. The modelling results can be verified and the model calibrated against rain recharge determined from a recharge calculation method or from geohydrological modelling. The preferred approach for model calibration would be where the unsaturated flow modelling form part a suite of unsaturated flow- and geohydrological models which are applied in an integrated manner.

4.4 Modelling peer review

Seepage impact predictions are technically complex and require the efforts of integrated teams of specialists, managed by project managers that have adequate experience in the field. Successful review of an impact prediction exercise requires levels of expertise similar to that of the team undertaking the assessment. The G4-BPG recommends an independent review process if an impact prediction is conducted in support of a mine closure application, or for a mine feature (such as a discard facility) that requires regulatory approval. The G4-BPG requires that the input data and key assumptions used in the modelling, the numerical modelling conducted for the base scenario and alternatives that were considered in the impact assessment, assessment of the uncertainty in the impact prediction, prediction results and conclusions, and the recommended post-modelling monitoring, model calibration and validation programme are reviewed, refined and agreed to by the reviewer.

5 DESIGN

A cover design ensures that the planned cover is not only technically the best option but is cost effective, with the appropriate balance between capital and operating expenditure. The landform design and the optimisation of materials movement are key to providing a cost-effective cover, as the rehabilitation and closure design provides the basis for developing cost estimates for the cover and facility.

Cover design must also account for the interaction between the landform, and site and facility-specific factors, while working to achieve the final land use described in the mine closure plan. The cover design should also be implementable, meet stakeholder expectations, and sustainably mitigate potential adverse environmental impacts. Soil covers should, therefore, be designed interactively with the proposed landform to ensure that the designs complement each other and result in the successful rehabilitation and closure of the facility with end landform in mind (INAP, 2017; WMAA, 2011).

It is important for discard facilities that the facility outer slopes are optimised to ensure that the slopes are not too steep that will promote erosion, and not too flat that will promote increased rainwater ingress (INAP, 2017).

Cover design aims to:

- Provide a design that is optimised, based on the cover impact prediction results, and meets defined cover performance objectives and criteria;
- Provide a cover that is cost-effective and easy to construct, maintain and care for, while meeting rehabilitation/cover goals and objectives;
- Integrate the cover design with materials movement optimisation, and the landform and facility closure designs to ensure that the designs complement each other;
- Provide cover and cover material specifications, good practice guidelines and monitoring plans that enable the contractor(s) to construct, rehabilitate, care and monitor a cover according to the final cover design.

The process of cover design will generally follow the process indicated in the flow-chart shown in Figure 5-1.

5.1 Conceptual cover design

Conceptual cover design should make use of the (most) viable soil covers identified in the baseline risk assessment. The design should account for:

- The facility closure objectives set out in a mine's closure plan, and cover performance objectives and criteria;
- Outcomes of the baseline risk assessment, site characterisation, cover materials balance and characterisation, predictive analyses and cover optimisation of viable cover options;
- Optimised cover materials movement that includes appropriate material movement quantities and methodologies associated to construct the covers to the required thickness, and stockpiles of growth mediums are minimise;
- Rehabilitated final topography that is stable and considers appropriate runoff- and erosion control measures, and long-term water management requirements;

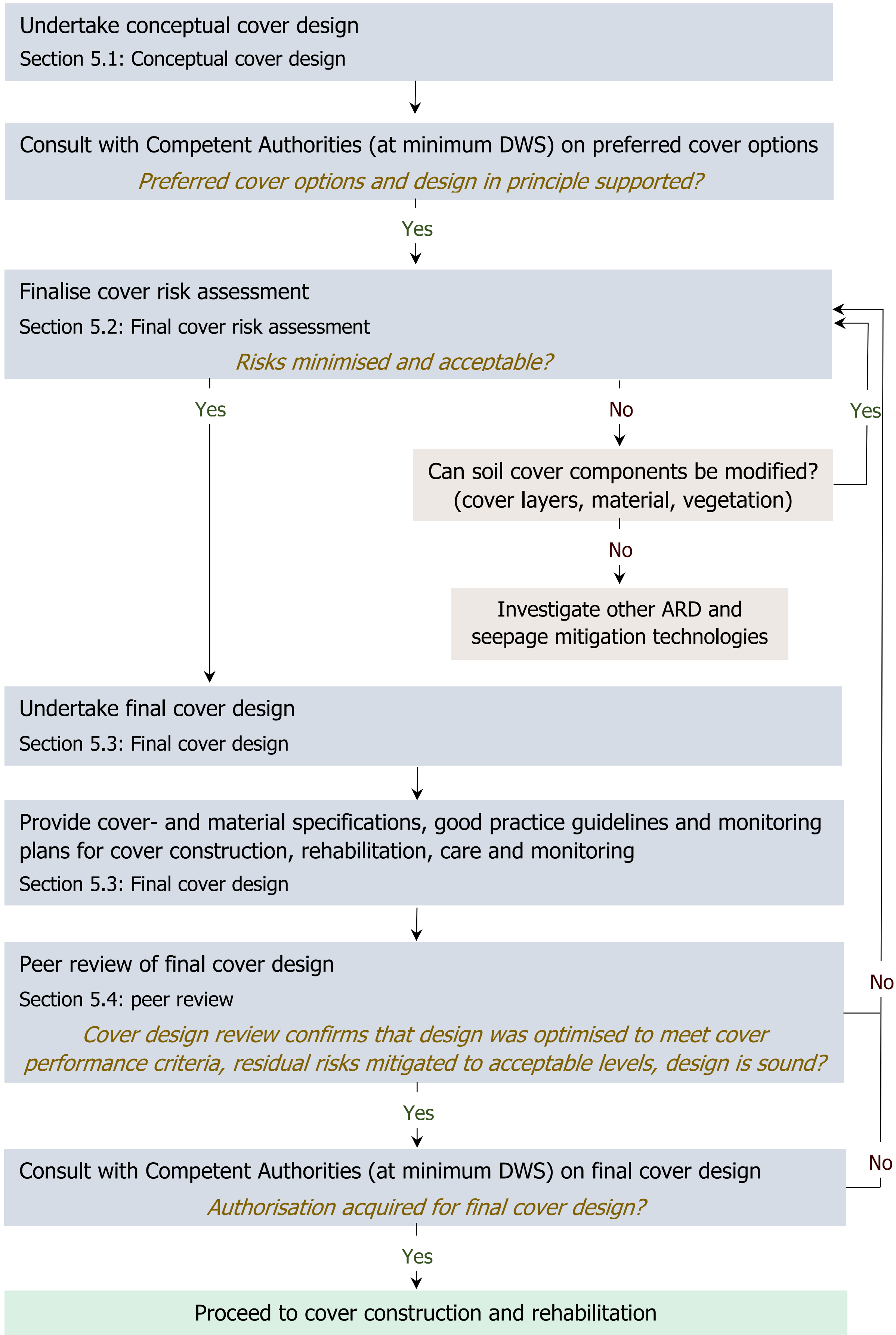

Figure 5-1: Process of cover design.

- Optimised facility outer slopes that the slopes are not too steep that will promote erosion and not too flat that will promote increased water ingress;
- Long-term care-and-maintenance of the covers are reduced, such as reducing soil loss and associated reduction in cover thickness; and
- Constructability of covers (LaRSSA *et al.,* 2019; INAP, 2017).

Landform design is documented in the Rehab-BPG.

The cover design must include a cover design report, predictive modelling of cover performance, plans (layout) and cross-sections of the cover option(s). The conceptual design and results of cover performance predictions should be discussed with the regulator as part of the approval process. The conceptual cover design can proceed to final design once agreement is reached on the preferred final cover option(s) and the costs of the preferred landforms has been established (WMAA, 2011).

Additional information

Importance of early planning: Greater attention should be given to estimating volumes of material needed early in the cover design process. If left to the final (detailed engineering) design stage of the project, material shortages in stockpiles could have marked cost implications to the project, or necessitate an alternative design. Early cover materials characterisation also provides a strong basis for the design of a cost-effective cover and landform (INAP, 2017).

5.2 Final/detail risk assessment

According to the G5-BPG, a risk-based approach should include the risk of failure of systems and management strategies. The consequences of systems failure should be taken into account and the necessary contingency measures should be addressed in management strategies and in financial provisions. The final (detailed level) risk assessment is informed by all of the work completed after the baseline risk assessment, as well as any other facility- and site-specific information.

For soil covers, (potential) residual risks can be identified in both the (screening level) baseline risk assessment and detailed risk assessment during impact prediction and cover design. Latent risks are more ambiguous, however, and it is accepted that the possibility exists that some unforeseen event could occur which may result in a greater post-closure seepage impact. Examples of latent risks for covers are:

- Surface subsidence that results in ponding and increased rain infiltration, or subsidence cracks with direct runoff inflow into the discard;
- Prolonged drought, an (uncontrolled) intense fire or extreme rain event that adversely affects cover vegetation;
- Climate change resulting into more rainfall that could lead to increased rainwater ingress and seepage impacts;
- Pedogenic processes that change material hydraulic properties that are fundamental to the performance of covers, which is more evident in compacted clay covers;
- Ecological change, which may be accompanied by a change in cover performance due to changes in plant transpiration rates and nutrient cycling; and
- Bio-intrusion that can lead to preferential flows. This can affect the performance of especially compacted clay and capillary break covers that rely on low-permeability barriers to minimise rainwater ingress (WMAA, 2011; Albright *et al.,* 2010).

According to WMAA (2011), the risk associated with latent risks should be classed as inherent risk if there are no controls, and residual risk where risk remains after redesign, mitigation, or implementation of management plans. If the residual risk has achieved an acceptable risk level in the comparative assessment, then the cover design can be finalised and approval sought from the relevant government authority.

Post-rehabilitation monitoring and maintenance requirements needs to be determined as provision of these requirements should be done as part of the final cover design. Monitoring requirements should be based on the defined soil cover performance requirements, as well as sensitivity- and gap analysis to address the potential risks to the environment. The maintenance requirements should be detailed to ensure that they are achievable and that conflicting aspects of the soil cover design have not led to impractical maintenance requirements. The results from the sensitivity analyses should be used to select parameters for post-closure performance monitoring of the WB cover (LaRSSA *et al.,* 2019; WMAA, 2011).

Additional information

Climate change and latent risk: Cover design and performance evaluation usually rely on historical meteorological data which inherently assumes that it represents reasonable ranges of future climate. Projections of long-term extreme events and shifts in climate states over long time periods, as well as annual and decadal variability in meteorological parameters, should preferably be accounted for to design covers with a long design life (Albright *et al.,* 2010). According to the Rehab-BPG, a useful exercise for predictive modelling is to project data based on the trends in climatic variability experienced over the last decade, and to increase variability over time. This should allow for more conservative rehabilitation planning on a defensible basis.

5.3 Final cover design

5.3.1 Finalise cover design

The objective of the final cover design is to update and refine the conceptual cover design with data and information from the calibrated and validated model, and the cover design risk assessment. The cover design must consist of a cover design report, site layout plans, cross-section drawings of the designed cover and design specifications. Cover design specifications, quality control monitoring plans and good practice guidelines are imperative as these will give the contractor all relevant information to construct cover according to final design. The final cover design must be peer reviewed to test the design validity and highlight missing steps or inadequacies in the proposed design (WMAA, 2011).

5.3.2 Provide cover construction specifications, guidelines and monitoring plan

Inclusion of cover- and cover material specifications in the final cover design are imperative to provide the contractor with relevant information to construct the soil cover according to the signed-off cover design (INAP, 2017).

The cover- and material properties specifications should include:

- Cover configuration:
    - Cover layer sequence,
    - Thickness of each cover layer and acceptable deviation from designed thickness;
- Vegetation to be established and optimum vegetation cover that should be achieved;
- Cover material property specifications for each layer:
    - Map indicting where the cover materials will be stripped, and the material layers (e.g. topsoil, subsoil, soft overburden) that will be stripped,
    - Optimum, and acceptable deviation in soil texture or sand and clay contents,
    - Maximum, and acceptable deviation in gravel/rock contents,
    - Optimum, and acceptable deviation in (dry) bulk density of placed cover materials,
    - Maximum plasticity index if the soil structure does not classify as apedal.

Guidelines must be developed to provide the contractor with relevant information on good practice to construct and rehabilitate the cover, and to care for and monitor a cover to meet performance criteria of the cover design. The following guidelines should be developed:

- Cover material stripping, stockpiling and placement;
- Cover construction and monitoring plan that should include:
    - Tests after a section of cover was constructed to verify that the required cover material has been used, and cover material properties are acceptable,
    - Corrective action to be implemented should the cover and cover material properties fall outside the acceptable deviation of the final cover design;
- Amelioration of the growth medium and vegetation establishment;
- Cover care and maintenance to maintain cover functionality in the long term to limit seepage impacts to the defined performance criteria; and
- Cover integrity and performance monitoring guideline and plan.
- Good practices on soil (growth medium) striping, handling, stockpiling, placement and remediation, and on vegetation establishment, which are well documented in the Rehab-BPG and used as guidance to develop the good practice guideline.

It is imperative that the schedule to strip, handle, stockpile and placement of cover materials are specified in the good practice guideline. These practices must be scheduled to occur during the dry season (mid-winter till onset of the rainy season) and when the soil moisture content is sufficiently low when bulk densities are required that do not limit root penetration.

Additional information

It is imperative that the cover design- and material specifications should be determined by the cover design engineer and from the results of the final risk assessment, and should be included in the signed-off final cover design (WMAA, 2011, Albright *et al.*, 2009).

5.4 Peer review

The peer review must be performed by a suitably qualified person who is independent of both the mine and consultant, and who has, at least, experience that is similar to that of the team that conducted the impact assessment and cover design.

The G4-BPG stipulates that the mine, its planning/design specialist and appointed reviewer meet with representatives of the Competent Authorities to obtain agreement from them on key issues. An agreement will take the form of written minutes of the meeting that is formally approved and signed off by the mine, its specialist, the reviewer and the Competent Authorities. The last step of review and approval of the impact assessment report will be written approval by a suitably authorised representative of the Competent Authority on their letterhead. The peer review is well documented in the G4-BPG.

5.5 Record keeping

Record keeping is required to show that the impact and risk assessments, and (final) cover design were peer reviewed, revised, and finalised, and that they have been accepted by the Competent Authorities. Records should include all relevant information on construction methods and monitoring, and good practice guidelines for ongoing care and monitoring of the cover. Records should be kept of the following:

- Final cover design, design drawings, and cover materials specifications;
- Volumes and source of cover materials (cover materials balance);
- Good practice guidelines and monitoring plans; and
- Site relinquishment criteria associated with the cover performance monitoring (WMAA, 2011; Albright *et al.*, 2010).

6 CONSTRUCTION AND REHABILITATION

Cover performance depends largely on whether contractors and construction supervisors understand the key steps involved in the construction of a cover in meeting required cover performance, and that these steps are implemented correctly according to the information provided in the final cover design (INAP, 2017, WMAA, 2011, Albright *et al.*, 2010).

Cover construction and rehabilitation aims to:

- Provide and familiarise contractors and construction supervisors with information on a cover that enables them to implement key steps to meet required cover performance;
- Construct soil cover according to specifications and good practice guidelines provided with the design;
- Progressively monitor and control cover construction quality;
- Ameliorate growth medium to establish and sustain good vegetation growth (vigour);
- Establish vegetation to achieve high transpiration rates that can be sustained in the long-term to limit rainwater ingress and seepage impacts.

The process of cover construction and rehabilitation will generally follow the process indicated in the flow-chart shown in Figure 6-1.

6.1 Cover construction

The contractor and construction supervisor should become fully acquainted with the following information provided in the final cover design:

- Specifications on cover design and cover materials properties;
- Good practice guideline to strip, handle, stockpile and place cover material; and
- Cover construction monitoring, corrective action and record keeping plans.

Cover and cover material properties should be monitored progressively, after sections of the cover have been constructed, to ensure that work adheres to the cover design. The parameters to be monitored and the frequency of monitoring will depend on site-specific cover construction objectives. Cover construction quality control is also required to ensure that cover construction, and the monitoring thereof, ensure that the objectives of cover construction are progressively met. Corrective actions must be implemented if deviations from cover specifications and guidelines occur. Added levels of supervision and quality control may be needed to ensure that the corrective actions have been effective.

Any deviations from the cover specifications, guidelines and quality monitoring plan that might occur, should be discussed and clarified with the cover designer so that necessary design amendments, or adjustments, can be made. The cover design can only be amended after confirmation that the changes will not compromise cover performance or relinquishment criteria. It is imperative that cover materials are placed according to the specified cover layer sequence, material type and layer thicknesses specified in the final cover design.

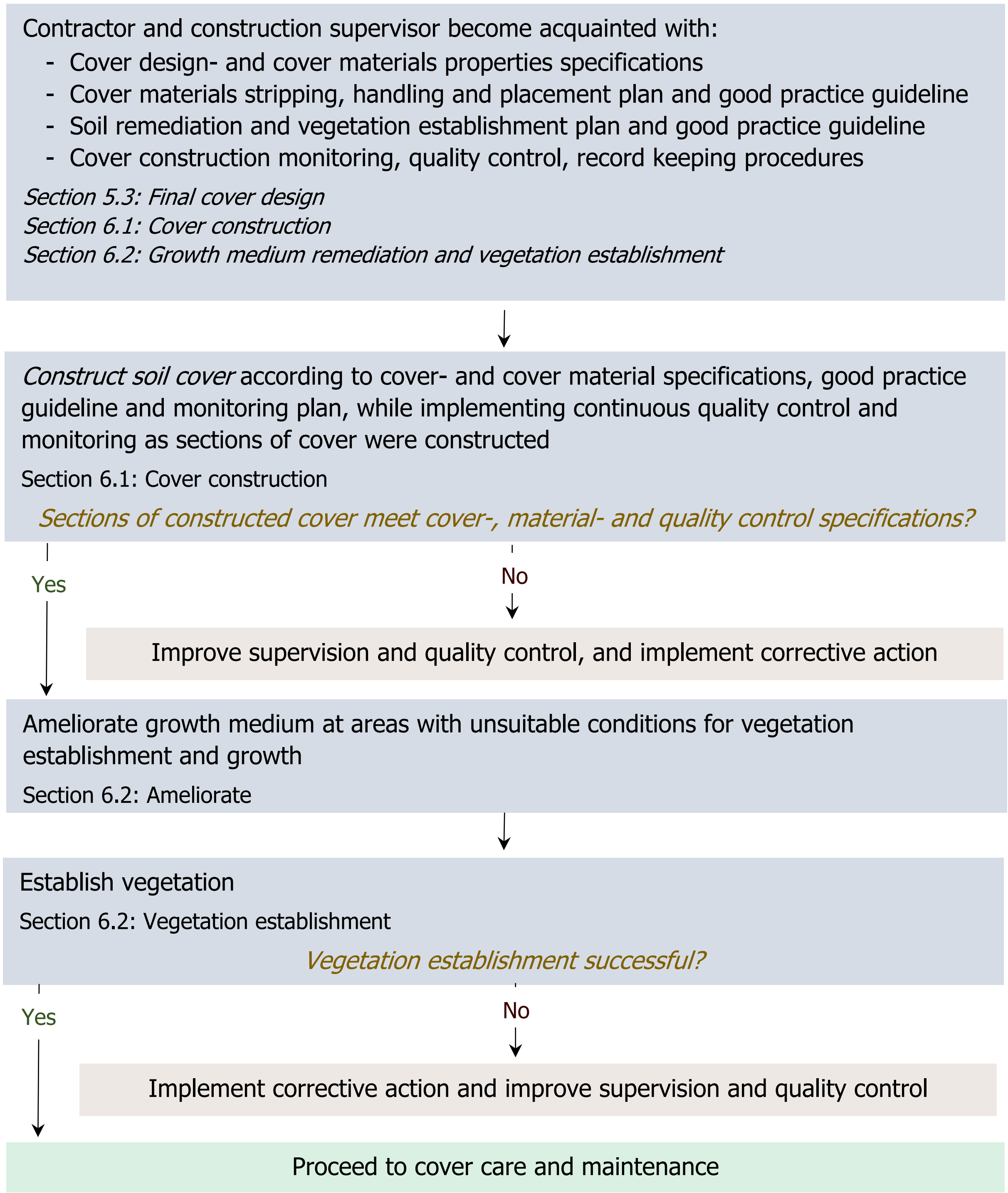

Figure 6-1: Process of cover construction, amelioration and vegetation establishment.

The following monitoring actions must be implemented during cover construction:

- Assess monitoring data at the frequency specified in the cover design;
- Ensure that monitoring is implemented correctly by intermittently assessing both the actions and outcomes of monitoring;
- Assure that monitoring outcomes are linked with corrective actions where necessary;
- Confirm that cover construction is implemented as per cover design and specifications;
- Keep records to prove compliance with the cover design and material specifications. The following records should be kept:
  - Sources and volumes of cover material used to construct the cover, and
  - Survey and sampling data to determine the extent to which the post-construction cover and material properties specifications align with the cover design (LaRSSA *et al.,* 2019; WMAA, 2011).

Record keeping is required to prove compliance with the cover design and material specifications. Typically, record keeping should be undertaken by the contractor and the designer. Records should be kept of the following (WMAA, 2011):

- Volumes and source of cover construction materials;
- Survey of post-construction conditions; and
- Construction quality monitoring and control.

6.2 Growth medium amelioration and vegetation establishment

The stimulation of vegetation growth (vigour) and root development is important for soil covers to optimise water losses through transpiration at rates required to reduce rainwater ingress and ensure that seepage impacts are minimised to meet performance criteria.

6.2.1 Alleviation of compaction

Dry bulk densities, or penetration resistance, should be measured progressively as sections of the cover are completed. Areas should be identified where alleviation of compaction is required. Alleviation of compaction is described in the Rehab-BPG.

Careful consideration should be given to ripping requirements for a cover and particularly to the depth of ripping. Specific attention should be given to the following aspects when ripping of a cover is considered:

- Ripping through (and shattering of) a shallow compacted layer is required when root development is shallower than the minimum root depth specified in the cover design to achieve defined cover performance. It is imperative that ripping into a flow-limiting or capillary break layer is prevented;
- Ripping into the following layers must be prevented:
  - Flow-limiting layer: Ripping creates preferential flow paths for the rapid ingress of rainwater and oxygen through this layer,
  - Capillary break layer: Ripping will disrupt the abrupt transition between the material hydraulic properties of the overlying fine textured material and the medium/coarse sandy capillary break layer that creates the capillary break effect.

6.2.2 Soil fertility

Plant nutrients that are concentrated in the organic-rich upper section (e.g. 10 cm) of the A-soil horizon are diluted when the A and (apedal) B soil horizons are stripped. Soil organic matter and nutrients are further diluted when the C horizon, or portions thereof, are also stripped with the topsoil to be used for the growth medium. Consequently, fertilisers are required to improve soil fertility of the growth medium. Acidity is also a problem in many Highveld soils, so liming is usually required.

Soil chemistry and fertility needs to be determined before and during vegetation establishment and corrected according to results of soil analysis. Good practices on soil sampling and analyses for soil fertility and fertiliser application are well documented in the Rehab-BPG.

6.2.3 Vegetation establishment

Plant establishment, and long-term sustainability, is crucial to the success of a soil cover. After the remediation of the growth medium (to the required state for optimal vegetation establishment), the vegetation needs to be established in accordance to the pre-defined end land use of the closure plan.

Good practice on plant species selection, seedbed preparation and vegetation establishment are well documented in Rehab-BPG. Specific requirements for soil covers are:

- Plant species with high transpiration rates should be included in the vegetation mix to meet the performance objective of a soil cover in addition to the vegetation objectives related to biodiversity, land capability and erosion control. The differences in plant water uptake, use and transpiration, and responses to water stress between plant species and genera should be considered in the cover design to achieve long-term predicted cover performance for store and release covers (WMAA, 2011);
- Deep-rooted vegetation should be avoided for a cover that includes a flow-limiting (e.g. compacted clay) or capillary break layer to limit the risk for root penetration and resulting preferential flow paths from the dead root channels. The creation of preferential flow paths through flow-limiting or capillary break layers would compromise the designed cover performance;
- The cover designer should confirm that the combined effect of selected species can provide the transpiration rates required to meet cover performance criteria and predicted cover performance (WMAA, 2011; Albright, *et al.,* 2009).

7 CARE AND MAINTENANCE

Care and maintenance of the soil cover will involve actions required to sustain long term cover function to achieve defined cover performance criteria and to maintain functionality of the cover as part of the rehabilitated landscape. Care and maintenance should follow these good practices described in the final cover design.

The mine and/or contractor must become fully acquainted with the post-rehabilitation care and maintenance guideline and monitoring plan and corrective action of the cover as included in the signed-off final cover design. Any deviation from the cover care and maintenance good practice guideline and plan that is foreseen due to practical implementation, must be discussed and clarified with the cover designer and amended/refined accordingly if required and only after confirmation that the cover performance or meeting site relinquishment criteria are not compromised.

Cover care and maintenance aims to:

- Apply maintenance fertiliser to sustain vigorous vegetation growth;
- Utilise and manage vegetation to minimise care and maintenance;
- Repair damages to erosion structures and soil cover, and control erosion.

The process of cover care and maintenance will generally follow the process indicated in the flow-chart shown in Figure 7-1.

7.1 Soil fertility

Maintenance fertilisation is required until the nutrient cycles for sustainable and successful revegetation is established. Until the desired fertility status has been achieved, the growth medium should be periodically tested for nutrient deficiencies and availability. Analytical results should be used to determine fertiliser content, application rate and timing as described in the Rehab-BPG.

7.2 Vegetation management

Vegetation becomes a self-replenishing intervention with minimal care and maintenance if managed efficiently after establishment. This could considerably improve the sustainable functioning of a cover where high transpiration rates are required (WMAA, 2011). Good practices on vegetation management and weed control are covered in the Rehab-BPG.

7.3 Erosion control and settlement

Short-term maintenance activities include repair of erosion features and re-establishment of drainage channels and waterways. Longer-term maintenance should include cleaning out of sediment and vegetation from drainage channels, and the repairing of erosion damage until the landform reaches equilibrium (INAP, 2017).

Settlement and erosion damage, such as gullies, should be repaired by in-filling with cover material, followed by the re-establishment of vegetation (WMAA, 2011). It is important that sufficient growth medium is retained in stockpiles to fill in the depressions and gullies, thus ensuring that satisfactory surface drainage will be maintained (LaRSSA *et al.,* 2019).

Ongoing care and maintenance of berms is required that may require that berms need to be re-shaped and/or in-filled. Maintenance of vegetation at berms is a challenge and important to limit impacts that could exacerbate erosion in these areas (LaRSSA *et al.,* 2019).

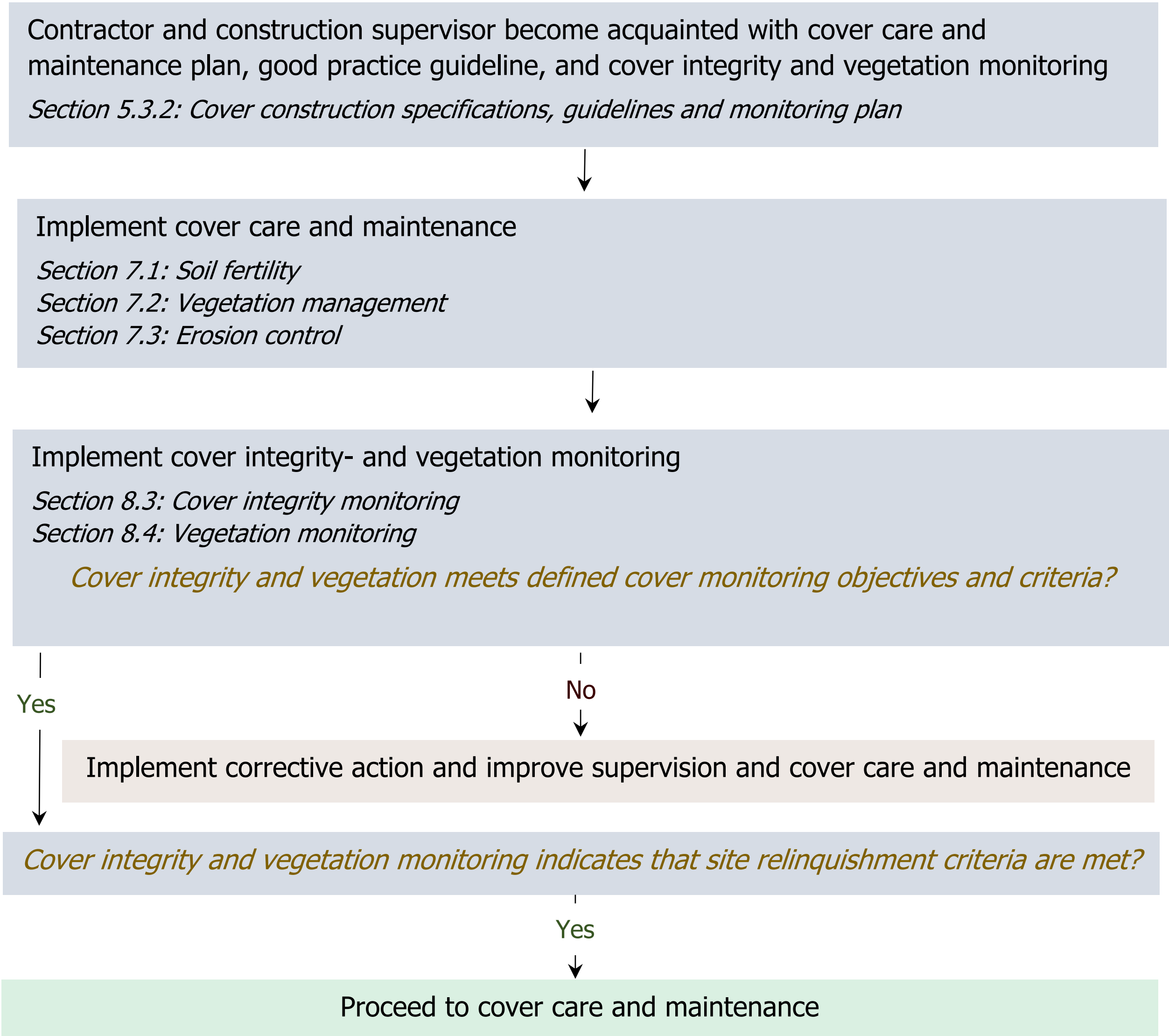

Figure 7-1: Process of cover care and maintenance.

The Rehab-BPG emphasises *that weed control* must be a proactive practice to prevent weed infestation of the rehabilitated facility, and to ensure that that the problem will not become more difficult and expensive to control. Weeds can be removed by hand or the use of selective contact or systemic herbicides on the target weed species. A broadleaf herbicide must be selected that does not kill the re-vegetated grass species when controlling broadleaf invasive weeds. Trees can be removed by cutting or ringbarking, following-up with the application of herbicides to control any coppice growth and newly germinated seedlings as they emerge.

8 MONITORING

Monitoring data are required to evaluate the success of cover construction and rehabilitation, and to confirm that the required ongoing care and maintenance needs are addressed. Monitoring is also required to verify and ensure that cover performance objectives and criteria are achieved for the period required to prove performance, and that cover functions are maintained to meet performance criteria. Monitoring provides therefore an early warning indication for reduction in cover functioning that might indicate that cover performance criteria may not be met.

Ongoing monitoring of cover integrity against established cover integrity action plans and relinquishment criteria enables tracking of the progress of ecosystem recovery over time. Monitoring enables early detection of rehabilitation 'non-successes' or unintended secondary impacts, and allowing for swift refinement of rehabilitation actions, or implementation of suitable interventions to correct the situation (LaRSSA *et al.,* 2019).

The type of monitoring and monitoring indicators are facility specific and will depend on the closure objectives, cover performance- and site relinquishment criteria that have been agreed upon, and the results from the cover design risk assessment.

Cover monitoring aims to:

- Monitor the integrity of the cover to sustain vegetation growth and cover functioning to achieve required cover performance in the long-term;
- Vegetation monitoring to achieve optimal conditions for good vegetation cover and growth (vigour), plant transpiration and root development to achieve cover performance criteria and sustainable functioning of the cover;
- Monitor groundwater quality, and rainwater ingress if required, to assess deviation between the actual and predicted groundwater quality impacts and to establish a reliable performance record of the design, care and integrity of the cover.

8.1 Monitoring actions

Monitoring should be conducted according to the activities and schedule included in the monitoring plan of the final cover design. Important monitoring actions for a soil cover are:

- Verify that monitoring is implemented according to the monitoring plan at the specified monitoring frequency, and if not, implement corrective action;
- Compare monitoring data against cover integrity (functioning) and performance criteria at the specified monitoring frequency to assess if criteria are met;
- If monitoring data indicates that criteria are not being met, investigate if cover care and maintenance should be improved or if intervention measures will be required. If follow-up investigation warrants intervention measures, in addition to the cover care and maintenance measures, ensure these are employed;
- Keep records to prove compliance with cover care and maintenance and cover performance requirements.

8.2 Cover integrity monitoring

Cover integrity monitoring is vital for the prevention of exposing the discard and decreasing the performance of the soil cover (WMAA, 2011). Cover integrity monitoring is, therefore, required for those properties that affect cover functioning. Cover integrity monitoring is also important to timeously identify and implement improved cover care and maintenance to meet performance criteria, rather than to later have to implement more complex and expensive intervention measures

(INAP, 2017). Results of cover integrity monitoring can also be used to demonstrate that criteria for site relinquishment, other than seepage impacts are met.

Cover integrity monitoring, of the rehabilitated WB cover, should be in accordance with the monitoring that is specified in the signed-off final cover design, as well as with the good practice guideline and monitoring plan specified in the final cover design.

Cover integrity monitoring must, at least, include visual inspections to timeously identify *erosion damage, signs of significant burrow animal damages, slumping or settlement and damage to the cover* that requires remedial action. This includes damage to erosion control structures and poorly functioning drainage systems, animal burrow damages to the cover, surface cracks from differential settlement or desiccation, and surface sealing or crusting that result in bare areas.

High erosion rates will result in unacceptable reductions to cover thickness and water storage capacity, which will inhibit plant growth and reduce the ability to manage rainwater and oxygen ingress. Erosion also results in surface water quality concerns due to sediment transport, and blockage of water channels by sediment deposition. At many mines, growth medium are a scarce resource, and its loss represents a cost risk. *Erosion monitoring* is required to confirm that erosion rates, reduction in cover thickness and landform changes are within predefined acceptable levels, and areas with excessive erosion and landform changes are identified for remedial action. Erosion monitoring can range from simple, quick and low-cost methods to provide first estimates of erosion to more complex methods to determine erosion rates with a higher degree of accuracy.

The *surface stability* of a cover surface against soil dispersion and development of a surface seal or crust is important as this can result in an increase in downslope erosion damage. Surface stability also plays a role in gully formation, poor plant germination and vegetation vigour. Less stable soil surfaces will tend to intensify the effects of extreme rain or intense drought conditions.

Monitoring of the *growth medium* is directed at achieving optimal conditions for vegetation growth (vigour) and root development to maintain high transpiration rates and achieve cover performance criteria. Monitoring is required to verify that soil fertility and optimum soil chemistry is maintained.

8.3 Vegetation monitoring

Vegetation monitoring is required to achieve optimal conditions for good vegetation cover and growth (vigour), plant transpiration and root development to achieve cover performance criteria and sustainable functioning of the cover.

Vegetation characteristics that could be monitored include:

- Biomass yield and root depth as an indicator for potential plant transpiration and rainwater ingress;
- Canopy and ground cover as indicators for erosion control; and
- Basal cover, species composition and diversity as indicators related to vegetation composition and structure.

The proportion or density of plant species with high transpiration rates, dense vegetation cover and deeper roots are important indicators of cover performance, and require specific attention for soil covers. Species with a dense vegetation cover and root system are also important indicators of erosion control and sustainable cover performance.

8.4 Cover performance monitoring

The primary performance objective of a soil cover is to reduce seepage impacts to acceptable limits. This is mainly achieved by minimising rainwater ingress into discard. Performance monitoring is required to demonstrate that the cover performance target criteria are met, and demonstrate that the residual seepage impacts and risk are mitigated to the required level during a specified period.

Cover performance monitoring will be determined by defined cover performance objectives and criteria, revised performance criteria based on the results of risk-based numerical modelling, or the (final) cover design risk assessment. Rainwater ingress rates may be defined as a cover performance objective in addition to water quality criteria. This may be required to minimise the seepage volume to be treated to a desired (maximum) range.

8.4.1 Modelling results as basis for cover performance monitoring

Predictive modelling is often the preferred means of quantifying outcomes of rehabilitation projects for surface coal mined land, and to define monitoring points and performance criteria. This is largely due to a lack of reliable case studies or site data with a sufficient record length (LaRSSA *et al.,* 2019). Time series results of predictive modelling, presented in the form of graphs that show how seepage volumes and quality for the various CoCs vary into the future at the defined receptor(s), provide a basis for cover performance monitoring. The planned schedule of monitoring activities is a result of the risk assessment undertaken for the specific discard facility (DWAF, 2008a).

Detailed predictive modelling should be used to analyse potential future seepage impacts of the rehabilitated discard facility. Performance monitoring can be linked to appropriate pre-agreed periods of post rehabilitation monitoring to demonstrate compliance to target performance criteria. If the monitoring results convincingly align with predicted results, then the long-term residual (and latent) risk can be reasonably quantified using the predictive model, and site relinquishment can be sought (INAP, 2017; DWAF, 2008b). According to the G5-BPG, DWS must confirm that closure objectives on seepage impacts agreed to are being complied with, or predictions of future impacts are valid.

The performance monitoring of a soil cover should continue from monitoring conducted for model calibration and validation after vegetation has been successfully established. WMAA (2011) indicated that the higher frequency monitoring conducted for model calibration can be used to determine trend(s) in cover performance, whereafter the monitoring frequency and detail can be reduced (e.g. at five-year intervals).

8.4.2 Groundwater quality monitoring

Groundwater quality (and levels) must be monitored at agreed receptors (locations) in order to determine the impact of the discard facility with a soil cover on groundwater quality.

The *objectives* of groundwater quality monitoring are to:

- Determine the chemical composition of the groundwater and identify CoCs or water quality parameters that provide early indications of the migration of a contaminant plume through the groundwater;
- Collate accurate data on the chemical composition of the groundwater and interpret trends and impacts of changes that occur;
- Comparatively assess any deviation between the actual and predicted groundwater quality impacts for model verification and recalibration;

- Pre-empt and avoid migration of CoCs from the discard facility; and
- Establish a reliable performance record of the design, care and integrity of the cover and consequences of corrective mitigation actions.

To satisfy the above objectives a *groundwater quality monitoring system* must be designed, established and implemented to provide:

- Ambient water quality;
- State of groundwater quality at the time of a rehabilitated facility and closure;
- Early Warning Monitoring Systems; and
- Regional Monitoring Systems on and off-site.

The Water Use Licence (WUL) specifies all chemical and physical (not necessarily excluding biological) *parameters for monitoring*. These are normally categorised into 3 levels of monitoring namely background, detection and investigative. Investigative monitoring normally applies when pollution is detected as compared to background quality or water quality deterioration trends.

Sampling must be representative of the water body. Water samples must be preserved and specialists can be consulted on preservation and suitable instruments for sampling. *Monitoring frequency* must consider the requirements of DWS in the WUL or an amendment thereto. There will normally be a requirement for monthly monitoring in the first year or two after installation of the monitoring boreholes. This frequency should reduce post-rehabilitation and at closure. Should monitoring results indicate little or no change with time, monitoring frequency may be decreased. A reduction in the monitoring frequency normally requires a water use licence amendment from DWS. Water quality indicators detect migration of the seepage plume and any contamination leaving the property.

If the soil cover performance does not fall within the pre-defined acceptable criteria, it could due to the following reasons:

- Differences in the weather/climate, according to initial predictions;
- Decrease in the cover water holding capacity and/or an increase in hydraulic conductivity, as compared to final cover design; and
- Vegetation composition, structure and function not performing as expected; possibly due to poor germination and growth, interference with the establishment process such as pre-mature or unmanaged grazing, burning and/or cutting, or unmanaged infestation of invasive species/weeds (WMAA, 2011).

8.4.3 Cover performance monitoring for site relinquishment

For the purposes of this guideline, the primary cover performance objective and criteria for site relinquishment relate to acceptable seepage impacts. These impacts could be demonstrated through water quality monitoring at key points. Water Quality Objectives (WQO) for post-rehabilitation, closure (site relinquishment) and post-closure stages need to be defined and authorised in the WUL or environmental authorisation. Seepage impacts may include acceptable rainwater ingress rates that limit pit decant or the frequency thereof, management of the final void water levels within defined ranges, and limiting the volume of pit water or seepage from a discard facility that would require treatment post-closure.

Detailed cover performance monitoring conducted for an agreed period after rehabilitation should demonstrate compliance to WUL objectives or gazetted water quality standards, and acceptable rainwater ingress rates, if required. If the results of post-rehabilitation monitoring align well with the predictive modelling described in this guideline, and cover performance criteria for site relinquishment can be met, then the long-term residual and latent risk can be reasonably quantified, and site relinquishment can be sought.

8.5 Cover contingency planning and intervention measures

Contingency planning is required in the event that the cover does not meet cover performance criteria. Contingency planning may include using monitoring data and numerical modelling to determine whether the performance based on these actual data is within an acceptable range. Failure for meeting relinquishment to meet performance criteria is likely to be due to:

Professional advice should be sought when deviation from the predicted cover performance of the final cover design is identified and to recommend intervention strategies. WMAA (2011) recommended intervention measures that are viable to improve cover performance, which may involve one or combination of:

- Divert rainfall as runoff in a controlled manner;
- Repair settlement to prevent ponding by in-filling with cover material and revelation;
- Repair erosion damage (such as gullies), followed by re-establishment of vegetation
- Increase cover thickness by e.g. topdressing;
- Incorporate lime or mulch into growth medium at bare areas with surface seals/crusts;
- Top-dress fertilisers or lime to correct soil chemical imbalances;
- Over-sow with deeper rooted grass species;
- Plant or increase planting density; and
- Replant species with high transpiration demand were replaced during plant succession.

Intervention measures that were applied should be documented as part of a contingency plan.

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Appendix A

Material properties to consider in suitability rating and selection of cover material

1. Growth medium

The following properties should be considered in selecting material for a growth medium:

- Material must be physically and chemically stable, and should not have signs of soil dispersion, erosion damage, surface seals and crusts;
- Comprises the organic A soil horizon, but can also include apedal B soil horizons;
- Suitable soil textures may include:
  - USDA-textute[1]: Sandy loam, loamy sand and sandy clay loam,
  - USCS-texture[2]: Silty sand (SM) and clayey sand (SC, marginally suitable);
- Compaction must be minimised when the A- and apedal B-horizons are stripped, handled, and stockpiled for use as a growth medium.

2. Water retention layer

The following properties should be considered in selecting material for a water retention layer:

- Suitable material can include fine-textured apedal and neocutanic B-horizon soils, saprolites and unconsolidated subsoils, or weathered (softs) overburden;
- Material must have high silt and/or clay contents (fine-textured material, e.g. ≥35%) and a high very fine sand fraction;
- Gravel (>5 mm) content should be <35% by volume;
- Soil structure must be massive or weakly structured (apedal);
- Slight to moderate plastic material. Plasticity index for materials that are not classified as apedal should be less than 18;
- Suitable soil textures may include:
  - USDA-texture[1]: Sandy clay loam, loam, clay loam, silty clay loam, silt, silty loam
  - USCS-texture[2]: Low plasticity silt (ML) or clay (CL), clayey sand (SC); and
- K_{sat} determined from an in-field test or on intact material in the laboratory must be $>10^{-8}$ m/s, and preferably $\leq 10^{-6}$ m/s (Vermaak *et al.,* 2004).

3. Compacted clay (hydraulic barrier) layer

The following properties should be considered in selecting material for a compacted clay layer:

- K_{sat} determined from an in-field test must be $<10^{-8}$ m/s (DWAF, 1998), but preferably $<10^{-9}$ m/s (INAP, 2017; 2009; Albright *et al.,* 2010).
- Slight to moderate plastic material, plasticity index must be 5-18 (DWAF, 1998); and
- Suitable soil textures may include:
  - USDA-texture[1]: Clay loam and sandy clay, and
  - USCS-texture[2]: Low plasticity clay (CL) or silt (ML) and clayey sand (SC).

Note: [1.] USDA-texture: United States Department of Agriculture (USDA) soil texture triangle, which the SA soil taxonomy soil classification system is based on.

[2.] USCS-texture: Unified Soil Classification System (USCS), which engineers use.