DEVELOPMENT OF RISK CRITERIA FOR WATER MANAGEMENT ASPECTS OF MINE CLOSURE

Report to the
Water Research Commission

by

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This report forms part of a series of two reports. The other report is *Development of Risk Criteria for Water Management Aspects of Mine Closure. Guidance for the Mining Industry for the Management of Post-Closure Water Management Risks over the Full Life-Cycle of a Mining Operation* (WRC Report No. TT 628/15)

EXECUTIVE SUMMARY

STATEMENT OF THE PROBLEM

Despite the existence of Best Practice Guideline G4:Impact Prediction (BPG G4) and Best Practice Guideline G5: Water Management Aspects for Mine Closure (BPG G5), a stalemate "chicken and egg" situation exists in South Africa where mines are unable to obtain mine closure because of perceived unknown/unmanageable post-closure risks to the water resource. This is a complex problem with causative factors originating from both the mining industry and the regulator. There is a definite need to unlock this stalemate as its continuation is bad for all parties concerned. The onus rests on the regulator to make the necessary policy and/or regulatory shifts to provide clarity on what is required for mine closure to be approved, while at the same time ensuring that it fulfils its mandate of protecting the national water resource.

While it may at first glance be considered intuitively correct for regulators and potentially impacted stakeholders to insist that mine closure should not be approved unless it can be demonstrated that there is zero risk that there will be long-term residual impacts on the water resource, this logic is flawed for a number of reasons:

1. Zero risk can never be demonstrated and proved in advance and this approach will unavoidably lead to a situation where mine closure is never approved;
2. In circumstances where mine owners are reasonably convinced that mine closure will never be approved no matter what measures they implement, there is simply no incentive to spend limited financial resources to take any pro-active measures towards minimising long-term risks to the water resource and the most appropriate course of action is generally perceived to be to do the minimum and wait;
3. In circumstances where the regulator has poor or limited capacity to ensure that mines do take all the necessary pro-active measures towards minimising long-term risks to the water resource, mine owners have limited incentives, beyond adherence to corporate ethical principles, to implement such measures; and
4. In circumstances where the regulator has limited technical capacity to properly review scientifically complex assessments and predictions of future risk, the regulator is inclined to avoid making decisions on these assessments and consequently mine owners have little incentive to incur the costs associated with undertaking and submitting these complex and costly assessments.

If the above four statements are true then a "stalemate" status quo situation will exist where mine owners do not develop and submit rigorous closure plans with regard to water management issues, where regulators do not approve mine closure plans and where mines that have ceased operations only implement minimum-level care and maintenance measures until such time as financial resources are exhausted and the mine reverts to an abandoned and ownerless status.

Alternatively mines may expend their limited financial resources allocated to closure and post-closure management to implement measures that they believe are correct, without ever evaluating the long-term post-closure risks of these measures to the water resource in a rigorous manner that satisfies the information needs of the State and other stakeholders, thereby running the risk that their limited funds become exhausted while the residual post-closure risk is still higher than that required to approve mine closure, once again leading to the abandoned and ownerless status.

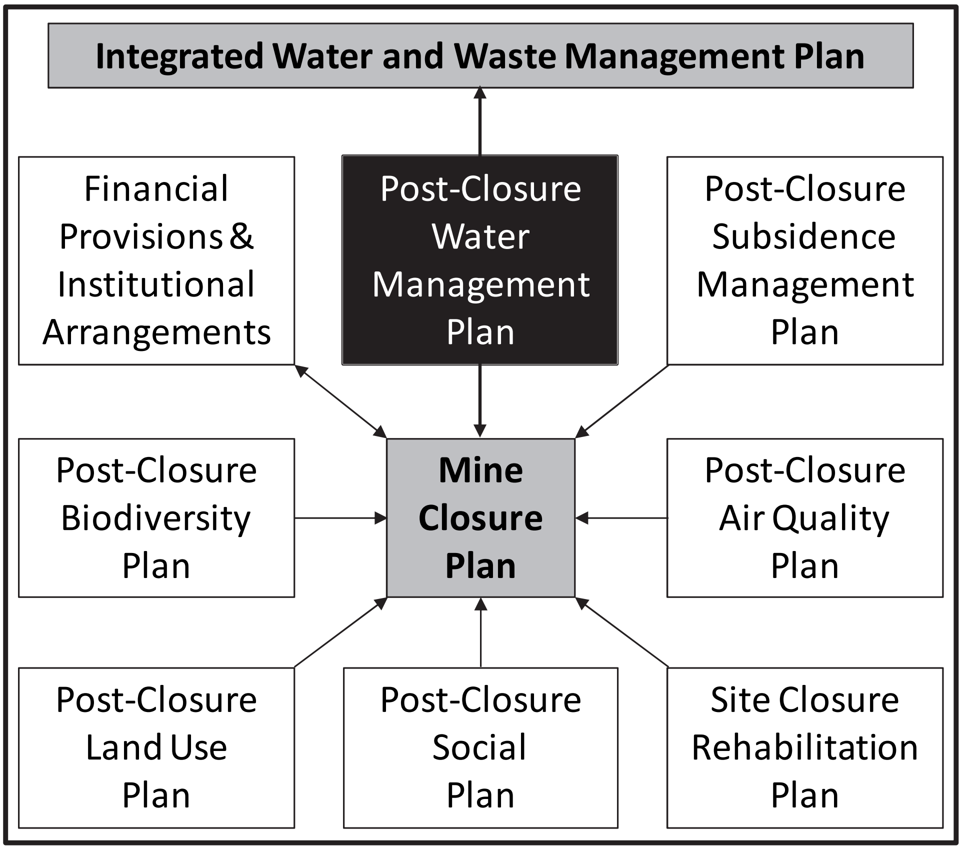
Perpetuation of a status quo stalemate situation where mines do not undertake and submit the correct scientific assessments of post-closure risk because of a perception that they will never be approved by the regulator, or where the regulator is unwilling to approve a suitable post closure risk assessment because of either a lack of confidence in its own ability to make a correct decision regarding the validity of the assessment, or because the regulator is striving to enforce a zero risk option, is undesirable and poses a risk to all stakeholders and future taxpayers in South Africa. The risk to stakeholders and taxpayers is that removal of all incentives (positive or negative) for mine owners to take the necessary proactive measures to minimise post-closure risks to the water resource may lead to no actions being taken at all and places the mines in question at risk of eventually becoming abandoned and ownerless mines that become the de-facto responsibility of the state and its taxpayers.

As part of this research project, a workshop was held with a range of stakeholders from the mining industry and the regulators in order to discuss the most recent regulatory developments that relate to post-closure water management planning, to discuss the relevance and value of mine closure within the context of these new developments and to agree on a strategy to move forward. In summary, the key points agreed to at the workshop can be summarised as follows:

1. While the Department of Mineral Resources (DMR) is accepted as the most appropriate lead agent for the overall mine closure review and approval process, it was agreed that a separate identifiable post-closure water management plan, which would form part of the overall mine closure plan, should be exclusively reviewed by the Department of Water and Sanitation and Sanitation (DWS) at Head Office level and that the DWS decision should be binding and implemented by DMR without modification.
2. In the absence of the ability of mines to achieve “walk-away” mine closure, the concept of mine closure becomes meaningless and serves only to “tick the box” for legal compliance.
3. The post-closure water management planning process is viewed by the mining industry as a process that should be undertaken with the primary objective of addressing and managing their risk to long-term post-closure water management liabilities. This implies that the real “client” for the post-closure water management planning process is the mine itself rather than the regulator.
4. It was agreed that the risk-based process be applied for the development of a post-closure water management plan, in accordance with the procedures set out in BPGs G4 and G5 and confirmed to be aligned with international best practice by the project literature review.
5. The regulator (DWS) has an important role to play to ensure that all mines, irrespective of size, ownership and/or location, follow the risk management approach as set out in BPGs G4 and G5 in order to ensure that the risk of current mining operations becoming tomorrow’s abandoned and ownerless mines is minimised.
6. Mines should play the leading role in the development of regional post-closure water management strategies, together with the active participation of the DWS and/or Chamber of Mines as institutions that could become the long-term custodians/facilitators of these regional strategies.

The objective of this document is to define the technical aspects and procedures that need to be followed in order for mines to be able to manage and minimise their long term risks and liabilities and to provide the State (the regulator) with the requisite information to be able to review and approve a post-closure water management plan. The development of these technical aspects and procedures is based on the literature review of international practice, the existing Best Practice Guidelines and the application of sound scientific principles. It is furthermore assumed that all stakeholders (mine owners, regulators and the general public) agree that the previously defined stalemate status quo is undesirable, that generation of additional abandoned and ownerless mines is undesirable and that the responsibility lies with the mines for implementation of the correct management measures to minimise the risk of post-closure water management impacts. The focus of this report is on the major sources of water resource contamination that can persist up to and after mine closure, specifically contamination that may result from the mine workings (underground or open cast) and the various types of mine residue deposits. Mine closure will obviously need to deal with many additional water-related issues such as hydrocarbon contamination from hydrocarbon storage areas, rehabilitation of surface infrastructure areas and others that are not explicitly covered in this report.

The role of a post-closure water management plan in relation to a mine closure plan is shown in the Figure below. The mine closure plan is an overarching plan (much in the same way as an environmental management plan) which needs to integrate the outputs of various specialist studies and management plans, including the post-closure water management plan. The post-closure water management plan also feeds into the mine’s Integrated Water and Waste Management Plan (IWWMP). This report develops the concept of the Post-Closure Water Management Plan.



Role of the Post-Closure Water Management Plan within a Mine Closure Plan and an IWWMP

CONTEXT OF THE PROBLEM

The international literature review has confirmed a number of key points with regard to the assessment and management of post-closure water risks:

1. The evaluation and prediction of post-closure water management impacts and the identification of appropriate management measures that should be implemented to address these impacts must be based on the classical risk assessment process.
2. Successful management of post-closure water management impacts and risks is based on rigorous implementation of a correct specified procedure and not through compliance with some arbitrary definition of what constitutes an acceptable risk.
3. Successful management of post-closure water management impacts and risks will require unique solutions for each mine that result from the rigorous application of a universally valid procedure.
4. The risk assessment procedure must be transparent and must demonstrably address the key questions and concerns of affected stakeholders.
5. All risk assessment and impact prediction exercises have inherent uncertainty but this acknowledgement of uncertainty is not a flaw in the procedure, it simply requires that this uncertainty be understood and defined and that it be catered for in the development of management measures to deal with post-closure water management impacts.
6. The Best Practice Guidelines G4: Impact Prediction and G5: Water Management Aspects for Mine Closure do contain and describe the correct procedures that should be followed to ensure that post-closure water management risks are properly understood and addressed.

While various risk assessment models and frameworks exist and a number of these were discussed in the literature review, most approaches have common elements that are best captured in the family of standards relating to risk management that have been codified by the International Organisation for Standardization (ISO) and issued as ISO 31000.

The key requirements of a good risk assessment have been defined as the following:

- Transparency in data and models (ability to replicate)
- Rigorous expert peer reviews
- Opportunity for stakeholder comment and explicit response to those comments
- Responsiveness to informational needs of the regulator

There are a number of approaches that could be followed to determine when an assessed risk is acceptable and when it is not and mitigation measures should be considered. The different approaches range from imposition of arbitrary limits, economic cost-benefit assessments to political decisions. The general consensus in the literature is that the "acceptability" of a risk is a judgement decision properly made by those exposed to the hazard or their designated health officials. It is not a scientifically derived value or a decision made by outsiders to the process. It has been stated in the literature that:

"The solution to developing better criteria for environmental contaminants is not to adopt arbitrary thresholds of "acceptable risk" in an attempt to manage the public's perception of risk, or develop oversimplified tools for enforcement of risk assessment. Rather, the solution is to standardize the process by which risks are assessed and to undertake efforts to narrow the gap between the public's understanding of actual versus perceived risk."

SOLUTION TO THE PROBLEM

Based on the literature review and the content and approach advocated in the Best Practice Guidelines BPG G4 and BPG G5, it is proposed that the solution to the stalemate problem facing mine closure is to recognise and implement the following principles:

1. Planning for successful and sustainable mine closure and post-closure water management is a process that starts at the earliest stage in the mine's life and progresses in terms of certainty and clarity as the mine proceeds along its life cycle.
2. In certain cases, where high risks exist that a planned mine will not be able to close in a manner that is sustainable and acceptable, it could be appropriate to reach the decision that such a mining operation should not be started, i.e. project No Go decision.
3. The Department of Water and Sanitation needs to engage with the mines with regard to their planning for mine closure and post-closure water management throughout the mine life cycle and not only consider the mine closure question at the end of mine life.
4. The Department of Water and Sanitation must clearly state the mine closure questions to which it seeks answers at each stage of the mine life cycle and must also provide guidance on how these questions should be addressed.
5. The mines must apply the best practice risk-based impact prediction methodology as defined in the DWS Best Practice Guidelines BPG G4 and BPG G5 as it is aligned to the international best practice as shown in the literature review undertaken as part of this project.
6. The interests and views of all stakeholders must be considered in developing closure and post-closure water management objectives that the mine's closure plan must strive to meet.
7. The risk assessment and impact predictions underpinning the mine closure and post-closure water management plan must be undertaken by suitably qualified persons and must incorporate specialist independent review that is integrated throughout the whole impact prediction process in line with guidance provided in BPG G4.

While most of the above issues are captured in the referenced Best Practice Guidelines, clarity is required on the mine closure related questions that the mine needs to address in each of its life cycle phases in order to meet the informational needs of the Department of Water and Sanitation. It is therefore also important that the information routinely provided to the mine in terms of updated IWWMPs (Integrated Water and Waste Management Plan) includes the required information on the mine's closure and post closure water management plan relevant to the life cycle phase that the mine finds itself in.

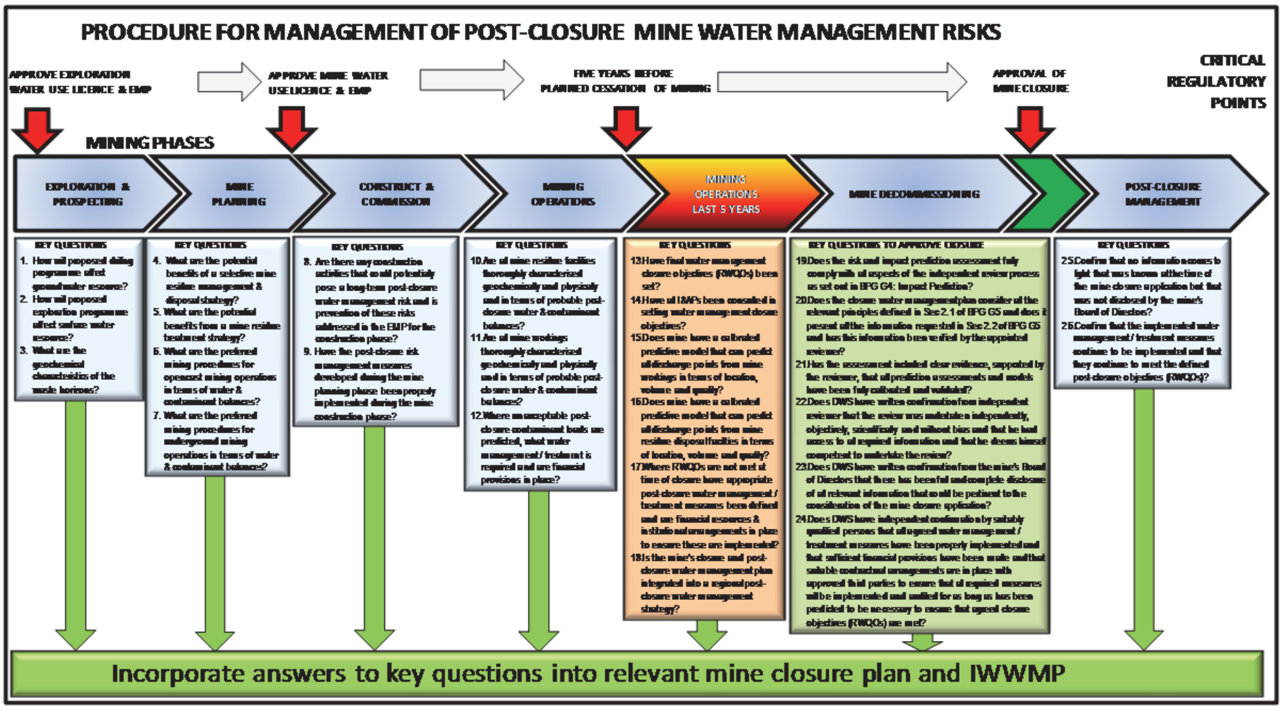
While the mining life cycle can be divided into different phases in different ways, the following definition of life-cycle phases is used in this document:

1. Exploration and prospecting
2. Mine planning (ranging from pre-feasibility through to detailed and final planning)
3. Construction and commissioning
4. Mining operations
5. Last five years of mining operations before planned mine closure
6. Mine decommissioning (ending with approval of mine closure by regulators)
7. Post-closure management

While it is obvious that closure-related considerations become more important as mines progress along the life cycle path towards mine closure, there are in fact, mine closure considerations that need to be considered during most of the abovementioned life cycle phases as described in the following section.

ANSWERS TO THE PROBLEM

The key questions that relate to the mine closure and post closure water management plan during each of the life cycle phases of the mine and that need to be answered are listed below. All these questions should be answered using the procedural methodologies outlined in BPG G4 and BPG G5. The key questions that have been developed for each of the mine life-cycle phases is shown in the figure below.



Key Post-Closure Water Management Questions for each Phase of the Mine Life Cycle

Key questions in the exploration and prospecting phase

It needs to be recognised that there are a number of closure-related issues that need to be considered in the exploration and prospecting phase of a mine if the post-closure risk to the water resource is to be minimised. Key questions that should be asked and answered by way of an appropriate risk assessment and impact prediction exercise are the following:

1. How will the proposed drilling programme affect the integrity of the groundwater resources in the area where prospecting and exploration is intended to take place?

2. How will the proposed exploration programme affect the surface water resources in the area where prospecting and exploration is intended to take place?
3. What are the geochemical characteristics of the waste horizons that will be generated should the planned mine proceed and how should this mine residue be managed?

Key questions in the mine planning phase

Mines that enter the mine planning phase will be faced with considering alternatives for a wide range of features and actions associated with the planned mine. The interest in this phase of the mine life cycle with regard to mine closure and water management relates only to those actions that will persist throughout the life of the mine and which may potentially have impacts and risks beyond mine closure. The actions of interest will relate to the actual mining operations and the mine residue management options that will be implemented. It is also accepted that there is a relatively high level of uncertainty regarding many aspects of the future mining operations at the mine planning phase and that the type of risk assessment and impact prediction that can be undertaken at this stage will of necessity be of a "screening-level" and based on a precautionary and conservative set of assumptions in lieu of solid and reliable data. Nevertheless, there are important questions that need to be asked and answered during the mine planning phase as described below.

1. What are the potential benefits that could be obtained from implementing a selective mine residue management and mine residue disposal strategy?
2. What are the potential benefits that could be obtained from implementing a mine residue treatment strategy to remove/reduce the pollution potential of the most reactive mine residue streams?
3. Based on evaluation of a most likely operational and post-closure pit water and contaminant balances, what are the preferred mining procedures for any planned opencast mining operations?
4. Based on evaluation of a most likely operational and post-closure mining void water and contaminant balance and risks of surface subsidence, what are the preferred mining procedures for any planned underground mining operations?

Key questions in the mine construction and commissioning phase

While the mine planning phase should have adjusted the planned operations, where necessary, to give attention to potential post-closure risks and to choose alternatives that pose the lowest post-closure water management risk, it is essential to ensure that these measures are properly and effectively implemented during the construction phase. It is also essential to ensure that the construction activities themselves do not cause long-term post-closure risks and it is therefore critical to ensure that the construction EMP addresses these risks and that its implementation is properly managed. There are therefore important questions that need to be asked and answered during the mine construction phase as described below.

1. Are there any construction activities that could potentially pose a long-term post-closure water management risk and is prevention of these risks addressed in the environmental management plan (EMP) for the construction phase?
2. Have the post-closure risk management measures developed during the mine planning phase been properly implemented during the mine construction phase?

Key questions during the mine operations phase

Any extensions to underground or opencast workings or development or new mine residue disposal facilities that are contemplated during the mine operations phase should be subjected to the same questions and risk assessments and impact predictions as described in the mine planning phase. The difference would be that the assessment should be capable of being undertaken on a quantitative basis as opposed to a screening level basis as there should be good data sourced from historical mining operations that can be used in predicting the impacts of future mining operations. Activities that should trigger mine closure related risk and impact prediction assessments before being approved would therefore include the following:

- planned disposal of mine residues onto new or existing (but not previously used by the mine) surface mine residue deposits or into mining voids
- opening of new opencast or underground mining operations

Mines that already find themselves in the mine operations phase without having had the opportunity to ask the questions listed in the mine planning phase above will have less opportunity to identify and apply pro-active pollution prevention management actions to some of the elements of their mining operations insofar as mining operations are already in place and existing mine residue disposal facilities are also already in place. However, key questions that should be asked during this phase are the following:

1. Are all existing mine residue facilities thoroughly characterised in terms of their physical and geochemical heterogeneity and their probable post-closure water balances?
2. Are all mine workings (opencast and underground) thoroughly characterised in terms of their physical and geochemical heterogeneity and their probable post-closure water balances?
3. Where unacceptable contaminant loads are predicted, what water management and treatment alternatives would be required to treat these loads to an acceptable level and are the financial provisions for such water management/treatment included in the mine's closure financial provisions?

It must be emphasized that while mines will only be required to compile provisional mine closure plans during that part of the operating phase that is further than five years from closure, this time should be used productively to ensure that all predictive models are developed and calibrated and that a reasonably confident assessment of the measures required at closure and post-closure can be made and financially provided for. It is too late to only define final closure and post-closure measures 5 years before actual mine closure if good provisional assessments have not been made previously. It is generally not feasible for a mine to generate the funds to provide for new closure and post-closure management activities within the last 5 years if reasonable estimates and provisions have not been made in the preceding years.

Key questions at five years before planned mine closure

At the point where the current mine plan indicates that the mine will cease operations and commence with decommissioning and closure activities within five years, an important shift occurs with regard to the mine closure planning process from the water management perspective. This point will also be reached should the mine at any other time suddenly find itself with less than five years of operating life left, e.g. should there be a dramatic fall in commodity prices or ore grades or any other factor that unexpectedly makes the mine's operations uneconomical.

At this point, the mine closure plan which has been in a continuous evolving provisional plan stage throughout the life of mine, needs to be converted into a final and approved mine closure plan and post-closure water management plan.

It has previously been emphasized above that the mine should essentially have final, complete and calibrated predictive models for all the mine workings and the mine residue disposal facilities at this point and that good estimates of closure and post-closure management measures and associated costs should be in place with finances already available in the mine's closure funds. The conversion of the provisional mine closure plan to a final mine closure plan should therefore not result in any radical changes to the plans or the financial provisions. The purpose of conversion to a final closure water management plan is to obtain finality on the RWQOs that the mine will need to meet and to enable the mine to then make final decisions on closure and post-closure measures to be implemented to meet the RWQOs. Certain parts of the mine can then also proceed to final decommissioning, with time then being available in the last five years of operation to collect monitoring data to demonstrate that predictive models are accurate and reliable and that specified closure management actions are in fact capable of meeting the specified RWQOs.

In order to facilitate this process, the following key questions need to be asked and answered at this stage in the mine's life cycle and incorporated into the final mine closure water management plan.

1. Have the final closure objectives (RWQOs) with regard to water management been defined and set?
2. Have all interested and affected stakeholders been consulted in the setting of these final closure water management objectives?
3. Has the mine developed and calibrated a predictive model that is capable of predicting all points of discharge from the mine workings (opencast and/or underground) in terms of location, volume and

quality for all contaminants of concern for a period of time until such discharges are acceptable in terms of agreed RWQOs?

4. Has the mine developed and calibrated a predictive model that is capable of predicting all points of discharge from the mine residue disposal facilities (coarse and fine and disposed of on surface and/or underground) in terms of location, volume and quality for all contaminants of concern for a period of time until such discharges are acceptable in terms of agreed RWQOs?
5. Where RWQOs are not met at the time of mine closure, have appropriate post-closure water management/treatment measures been specified, designed and costed by a suitably qualified person and have financial resources and institutional arrangements been made to implement and finance these measures for as long as they are predicted to be required, i.e. until the RWQOs can be met without such measures being in place?
6. Is the mine's closure and post-closure water management plan integrated into a regional post-closure water management plan?

Key questions at the point of considering approval of mine closure

At the point where the mine has implemented the management measures contained in the approved mine closure and final post-closure water management plan, the mine would then approach the Department of Water and Sanitation (through the Department of Mineral Resources) to approve the granting of mine closure. At this point, it is assumed that the mine will have followed the procedures set out in BPG G4 and BPG G5 and the appropriate questions that need to be asked are those that are stipulated in BPG G5. The requirements that need to be met with regard to these questions are described in BPG G5.

1. Does the risk and impact prediction assessment fully comply with all aspects of the independent review process as set out in BPG G4: Impact Prediction?
2. Does the closure plan consider all the relevant principles described in Section 2.1 of BPG G5 and does it present all the information requested in Section 2.2 of BPG G5 in a clear written report and has all such information been verified by the appointed reviewer?
3. Has the assessment included clear evidence, supported by the independent reviewer, that all impact prediction assessments and models have been fully calibrated and validated using information collected from a verification monitoring programme?
4. Does DWS have written confirmation from the appointed reviewer that his/her review was undertaken independently, objectively, scientifically, without bias or favour to any party, that he/she was given full access to all information required to undertake the review and that he/she deems him/herself competent to have undertaken the review?
5. Does DWS have written confirmation, from a duly appointed representative of the mine’s Board of Directors, that the mine closure application is based on full and complete disclosure of all information that could in any way be pertinent to the consideration of the mine closure application and that no potentially damaging information has been withheld?
6. Does DWS have confirmation, through an independent assessment by suitably qualified persons, that all the stipulated and agreed water management actions and measures (including any water treatment plants that may be required) have been properly implemented and that sufficient/adequate financial provisions have been made and that suitable contractual arrangements have been entered into with approved third parties to ensure that all the required operational, maintenance and financial measures will be implemented and audited for as long as has been predicted to be necessary to ensure that the agreed closure objectives are met?

Key post-closure questions

After mine closure has been approved, residual water management/treatment measures that may need to be implemented for a specified number of years will be managed by third parties agreed to at the point of approval of mine closure.

1. Confirm that no information comes to light that was known at the time of mine closure application but that was not disclosed (in reference to Question 5 in Section 5.4.6 above).
2. Are the implemented water management/treatment measures continuing to be implemented and do they continue to meet the defined RWQOs?

PROBLEM SOLVED

If all the above-mentioned questions are answered by way of undertaking assessments aligned with the procedures set out in BPG G4 and BPG G5 and as expanded upon in this document, then there should be very little new information or surprises at the time that the mine requires approval from the Department of Water and Sanitation for closure. The Department of Water and Sanitation will have an information trail that leads from the start of the mine up till closure for all new mines and will also have a clearly defined set of questions (and desired answers) for mines that are already in operation and that enter this process at some advanced stage in the mine life cycle.

The additional benefit to the mines is that the questions that are being asked and the studies that need to be undertaken to answer the questions, are fundamentally aimed at identifying and maximising the opportunity for the implementation of pollution prevention strategies. The old maxim that "prevention is better than cure" most certainly applies to mine water management too, and the investment of time and resources into answering the questions will provide payback in terms of reduced costs for the mine closure and post-closure water management plan and the surety that the final application for mine closure can be approved by the Department.

Most importantly, by following the processes and methodology described in this report and the BPGs G4 and G5, the mine will have undertaken the appropriate risk management process to understand, manage and minimise its long term exposure to risk and liability associated with post-closure water impacts.

If the questions defined in this document are answered using the methodology set out in the relevant BPGs then there is no technical or scientific reason for the Department of Water and Sanitation to not approve the post-closure water management plan at the end of mine life.

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GLOSSARY

Acceptable risk
Level of human and/or material injury or loss from an industrial process that is considered to be tolerable by society or authorities in view of social, political and economic cost-benefit analysis.

Best Available Technology (BAT)
BAT refers to methods of production and treatment that are as efficient and advanced as possible and technologically and economically feasible, and to methods of designing, constructing, maintenance and operation with which the contaminative effect of activities can be prevented or most efficiently reduced.

Inherent risk
The probability of loss arising out of circumstances or existing in an environment, in the absence of any action to control or modify the circumstances.

Qualitative risk assessment
The comprehensive identification and description of hazards from a specified activity, to people or the environment. The range of possible events may be represented by broad categories, with classification of the likelihood and consequences, to facilitate their comparison and the identification of priorities.

Quantitative risk assessment
The application of methodology to produce a numerical representation of the frequency and extent of a specified level of exposure or harm, to specified people or the environment, from a specified activity. This will facilitate comparison of the results with specified criteria.

Risk
1. A probability or threat of a damage, injury, liability, loss, or other negative occurrence that is caused by external or internal vulnerabilities, and that may be neutralized through pre-emptive action.
2. The product of the impact of the severity (consequence) and impact of the likelihood (probability) of a hazardous event or phenomenon. For carcinogenic effect, risk is estimated as the incremental probability of an individual developing cancer over a lifetime (70 years) as a result of exposure to a potential carcinogen. For non-carcinogenic effect, it is evaluated by comparing an exposure level over a period to a reference dose derived from experiments on animals.

Risk assessment
1. The identification, evaluation, and estimation of the levels of risks involved in a situation, their comparison against benchmarks or standards, and determination of an acceptable level of risk.
2. The qualitative and quantitative evaluation performed in an effort to define the risk posed to human health or the environment by the presence or potential presence and use of specific pollutants

Risk management
The identification, analysis, assessment, control, and avoidance, minimization, or elimination of unacceptable risks. An organization may use risk assumption, risk avoidance, risk retention, risk transfer, or any other strategy (or combination of strategies) in proper management of future events.

Risk mitigation
A systematic reduction in the extent of exposure to a risk and/or the likelihood of its occurrence. Also called risk reduction.

Semi-quantitative risk assessment
The systematic identification and analysis of hazards from a specified activity, and their representation by means of both qualitative and quantitative descriptions of the frequency and extent of the consequences, to people or the environment. The importance of the results is judged by comparing them with specific examples, standards or results from elsewhere.

ABBREVIATIONS

1D, 2D, 3D	1, 2, 3 dimensional
µg/L	microgram/litre
µm	micrometers
ABA	acid base accounting
AG	acid generating
AGP	acid generation potential
AMD	acid mine drainage
AP	acid production potential
ARD	acid rock drainage
BATNEEC	Best Available Technique Not Entailing Excessive Costs
BCRC	British Columbia Research Confirmation test
BCRI	British Columbia Research Initial test
BPG	Best Practice Guideline
°C	degrees Celsius
cm	centimetre
DEA	Department of Environment Affairs
DMR	Department of Mineral Resources
DWS	Department of Water and Sanitation
gm	gram
HCT	humidity cell test
hr	hour
ICMM	International Council on Mining and Metals
ICP-MS	Inductively-coupled plasma – mass spectrometer
K_d	distribution coefficient
kg	kilogram
L	litre
m	metre
MEP	multiple extraction procedure
MEND	Mine Environmental Neutral Drainage
min	minute
mL	millilitre
mm	millimetre
MPRDA	Mineral and Petroleum Resources Development Act 28 of 2002
MPRDAA	Mineral and Petroleum Resources Development Amendment Act 49 of 2008
NAG	net acid generating test
NCV	net carbonate value test
NEMA	National Environmental Management Act 107 of 1998
NEMAA	National Environmental Management Amendment Act 62 of 2008
NEMLAA	National Environmental Management Laws Amendment Act 25 of 2014
NEMWA	National Environmental Management: Waste Act 59 of 2008
NEMWAA	National Environmental Management: Waste Amendment Act 26 of 2014
NP	neutralization potential
NWA	National Water Act 36 of 1998
NWAA	National Water Amendment Act 27 of 2014
RWQO	receiving water quality objective
QA/QC	quality assurance/quality control
SC	specific conductance
SEM/EDS	scanning electron microscopy/energy dispersive system
T	temperature
US EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VOC	volatile organic compound
WET	California waste extraction test
XRD	X-ray diffraction
XRF	X-ray fluorescence

CHAPTER 1: INTRODUCTION AND BACKGROUND

1.1 MOTIVATION FOR THE PROJECT

The Department of Water and Sanitation (DWS) recently produced a series of Best Practice Guidelines (BPGs) that give specific guidance on procedures to be adopted in the development of mine closure plans (BPG G5) and in the prediction of future impacts that are associated with mine closure (BPG G4). The key principles contained in these BPGs are also in the process of being captured in new regulations that will apply to the mining industry in replacement of the current GN704 regulations.

While these Best Practice Guidelines provide clear methodologies for undertaking the assessments that are required to support a mine closure application, it remains the responsibility of the State (DWS) to ensure that the risk of unforeseen long-term water pollution problems arising after closure has been granted, is absolutely minimized, taking into account financial realities and practicalities and sustainability of water management measures. This is based on the statements made in BPG G4 and G5 that the State will accept the risk of unforeseen impacts on the water resource arising after mine closure has been approved (although this position is questioned in more recent developments as set out in Chapter 4 below). In exercising this responsibility, DWS officials are required to provide guidance and decision making with regard to the following key technical issues in the impact prediction and closure application process:

- agreement on the acceptable levels of confidence for the prediction that will limit the State's liability to acceptable levels;
- agreement on the statistical representivity of the datasets used in the prediction and their suitability for addressing the issues that pertain to the particular closure application;
- agreement on the definition and descriptions of uncertainty inherent in the predictions and acceptance that the defined uncertainty meets the requirements of the regulator; and
- agreement on the suitability and adequacy of financial provisions to cater for uncertainties and risks for post-closure water management and treatment

The Best Practice Guidelines do not provide any practical guidance on how the above issues should be addressed and these are left to the discretion of DWS officials that assess the mine closure application. The above issues are technically complex issues to address and agree on and failure to reach such agreement will prevent the finalisation of impact predictions and mine closure applications. Furthermore, agreement on the wrong criteria for the above issues could expose the State (and taxpayers) to unacceptable liabilities with regard to long-term impacts on the water resource.

It is therefore in the clear best interests of all stakeholders with an interest in post-closure water impacts from mining operations, i.e. mining companies, regulators, interested and affected members of the public and taxpayers in general, that the abovementioned agreements that are reached are technically correct and defensible.

In developing the proposed technical approach to dealing with the abovementioned issues, a review of the international literature and international practice was conducted and reported on in a separate report: Literature Review of International Practice, November 2012 (see Annexure A to this report). This technical report draws heavily on the information captured in the aforementioned Literature Review. A workshop with a range of stakeholders from the mining sector and The Department of Water and Sanitation was held in October 2014 to discuss the current practice, philosophy and risks associated with mine closure and the outcome of this process and the impact that these discussions have had on the project is captured in Chapter 5.

The focus of this report is on the major sources of water resource contamination that can persist up to and after mine closure, specifically contamination that may result from the mine workings (underground or open cast) and the various types of mine residue deposits. Mine closure will obviously need to deal with many additional water-related issues such as hydrocarbon contamination from hydrocarbon storage areas, rehabilitation of surface infrastructure areas and others that are not explicitly covered in this report.

The role of a post-closure water management plan in relation to a mine closure plan is shown in the Figure below. The mine closure plan is an overarching plan (much in the same way as an environmental management plan) which needs to integrate the outputs of various specialist studies and management plans, including the post-closure water management plan. The post-closure water management plan also feeds into the mine's Integrated Water and Waste Management Plan (IWWMP). This report develops the concept of the Post-Closure Water Management Plan.

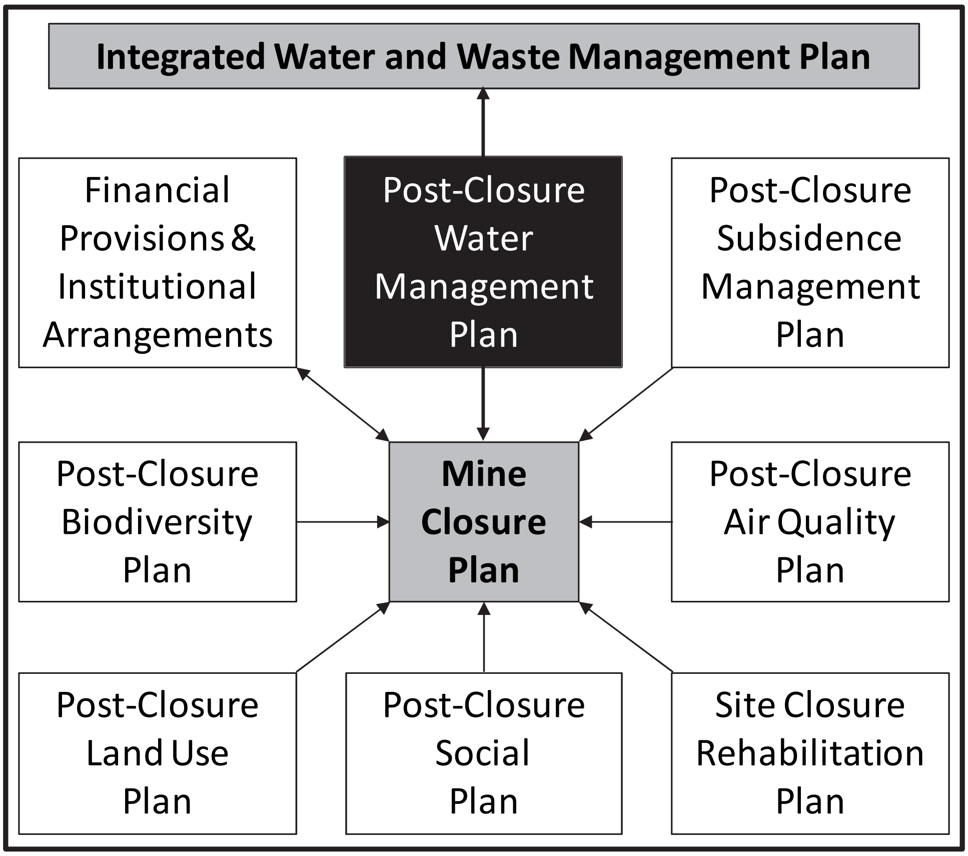

Figure 1: Role of the Post-Closure Water Management Plan within a Mine Closure Plan and an IWWMP

1.2 PROJECT OBJECTIVES AND AIMS

The project was structured to address the following three major objectives:

1. To provide a review of international practice on acceptable levels of confidence and uncertainty in the prediction of post-closure water impacts and approaches in defining financial provisions for post-closure water management/treatment.

2. To engage with all relevant stakeholders in South Africa (regulators, mining industry and consultants) in order to reach broad consensus on acceptable levels of confidence in post-closure impact prediction, approaches for defining acceptable levels of statistical representivity of datasets, methods for defining prediction uncertainty and methodologies for determining financial provisions for post-closure water management/treatment at mines.

3. To prepare a report that gives clear guidance to all stakeholders on how to define and agree on acceptable levels of confidence for a closure-related impact prediction, how to define when datasets are statistically representative, how to define and describe prediction uncertainty and how to determine financial provisions for post closure mine water management and treatment.

It should be noted that the literature review that was undertaken as the first task of the project, clearly indicated that the international approach was NOT to set predetermined levels of confidence but to focus on the process and procedures that were followed in determining the assessed risk. The focus of the project was therefore changed to develop additional guidance on the procedures to assess and quantify uncertainty in predictions and to provide clear guidance on the key questions that should be asked when developing a post-closure water management plan. The project then also developed a process and procedures that should be followed in answering the key questions.

1.3 PROJECT TASKS AND METHODOLOGY

The project was subdivided into six tasks, namely:

1. **Task 1: Determine international practice.** Literature reviews were undertaken on all the above mentioned technical topics to determine current practice in other countries, including North America, Europe and Australia. Direct contact was also made with regulators and specialists in these countries with whom project team members have professional relationships. An assessment was made of the suitability and/or limitations of application of these international approaches to the South African situation. This literature review did not address the technical aspects of how a risk assessment process should be done as this has been adequately covered in other research projects on similar topics undertaken for the WRC and INAP. The literature review instead focused on determining methodologies and procedures used and adopted in other countries for agreeing on the level of uncertainty and residual risk within mine closure assessments that will allow them to be approved. This issue had not previously been addressed in any South African research projects or in INAP's GARD Guide and is the key issue that must be agreed upon to allow closure assessments to be fairly evaluated and approved. A status report was prepared that presents the outcome of the work undertaken in Task 1. The outcome of this task is presented in Annexure A.

2. **Task 2. Prepare workshop documentation.** The following two reports were planned to be prepared as input documents for the workshops to be held in Task 3:

   - Technical Report: This report would provide a summary of the issues that form the subject matter of this research project and why they are important and why consensus is required on how these issues are addressed in mine closure assessments. The report would then provide an overview of the international best practice on the issues and would provide a recommendation on how these issues could be addressed within the South African context. This report would be issued to all workshop participants in the Task 3 workshops.
   - Regulators Report: This report would provide an overview of the technical issues that form the subject matter of this research project from the specific viewpoint of how they impact decision-making within the regulatory function. The recommendations made in the Technical Report would also be expanded upon from the regulatory perspective.

   Based on the outcome of the literature review and discussions with the Reference Group representatives, it was later decided that a single workshop would be held to incorporate all stakeholders and a single workshop document was therefore prepared.

3. **Task 3. Hold initial workshops with individual stakeholders.** As it was anticipated that the topics covered in this research project would most probably lead to very divergent opinions from the different stakeholders and as it was also expected that different stakeholders might have very different technical capabilities in engaging sensibly on these topics, it was proposed to hold separate workshops with the

different stakeholders. Three different stakeholder groups were identified and three different workshops were therefore planned:

- Workshop 1: Specialists Workshop to be held with consultants, academics and researchers. Persons attending this workshop were expected to be technically proficient in the subject matter and would be expected to be fully capable of participation in the workshop after having read the Technical Report prepared in Task 2.
- Workshop 2: Industry Workshop to be held with representatives of the mining industry. Persons attending this workshop were also expected to be technically proficient in the subject matter and would be expected to be fully capable of participation in the workshop after having read the Technical Report prepared in Task 2.
- Workshop 3: Regulator Workshop to be held with representatives of government departments involved in regulating the mining industry. Persons attending this workshop were expected to be a mix of those who are and those who are not technically proficient in the workshop subject matter and the separate Regulator's report would also have been submitted to these persons ahead of the workshop, in addition to the status report prepared in Task 2. The workshop would also commence with a simplified technical overview of the issues in order to ensure that attendees are provided with the capacity to participate in the workshop in a meaningful manner.

Based on the outcome of the literature review and discussions with the Reference Group representatives, it was later decided that a larger single workshop would be held to incorporate all stakeholders and to ensure a free flow of ideas and views between all stakeholders. Given that a stalemate type of situation had developed between the regulators and industry, it was also felt that a single integrated workshop would be beneficial in resolving the stalemate and would also provide a platform to share ideas. This workshop was successfully held on 24 October 2014.

4. **Task 4. Prepare draft project report.** The outcome of the workshop that was held as part of Task 3 was documented in a draft project report that recommends an approach to deal with the technical subject matter of the research project in a manner that presents the best practical and broadest consensus approach of all the stakeholders while retaining scientific validity within an international context. This report also included reference to the literature review and was intended to serve as the basis for the workshop to be held in Task 5.

5. **Task 5. Final project workshop.** The report prepared in Task 4 was distributed to the participants that registered for the final project workshop. A combined workshop was held with all stakeholders to discuss the document and endeavour to reach a reasonable consensus on the approach to be followed with regard to the different technical issues addressed in this research project. This workshop was successfully held on 23 January 2015

6. **Task 6. Prepare final project report.** The outcome of the Task 5 final workshop was considered and used to update the draft report prepared as Task 4. It needs to be clearly stated, however, that the final report did not aim to produce a consensus view and that the project outcome needed to be scientifically valid and consistent with international practice, adapted for particular South African considerations.

1.4 RESEARCH PRODUCTS

A number of progress reports have been submitted to the WRC. This report is the final detailed research report and addresses all the various tasks and deliverables as described in Section 1.3 above.

1.5 CAPACITY AND COMPETENCY DEVELOPMENT

This project did not include any researchers or students for the purpose of capacity and/or competency development. However, the workshops that were held as part of Tasks 3 and 5. Invitations were sent to representatives from the following government departments:

- Department of Water and Sanitation (DWS)
- Department of Mineral Resources (DMR)
- Department of Environment Affairs (DEA)

These invitations were followed up extensively by both the project leader and representatives from the Chamber of Mines, but despite these efforts, only DWS representatives attended the workshops. Attempts to build capacity on post-closure water management issues within the DMR and DEA, who are both involved in regulating these issues on mines was therefore unsuccessful due to a lack of interest on the part of these Departments to participate.

CHAPTER 2: RISK ISSUES IN THE BEST PRACTICE GUIDELINES

The two most important Best Practice Guidelines issued by the DWS that have a bearing on risk issues associated with mine closure are BPG G4: Impact Prediction and BPG G5: Water Management Aspects for Mine Closure. Key risk-related issues raised in these two important BPGs are summarised below as these provided the guidance to the scope that was addressed in this literature review. This section is taken directly from the Literature Review as there is no better way to adequately summarise the content of these two BPGs than what is contained in sections 2.1 and 2.2 below.

2.1 BPG G4: IMPACT PREDICTION

This BPG provides a recommended approach that should be followed by mines when making predictions of future impacts arising from management actions that have historically been undertaken or are currently being undertaken. Such predictions of future impact could potentially be undertaken for a range of situations, including that which is the interest of this project, i.e. mine closure.

The concepts of risk are captured within the general impact prediction principles set out in Chapter 2 of the BPG, specifically the following:

- The traditional and established risk assessment methodology (source term, pathway and receptor) must be used in order to develop an appropriate conceptual model of the scenario to be evaluated – ensure that this step is discussed with and agreed to with all persons who will be reviewing the results of the assessment.
- Understand the need for proper data collection and that confidence in prediction is dependent on quality of data and use of correct tools.
- Understand and define the uncertainty inherent in the impact prediction, based on composite uncertainties of the data collection process, the assumptions made, and the limitations of the tools used.

Chapter 3 of the BPG is titled: "Risk-based Approach to Impact Prediction" and provides guidance on the risk assessment methodology that should be followed in undertaking an impact assessment. Some key statements made in this chapter are highlighted below.

The risk-based approach to impact prediction is favoured by DWS and is consistent with policies and approaches that are subscribed to by DWS in the review and approval of water use licence applications. It is recognized by DWS that any prediction of future impacts has inherent uncertainty which means that there is always a risk that the prediction proves to be incorrect due to the occurrence of some unforeseen future event.

However, in order to accept the risk-based approach and the consequences that go with it, this BPG sets out very specific requirements that must be complied with in order to ensure that the risk is a manageable one. For this reason, the BPG also defines a specific methodology and requires the concurrent involvement of an independent reviewer whenever the impact assessment is used as part of a mine closure application. The defined methodology also requires specific consideration and definition of uncertainties within the assessment process.

*The general principle inherent in the mine closure risk assessment methodology is that the mine must take responsibility for all risks that can be foreseen, by way of a post-closure financial provision, DWS accepts the risks associated with unforeseen events, provided that the impact prediction process complies with the requirements set out in this BPG and in **BPG G5: Water Management Aspects for Mine Closure**.*

The most basic risk assessment methodology is based on defining and understanding the three basic components of the risk, i.e. the source of the risk (source term), the pathway along which the risk propagates, and finally the target that experiences the risk (receptor).

*It needs to be recognized that **source terms** are mining features that are dynamic in nature and that exhibit a variable quality over time, due to changes in hydrology and to changes in the chemistry as sulphide minerals or neutralizing minerals become depleted or vary in reactivity, or as secondary minerals precipitate or redissolve as conditions change. An impact assessment that defines the source term as a static constant feature over time is unlikely to be realistic and would be inappropriate for anything other than the most basic screening level assessment.*

As with the source term, the first step in defining the pathway would be to take cognizance of the questions that need to be answered and to then construct a suitable detailed conceptual model that defines the various pathways of interest and the variables and factors that need to be considered when assessing these pathways. It will normally be important to understand which hydrological conditions will result in the worst case scenario for the receptor of interest and to understand the statistical frequency with which such scenarios could occur.

The critical receptor should be clearly defined in the conceptual model and should then be agreed upon with the affected parties and DWS before the risk assessment and impact prediction is undertaken. The agreement on the guidelines and quality objectives that should apply at the critical receptor must involve DWS officials in addition to other water users where appropriate.

Chapter 4 of the BPG provides very clear guidance on the methodology that should be followed in undertaking an impact prediction, together with points in the process where the external reviewer and DWS need to be consulted to reach agreement on key issues. This methodology is summarised in Figure 2 below.

Chapter 5 of the BPG is titled: "Key Impact Prediction Questions" and provides guidance on the type of questions that the impact prediction exercise should be able to answer during different life-cycle phases of the mine. Examples of key questions are the following:

What is the long-term impact of all waste residue deposits (fine and coarse waste) on the water resource (surface and groundwater) in terms of volumes and quality of drainage over the life of mine and post-closure?

What final rehabilitation should be undertaken for the different waste residue deposits in order to meet long-term risk management objectives for the water resource?

Will the mine void (pit or underground mine) decant after mine closure? If yes, where, when, how much and at what quality over time?

What are the drainage volumes and quality for all contaminants of concern for all source terms that pose a potential risk of impacting on the water resource – such profiles to show predictions at least 100 years into the future, or longer if longer periods are required to quantify the impact, as recommended by the specialist and agreed to by the independent reviewer and DWS.

What will the long-term impact be at the critical receptor for the contaminants of concern?

What additional water management (e.g. covers, infiltration reduction measures, etc.) or treatment measures need to be instituted to reduce the contaminant loads from the various source terms or to intercept the pathways in order to ensure that the critical receptor is not adversely impacted?

Finally, Chapter 7 of the BPG is titled: "Principles of Uncertainty" and provides guidance on understanding, describing and quantifying the uncertainties inherent in the impact prediction. Key statements on this topic are reproduced below.

It must be clearly understood that uncertainty is inherent in any prediction exercise and does not represent a fatal flaw with the methodology. Any future prediction of water impacts is based on assumptions about future rainfall, data values that are approximations of reality and tools that attempt to describe natural processes as *mathematical formulae. While it is accepted that uncertainty is inherent in any prediction, the important issue is that the specialist undertaking the prediction must be able to describe and define the uncertainty in the prediction, in order that margins of safety can be built into management options and/or financial provisions.*

Types of uncertainty mentioned in BPG G4 Chapter 7 include: sampling uncertainties; sample storage and preparation uncertainties; analytical uncertainties; assumption and estimate uncertainties; hydrological uncertainties; extrapolation uncertainties; mathematical modelling uncertainties; and model coupling uncertainties.

The BPG G4 also provides some discussion on the use of sensitivity analyses and probabilistic modelling as tools to defining uncertainty.

Finally, Chapter 7 has the following to say about the issue of defining acceptable confidence limits:

The definition of acceptable confidence limits and an acceptable degree of uncertainty is a difficult yet important task. From the regulator's perspective, the acceptable confidence limit refers to the mine closure situations where the objective of mine closure is to transfer risk and liability to the State. The confidence limits indicate the probability that the end result will be outside the boundaries defined in the impact prediction exercise, e.g. for a 90% confidence limit, the chance of the real life situation at a future date being outside the predicted boundaries is 10%. Once this has been defined, the appropriate margins of safety for developed management actions and financial provisions can be identified.

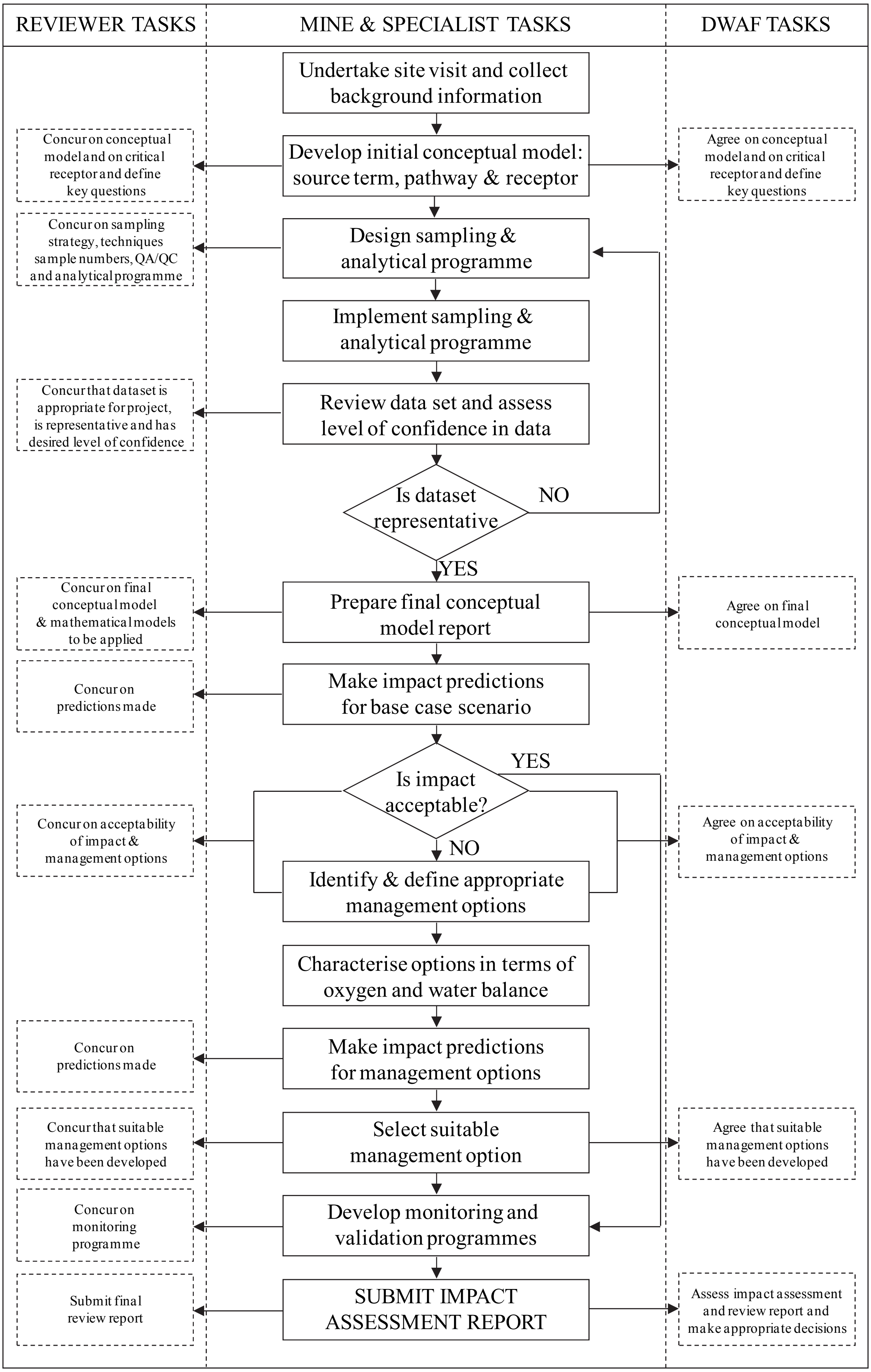

Figure 2: Impact Prediction Methodology and DWS/Reviewer Roles and Tasks

2.2 BPG G5: WATER MANAGEMENT ASPECTS FOR MINE CLOSURE

This BPG provides considerable detail on the methodologies and approach that should be followed to gain an understanding of the post-closure water management risks and how to make provision for managing these risks.

This BPG makes the following comments In Chapter 2 relating to risk assessment and risk issues:

2.2.1 Technical process principles

Risk-based approach

This implies consideration of several issues, including:

- *Demonstrable conservatism must be built into any assumptions that need to be made in lieu of appropriate data sets (precautionary principle). These assumptions should be clearly documented and motivated.*
- *A risk-based assessment should be undertaken by a suitably qualified person(s) with the necessary qualifications and experience to ensure the results are credible and unbiased. (**Suitably qualified and experienced person** is defined as person having a level of training and experience with the type of work to be done and recognised skills in the type of work to be done. **Prediction Specialist** is defined as a person with the requisite training, skill and expertise to participate in an impact prediction exercise and who is capable of signing a declaration of his expertise and ability to undertake the work in question and his/her willingness to subject him/herself to independent specialist review.)*
- *Wherever quantitative environmental risk assessments or impact predictions are made, the mine should, through prior consultation with the authorities, obtain agreement on the modelling techniques and tools to be used. This will ensure that such techniques are acceptable to the authorities, and that the results will be acceptable – see **BPG G4: Impact Prediction**.*
- *The surface residue deposits that remain after mine closure can never be maintained in a completely reducing environment and must be considered to pose a potential water related risk until shown otherwise by way of a suitable semi-quantitative or fully quantitative geochemical assessment – see **BPG A2: Water Management for Mine Residue Deposits**.*
- *Underground and opencast mine workings will fill up either partially or completely with water over time (slow or fast depending on geohydrological setting) and this water will be contaminated (either for a limited time or in perpetuity). A key element influencing the risk that these processes pose to the water resource is whether or not this contaminated water will decant into the underground aquifers or into the surface water resource and to what extent the natural water resource can assimilate this contamination. The mine workings must, therefore, be considered to pose a potential water related risk until shown otherwise by way of a suitable semi-quantitative or fully quantitative geohydrological and geochemical assessment – see **BPG A5: Water Management for Surface Mines** and **BPG A6: Water Management for Underground Mines**.*
- *In certain mining regions (e.g. near dolomitic compartments), mine dewatering activities and placement of surface residue deposits pose a long-term risk with regard to formation of sinkholes, which in turn pose safety, water resource and land use risks that need to be assessed.*
- *An understanding is required that mine closure is not about greening, but rather long-term pollution control and risk/hazard management. This involves consideration of a range of issues, and a range of possible management strategies.*
- *A risk-based approach includes a cradle to grave assessment on waste or waste streams, that is, from the point where they are generated, to their final disposal or reuse.*
- *Lastly, a risk-based approach will include the risk of failure of systems or management strategies. The consequences of such failure should be taken into account and the necessary contingency and/or emergency measures should be addressed either in the management measures and/or in the financial provisions.*

Communication and public participation

- *All interested and affected parties (IAPs) should be involved in the development of the risk-based strategy. While the timing and extent of this will vary from site to site, it is a key aspect that a risk communication component is included.*
- *Inherent in a risk based approach is that a clear paper trail is required so that others can understand the method whereby risks have been quantified. As indicated previously, all relevant assumptions should be documented.*

2.2.2 DWS decision-making process principles

The very nature of risk-based management actions and strategies is that there is always a risk that some unforeseen long-term pollution problem develops. The primary departure point that DWS will be bearing in mind when undertaking or reviewing a closure application for a mine site where water pollution is believed to be a potential risk element, is that approval and granting of closure poses an increased risk to the State (and therefore the citizens of South Africa) of attracting liabilities previously only attributable to the mine. It is the responsibility of the State (DWS and DMR) to ensure that the risk of unforeseen long-term water pollution problems arising after closure has been granted, is absolutely minimized, taking into account financial realities and practicalities and sustainability of water management measures.

In order to ensure that this risk is minimized to an acceptably low level, DWS will review a closure plan or closure application in terms of its compliance with the principles set out below.

1. *There must have been consultation and agreement with DWS (see authorisation levels in DWS operational guidelines) and other Stakeholders on closure objectives for the mine and the mine closure plan must have demonstrated that it complies with these agreed closure objectives.*
2. *There must be full disclosure by the mine of all the data, facts, assumptions and any other relevant information that will or could potentially have a bearing on the decision to approve or to reject the closure application. Failure to fully disclose such information could result in the automatic rejection of the closure application. Discovery of such failure to fully disclose after closure has been approved could result in DWS applying corrective measures in terms of Section 19 of the NWA.*
3. *The risk assessment and impact predictions (see **BPG G4: Impact Prediction**) must be fully documented in a comprehensive technical report that sets out the detailed methodology that must, as a minimum, include the following information:*
   - *detailed description of the objectives of the assessment and the technical questions that were set to be answered in the assessment*
   - *detailed conceptual model for the individual components (source terms) and the integrated facility for which closure is being applied and the manner in which it interacts with the environment (i.e. all relevant impact pathways and critical receptors);*
   - *full disclosure and documentation of all data and assumptions used, with all assumptions to be motivated and properly referenced – such references to be made available to the State upon request;*
   - *statement on the statistical representivity of the dataset and its suitability for addressing the issues that pertain to the particular closure application;*
   - *detailed description of sampling techniques applied, analytical techniques used, data assessment techniques used and mathematical models used;*
   - *discussion on how the issue of uncertainty in data and assessment techniques has been accounted for in the predictions on future environmental impact and what confidence can be placed in the predictions;*
   - *detailed definition of verification monitoring programme to collect data for future (typically 3-5 years after prediction was made) validation of predictions and, in the case of an actual closure application, the results of the validation exercise confirming the accuracy and reliability of the predictions of future impact.*

- *findings of all peer reviews done as part of the process (see **BPG G4: Impact Prediction** on the precise role and input required from an independent reviewer), as well as how the findings were addressed;*
- *detailed documentation of all IAP consultations and how these consultations have been incorporated into the closure process to demonstrate real commitment to IAP involvement;*
- *details of all post-closure impacts and management and maintenance measures that have been proposed to mitigate and manage such impacts to the point where they are within the limits set and agreed for the critical receptor(s);*
- *financial provision for construction, operation and maintenance of post-closure water management measures where required and for as long as predicted to be required; and*
- *third party involvement (if any) in post-closure and contractual agreements.*

4. *The study must be undertaken by suitably qualified persons using appropriate public-domain mathematical models and assessment techniques that are generally accepted in the scientific community as being suitable for the assessment being undertaken. While proprietary models can, with suitable motivation, be used for assessments undertaken by mines for non mine-closure situations, this is not the case where mine closure is being sought. The requirement for public domain models is to ensure that the performance of the model in undertaking the assessment at hand can be independently validated and that a suitably qualified third party could review the input files used and recreate the predictions independently, if deemed necessary. The procedures set out in **BPG G4: Impact Predictions** should be applied.*

In all cases, the closure application must be evaluated taking into account the site-specific circumstances and the sustainability of the management measures put in place to address the long-term (post closure) environmental impacts.

2.2.3 Key questions in the DWS decision-making process

From DWS's perspective, based on the realistic assumption that DWS will not have the in-house expertise to properly review a detailed and integrated impact prediction assessment that incorporates integration of numerous hydrological, geohydrological and especially geochemical modelling exercises, the key questions that must be answered when considering a mine closure plan and/or mine closure application, are the following:

1. *Does the assessment fully comply with **all** aspects of the independent review process as set out in **BPG G4: Impact Prediction**?*
2. *Does the closure plan consider all the relevant principles described in Section 2.1 and does it present all the information requested in Section 2.2 (of BPG G5) above in a clear written report and has all such information been verified by the appointed reviewer?*
3. *Has the assessment included clear evidence, supported by the independent reviewer, that all impact prediction assessments and models have been fully calibrated and validated using information collected from a verification monitoring programme?*
4. *Does DWS have written confirmation from the appointed reviewer that his/her review was undertaken independently, objectively, scientifically, without bias or favour to any party, that he/she was given full access to all information required to undertake the review and that he/she deems him/herself competent to have undertaken the review?*
5. *Does DWS have written confirmation, from a duly appointed representative of the mine's Board of Directors, that the mine closure application is based on full and complete disclosure of all information that could in any way be pertinent to the consideration of the mine closure application and that no potentially damaging information has been withheld?*
6. *Does DWS have confirmation, through an independent assessment by suitably qualified persons, that all the stipulated and agreed water management actions and measures (including any water treatment plants that may be required) have been properly implemented and that sufficient/adequate financial provisions have been made and that suitable contractual arrangements have been entered into with approved third parties to ensure that all the required operational, maintenance and financial measures*

will be implemented and audited for as long as has been predicted to be necessary to ensure that the agreed closure objectives are met?

Provided that a clear YES answer can be given to the abovementioned six questions, then DWS will be in a position to consider the mine closure plan and/or mine closure application and to make an informed and motivated decision that can be forwarded to the mining proponent and can then prepare a record of decision*.*

Importantly too, provided the above 6 questions have been answered with an unambiguous YES and provided that no future information comes to light that shows that the above questions were not truthfully answered, the approval of mine closure by DWS, will constitute an acceptance by DWS that it accepts any future risks associated with the closed mine and that it will not utilise the NWA to seek redress from the mining company. This undertaking falls away in the event that it comes to light that any of the 6 questions were not answered truthfully.

The risk that DWS is prepared to accept in approving a mine closure application is the risk of the genuinely unforeseen events. The principles and procedures set out above and in the remainder of this document are aimed at ensuring that the technically correct process is followed, that suitably qualified persons are engaged, that appropriate independent review procedures are followed and that there is full disclosure of all pertinent information. This process will then culminate in the development of appropriate management actions to address predicted post-closure impacts and the provision of appropriate financial resources to implement these actions (i.e. polluter pays principle). ***However, it is accepted that, despite following the above mentioned procedures, the possibility exists that some unforeseen event could occur which results in a greater post-closure impact than that which was predicted. In such a case, provided the procedures in this BPG have been followed and there was full disclosure of all relevant information by the mine at the time of the closure application, then DWS accepts the risk and responsibility of managing such unforeseen impact.***

2.2.4 Financial provisions for post-closure water management

Finally, Chapter 8 of BPG G5 makes a number of key statements relating to risk and the need for financial provisions for post-closure water management. Chapter 8 of BPG G5 is reproduced in its entirety below.

In many mine closure situations, there is a risk of an unacceptable post-closure risk to the water resource, as determined by an appropriate risk assessment and impact prediction (see ***BPG G4: Impact Prediction****). In such situations, there will be a need to determine the financial provisions required to fund both the capital cost of appropriate water management measures and the operating costs associated therewith. In cases where the water management measures are required for a number of decades, provision may also be required to reconstruct the appropriate measures after their design life has been exceeded.*

While the DMR has prepared a guideline for determining financial provisions, there is no standardized formula or factor that can be applied to determining what the financial provisions for water management should be, as each mine site will have very site specific requirements. The generic approach that would underpin the determination of the water management financial provisions is as follows:

1. *Determine objectives for the water resource (i.e. set acceptable levels of impact or risk to the identified critical receptor) that the mine would need to meet on closure.*
2. *Undertake a quantitative risk assessment and impact prediction exercise (see* ***BPG G4: Impact Prediction****) for the base case situation (application of standard minimum best practice measures) and determine whether or not the water management closure objectives would be met.*
3. *If not, undertake a second round of quantitative assessments (see* ***BPG G4: Impact Prediction****) for a range of defined and agreed alternative management measures (give preference to pollution prevention and passive measures with minimum long-term maintenance requirements – see* ***BPG H2: Pollution Prevention and Minimisation of Impacts****) and determine whether any of these options meet the agreed water management closure objectives. If an option can be identified that meets the closure*

objectives, determine the capital and operating costs for that management option and include it into the mine's financial provisions.

4. *If, even after application of an appropriate water management option, the agreed water management closure objectives are not met, then provision must be made for interception of the source of water contamination (diffuse and point sources) and treatment of the intercepted water in order that the closure objectives can be met – see **BPG H4: Water Treatment**.*
5. *The duration of the required water treatment measures will depend on the outcome of the quantitative impact assessment that is undertaken and will need to coincide with the duration over which the closure objectives will not be met. An example is shown in Figure 3 below.*
6. *Determine the capital and operating costs for the full period over which the water treatment needs to be applied and incorporate this into the closure financial provisions.*

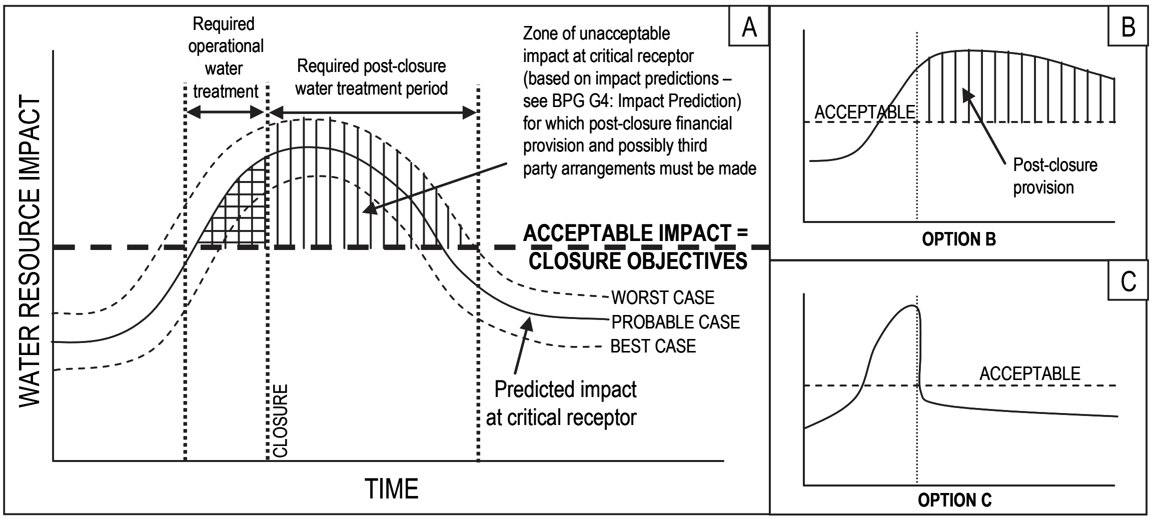

Figure 3: Potential for post-closure water treatment financial provision

*The assessments that need to be undertaken to determine the need for water management and/or water treatment measures would need to be undertaken in full compliance with the procedures set out in **BPG G4: Impact Prediction**. In particular, it will be necessary to ensure that the peer review process specified for mine closure-related assessments is complied with and that the specialist team undertaking the assessments incorporate persons with the appropriate skills and expertise in water management and treatment options.*

With the scarcity of water in South Africa and the future implementation of the Waste Discharge Charge System, mine closure management options that result in the interception and evaporation of contaminated water are not acceptable, and management measures should be implemented to eliminate this water use. The worst case scenario is that the intercepted water will need to be pumped to a water treatment plant and treated and provision for this eventuality must then be incorporated into the mine closure financial provisions. In cases where there are regional interconnections between mines, or there is a combined impact or use of a combined water treatment plant an apportionment of financial liability for any cumulative or combined water treatment need must be made to the satisfaction of the regulatory authorities.

*Where the need for water management and treatment actions is envisaged after mine closure, appropriate arrangements must be made for financing and managing the water management/water treatment operations for the designated period of time (in terms of the MPRDA and various regulations defined in R527) after mine closure. In this scenario, and as shown schematically in Figure 1 A above, the financial provision must cater for the possibility that the worst case scenario (as determined by probabilistic modelling – see **BPG G4: Impact Prediction**) may develop. It may also be necessary to enter into contractual arrangements with approved third parties (as provided for in the MPRDA). Other examples of impact predictions are shown in*

Figure 1 B and 1 C where perpetual and no post-closure water treatment requirements are shown as examples.

2.3 SUMMARY OF KEY ISSUES RAISED IN BPGS

Review of the extracts form BPG G4 and G5 which have been reproduced in Sections 2.1 and 2.2 above, indicate that there are a number of key issues that need to be explored and clarified to ensure that there is no ambiguity with regard to the requirements for mine closure. It is also clear that application of the risk-based approach to impact prediction requires the mine to reach agreement with DWS (and often with broader stakeholders too) on the following key issues:

1. The conceptual model that is being proposed as being appropriate for the risk assessment and impact prediction from the particular mine site.
2. The tools that will be used for site characterisation and for predictive modelling of source terms, pathways and effects on receptors.
3. Location of critical receptor(s) and what the acceptable water quality criteria for these receptors should be.
4. Assurance that demonstrable conservatism has been built in where assumptions are made in lieu of actual data.
5. Statistical representivity of data sets
6. That suitably qualified persons are undertaking the assessment and the review.
7. The key questions that need to be answered in the impact prediction exercise.
8. Agreeing on what the "foreseen risks" are.
9. The confidence limits that are deemed to be acceptable to the particular situation being assessed by way of defining and describing uncertainties in the assessment process.
10. Need to incorporate the risk of failure of systems

With regard to the issue of post-closure water treatment, the BPG G5 requirements can be summarised as follows:

11. A prescribed risk assessment process must be followed (as set out in BPG4)
12. Interception and evaporation of discharges is not a preferred option.
13. The possibility of regional interactions and the need for regional water management/treatment options must be considered.
14. Where post-closure water treatment is required, the extent of treatment must be determined using probabilistic modelling and must cater for the worst case scenario.

Points 1-9, 11 and 14 are all related to following the correct risk assessment and impact prediction process as using the correct process will automatically ensure that all these issues are addressed. Point 10 is a statement that needs to be addressed and agreement needs to be reached with DWS as to what failure events need to be catered for. Point 12 is a policy statement and Point 13 is a practical issue that needs to be addressed within the broader context of regional closure strategies.

CHAPTER 3: DEFINITION OF KEY TECHNICAL AND PHILOSOPHICAL ISSUES

3.1 DEFINITION OF TECHNICAL ISSUES

In essence, this research project aims to technical/procedural solution to the issue of post-closure water management risks that would meet the concerns of the various roleplayers and stakeholders that have an interest in post-closure water management issues on how issues of risk and uncertainty regarding post-closure water management impacts are determined, agreed upon and financially provided for. In this process, it is recognised that the key stakeholders are the mining industry, consultants who undertake impact predictions, regulators (primarily DWS and DMR) and representatives of the general public.

The desired outcome of the research project is clearly captured in the following problem statement made in the project proposal:

DWS officials are required to provide guidance and decision making with regard to the following key technical issues in the impact prediction and closure application process:

1. *agreement on the acceptable levels of confidence for the prediction that will limit the State's liability to acceptable levels;*
2. *agreement on the statistical representivity of the datasets used in the prediction and their suitability for addressing the issues that pertain to the particular closure application;*
3. *agreement on the definition and descriptions of uncertainty inherent in the predictions and acceptance that the defined uncertainty meets the requirements of the regulator; and*
4. *agreement on the suitability and adequacy of financial provisions to cater for uncertainties and risks for post-closure water management and treatment*

Point 1 will be addressed if the process described in BPG G4 is fully complied with and, most importantly, once data has been tabled to demonstrate that the recommended model verification and calibration procedures have been undertaken. The solution to this dilemma lies in following the scientifically correct process and not through arbitrary stipulation of a number such as 90% confidence limit. The correct approach is to present a thorough technical report that clearly demonstrates compliance with the technical procedures set out in BPG G4 and the additional clarification on key technical points provided in this document.

Point 2 will be addressed if the mining proponent complies with the requirements set out in BPG G4 and in the literature review on how the geochemical assessment and predictive modelling toolboxes should be used. Specific guidance needs to be provided on the correct procedure that should be followed to determine the statistical confidence that can be placed in the collected data and to confirm that the correct sampling density has been undertaken to account for variability in measured parameters.

Point 3 will be addressed by ensuring that the mining proponent follows the prescribed rigorous assessment procedure set out in BPG G4 and G5 which is based on international best practice and which, if followed properly, will give the assurance that the risk of a flawed prediction and flawed conclusions is negligible. The external review throughout the process is a key component of this assurance. Additional discussions on sources of uncertainty and recommendations on how to define and limit this uncertainty is provided in the attached literature review.

Point 4 will also be addressed by demonstrating compliance with the procedures set out in BPG G4 together with BPG G5.

3.2 DEFINITION OF PHILOSOPHICAL ISSUES

Despite the existence of BPG G4 and BPG G5, a stalemate "chicken and egg" situation exists in South Africa where mines are unable to obtain mine closure because of perceived unknown/unmanageable post-closure risks to the water resource. This is a complex problem with causative factors originating from both the mining industry and the regulator. There is a definite need to unlock this stalemate as its continuation is bad for all parties concerned. The onus rests on the regulator to make the necessary policy and/or regulatory shifts to provide clarity on what is required for mine closure to be approved while at the same time ensuring that it fulfils its mandate of protecting the national water resource.

While it may at first glance be considered intuitively correct for regulators and potentially impacted stakeholders to insist that mine closure should not be approved unless it can be demonstrated that there is zero risk that there will be long-term residual impacts on the water resource, this logic is flawed for a number of reasons:

1. Zero risk can never be demonstrated and proved in advance and this approach will unavoidably lead to a situation where mine closure is never approved;
2. In circumstances where mine owners are reasonably convinced that mine closure will never be approved no matter what measures they implement, there is simply no incentive to spend limited financial resources to take any pro-active measures towards minimising long-term risks to the water resource and the most appropriate course of action is generally perceived to be to do the minimum and wait;
3. In circumstances where the regulator has poor or limited capacity to ensure that mines do take all the necessary pro-active measures towards minimising long-term risks to the water resource, mine owners have limited incentives, beyond adherence to corporate ethical principles, to implement such measures; and
4. In circumstances where the regulator has limited technical capacity to properly review scientifically complex assessments and predictions of future risk, the regulator is inclined to avoid making decisions on these assessments and consequently mine owners have little incentive to incur the costs associated with undertaking and submitting these complex and costly assessments.

If the above four statements are true then a "stalemate" status quo situation will exist where mine owners do not develop and submit rigorous closure plans with regard to water management issues, where regulators do not approve mine closure plans and where mines that have ceased operations only implement minimum-level care and maintenance measures until such time as financial resources are exhausted and the mine reverts to an abandoned and ownerless status.

Alternatively mines may expend their limited financial resources allocated to closure and post-closure management to implement measures that they believe are correct, without ever evaluating the long-term post-closure risks of these measures to the water resource in a rigorous manner that satisfies the information needs of the State and other stakeholders, thereby running the risk that their limited funds become exhausted while the residual post-closure risk is still higher than that required to approve mine closure, once again leading to the abandoned and ownerless status.

Perpetuation of a status quo stalemate situation where mines do not undertake and submit the correct scientific assessments of post-closure risk because of a perception that they will never be approved by the regulator, or where the regulator is unwilling to approve a suitable post closure risk assessment because of either a lack of confidence in its own ability to make a correct decision regarding the validity of the assessment, or because the regulator is striving to enforce a zero risk option, is undesirable and poses a risk to all stakeholders and future taxpayers in South Africa. The risk to stakeholders and taxpayers is that removal of all incentives (positive or negative) for mine owners to take the necessary proactive measures to minimise post-closure risks to the water resource often leads to no actions being taken at all and places the mines in question at risk of eventually becoming abandoned and ownerless mines that become the de-facto responsibility of the state and its taxpayers.

The objective of this document is to define the technical aspects and procedures that need to be followed in order for mines to be able to manage and minimise their long term risks and liabilities and to provide the State (the regulator) with the requisite information to be able to review and approve a post-closure water management plan. The development of these technical aspects and procedures is based on the literature review of international practice, the existing Best Practice Guidelines and the application of sound scientific principles. It is furthermore assumed that all stakeholders (mine owners, regulators and the general public) agree that the previously defined stalemate status quo is undesirable, that generation of additional abandoned and ownerless mines is undesirable and that the responsibility lies with the mines for implementation of the correct management measures to minimise the risk of post-closure water management impacts.

CHAPTER 4: RECENT MINE CLOSURE-RELATED REGULATORY DEVELOPMENTS

A number of important regulatory developments occurred in 2014 that have a direct bearing on the mine closure process and the key principles that underpin BPGs G4 and G5, which have been viewed throughout this research project as the guidance documents for mine closure. In summary, the recent developments directly challenge the BPG statements that mines will be able to achieve "walk-away" closure where the risk and liability of unforeseen impacts on the water resource are accepted to be the State's responsibility. The key principles and assumptions that underpin the approach set out and described in the DWS BPGs are as follows:

1. Any mine can achieve "walk-away" closure (where the risk of unforeseen impacts and the liability associated with the management of such impacts, is accepted by the State), provided it can demonstrate, to the satisfaction of DWS, that all the key procedural requirements set out in the BPGs have been addressed.
2. Independent review has been integrated throughout the mine closure planning process in full compliance with the procedures set out in BPG G4 and G5, in order to give the appropriate authorised DWS officials reviewing the post-closure water management plan, confidence in the credibility of the plan.
3. The DWS does not and will not have the in-house expertise to assess the technical accuracy/adequacy of the assessment and will therefore need to rely on the independent reviewer to perform this technical function. The role of the DWS is to ensure, with the assistance of the independent reviewer, that the correct procedure has been followed and that the questions set out in Section 2.2.3 above have all been correctly answered.

At this stage, it would appear that the above principles and assumptions are not valid for the following reasons:

1. The National Water Amendment Act (Act 27 of 2014) did not make any changes to the existing Section 19 of the National Water Act (or any other pertinent sections) in order to bring into effect the principles embodied in the BPGs G4and G5 which would have made it legally possible for mines to obtain approval from DWS for a post-closure water management plan and thereby be relieved of future liabilities and responsibilities in terms of the Act for unforeseen impacts.
2. DWS is not adhering to the principles and procedures set out in BPG G4 and G5 when reviewing post closure water management plans (submitted as part of a mine closure plan) and is not ensuring that the critical independent review process is being applied as per the BPGs.
3. DWS is not adhering to its own Operational Guideline M5.0 (1998) which clearly states in Chapter 8 that the recommendation for approval of closure plans for all Category A mines resides with the National DWS office and in particular with the Director: Water Quality Management. In fact, it appears that consideration of and decisions relating to mine closure plans are being taken at regional level, although the technical expertise to assess compliance with all aspects of BPG G4 and G5 clearly does not exist at regional level.
4. The MPRDA as amended in terms of the MPRDA Amendment Bill, 2013, enables the DMR to retain a portion of the mine's financial provision for a period of 20 years after issuing the mine closure certificate and such a provision is certainly not in support of the concept of a "walk-away" closure.
5. In terms of Section 24R of the NEMA (amended in terms of the NEMAA and the NEMLAA) a mine will remain responsible for all impacts (including future unforeseen impacts) even after a closure certificate has been issued.

CHAPTER 5: STAKEHOLDER WORKSHOPS

5.1 FIRST STAKEHOLDER WORKSHOP

A first workshop on post-closure water management risk management was held with a wide range of Stakeholders on 24 October 2014. Invitations were sent to a total of 71 persons, as follows:

- Water Research Commission: 1 person
- WRC Project Reference Group: 1 person (all other reference group members were invited in capacity as industry or regulator)
- Golder Associates: 3 persons
- Environmental lawyer: 2 persons
- Chamber of Mines: 4 persons
- Gold mining sector: 7 persons
- Coal mining sector: 11 persons
- Platinum mining sector: 7 persons
- Other mining sectors: 5 persons
- Department Water and Sanitation: 13 persons
- Department Mineral Resources: 10 persons
- Department Environment Affairs: 7 persons

A total of 22 persons attended the workshop, as follows:

- Water Research Commission: 1 person
- WRC Project Reference Group: 0 persons
- Golder Associates: 2 persons
- Environmental lawyer: 2 persons
- Chamber of Mines: 3 persons
- Gold mining sector: 4 persons
- Coal mining sector: 3 persons
- Platinum mining sector: 4 persons
- Other mining sectors: 0 persons
- Department Water and Sanitation: 4 persons
- Department Mineral Resources: 0 persons
- Department Environment Affairs: 0 persons

Background presentations on the project, the BPGs G4 and G5, the regulatory framework and recent developments that relate to mine closure were made to set the scene for the workshop. Discussion at the workshop was structured to discuss and address the following 5 questions:

1. Obtain clarity on role of different government departments (DMR/DWS/DEA) in terms of review and approval of plans that relate to post-closure management of water impacts from mines.
2. Obtain clarity on what the term “closure” means with respect to post-closure water management impacts and liabilities.
3. Is “walk-away” closure at all possible or desirable in terms of SA environmental legislation and principles?
4. If not, what management objective must mines have when planning for post-closure water management?
5. What is the role of regional post-closure water management planning?

5.1.1 Role of government departments in review and approval of post-closure water management plans

This issue was debated at some length and the following key points were highlighted:

1. It was generally agreed that it was sensible and appropriate that the DMR be the lead agent with regard to handling the complete mine closure application process, particularly given the future situation where the DMR will administer the MPRDA, Waste Act and NEMA with regard to the mining sector.
2. It was also agreed that the mine closure plan should include a separately definable post-closure water management plan that dealt specifically with the post-closure water management issues and that this component of the mine closure plan should be sent to DWS exclusively for their review and approval. DMR should then be obligated to accept and implement the outcome of the decision made by DWS without further input or modification.
3. Whereas the current practice is to review mine closure applications at DWS Regional office levels with consultation with Head Office, it was agreed that this function should revert to Head Office as per the M5.0 Guideline.
4. It was agreed that the DWS should be the Department that reviews and approves the post-closure financing for water treatment and water management.
5. It was agreed that there was a need for regulations that clearly define what is required from mines with regard to post-closure water management planning.
6. It was also stated that issues regarding water use charges in the post-closure situation need to be considered by DWS and that guidance on this issue is required in order that this aspect can be considered when determining post-closure water management financial provisions.

5.1.2 The relevance of the concept of mine closure

It was agreed that Questions 2, 3 and 4 should be discussed concurrently and the outcome of these discussions can be summarised as follows:

1. The general feeling from the mining representatives was that with the current regulatory framework, closure was an unattainable concept.
2. It was also felt that in a situation where mines can be held accountable for truly unforeseen impacts, even after the correct process was followed and the post-closure water management plan was approved by DWS, and where a portion of the mine's financial provisions can be retained after approval of closure, that such approved closure had limited practical value and that mine closure was a redundant concept.
3. The only value of obtaining mine closure in such a situation would be to "tick the box" with regard to that specific legal requirement in compliance with corporate governance guidelines.
4. It was considered unlikely by the stakeholders at the workshop that the legal and regulatory framework that governs mine closure would be amended in future to make provision for the concept of walk-away closure as was described and envisaged in BPG G5.
5. It was therefore agreed that the post- closure water management planning process should be viewed by the mine less as an exercise of legal compliance and more as an exercise whereby mines should endeavour to manage and minimise their long-term risks of being held financially liable for water management impacts.
6. It was agreed that this risk can best be managed by following a robust and scientifically and technically valid process such as was described in BPGs G4 and G5. In this regard it was also confirmed that the literature review conducted as part of this WRC project had confirmed that the process as described and set out in BPGs G4 and G5 was aligned with international practice.
7. It was agreed that in order to ensure that the risk of today's current mining operations becoming tomorrow's abandoned and ownerless mines, that DWS did have an important role to play in ensuring that the correct procedures (as set out in BPG G4 and G5) are consistently implemented at all mines, irrespective of size or location.
8. It was emphasized that there was need both within the mining industry and the DWS to reconfirm the value of the BPGs and to ensure that all persons involved with post-closure water management were adequately trained in the application of the processes described in the BPGs.
9. It was also pointed out that in the situation where mines are sold from one owner to a new owner, that thorough review of the post-closure water management liabilities should be undertaken to the satisfaction of DWS and that measures should be put in place to ensure that appropriate financial provision for dealing with the assessed liabilities is put in place and reserved for the exclusive use of addressing those assessed liabilities. The role of DWS and DMR in ensuring that the financial provision

for the post-closure water management liabilities is properly applied by the new mine owner after the sale had taken place was emphasized.

10. It is acknowledged that there is currently no guidance or prescription on how a post-closure water management liability should be assessed, quantified and financially provided for.

5.1.3 The role of regional post-closure water management planning

This issue was debated at some length and the following key points were highlighted:

1. It was confirmed that the primary reason for requiring regional closure planning was to deal with the water management issues of mines that are hydraulically interconnected, i.e. the primary driver is a water management one. Care needs to be taken to ensure that this primary water management driver remains the focus of these regional strategies and is used as the basis to define the geographic boundaries for the regional strategies.
2. It was agreed that DWS should be the lead agent with regard to facilitating the development and implementation of regional post-closure water management strategies and that the DWS should be the long-term custodians of the various regional post-closure water management strategies.
3. It was agreed that as the mines were the parties that would have to manage the regional post-closure water management strategies and would bear the consequences of the strategies, that they should therefore be the parties developing the strategies, albeit with the active support and participation of the DWS. The potential value of involving the Chamber of Mines as a third party in the development and long-term implementation of such strategies was also discussed.
4. It was agreed that the DWS should develop regulatory mechanisms to force all mines to participate in the development of their respective regional post-closure water management strategies. One option would be to make active participation in the development of a regional post-closure water management strategy a condition in the mine’s water use licence. This could be done by amending existing licences and incorporating these provisions in all future new licences.
5. The need for the State to actively participate in the development of the regional post-closure water management strategies in areas where there were defunct, abandoned and ownerless mines was highlighted.

5.1.4 Summary of workshop outcome

In summary, the key points agreed to at the workshop can be stated as follows:

1. While DMR is accepted as the most appropriate lead agent for the overall mine closure review and approval process, it was agreed that a separate identifiable post-closure water management plan, which would form part of the overall mine closure plan, should be exclusively reviewed by DWS at Head Office level and that the DWS decision should be binding and implemented by DMR without modification.
2. In the absence of the ability of mines to achieve “walk-away” mine closure, the concept of mine closure becomes meaningless and serves only to “tick the box” for legal compliance.
3. The post-closure water management planning process is viewed by the mining industry as a process that should be undertaken with the primary objective of addressing and managing their risk to long-term post-closure water management liabilities. This implies that the real “client” for the post-closure water management planning process is the mine itself rather than the regulator.
4. It was agreed that the risk-based process be applied for the development of a post-closure water management plan, in accordance with the procedures set out in BPGs G4 and G5 and confirmed to be aligned with international best practice by the project literature review.
5. The regulator (DWS) has an important role to play to ensure that all mines, irrespective of size, ownership and/or location, follow the risk management approach as set out in BPGs G4 and G5 in order to ensure that the risk of current mining operations becoming tomorrow’s abandoned and ownerless mines is minimised.
6. Mines should play the leading role in the development of regional post-closure water management strategies, together with the active participation of the DWS and/or Chamber of Mines as institutions that could become the long-term custodians of these regional strategies.

5.2 SECOND STAKEHOLDER WORKSHOP

A second workshop on post-closure water management risk management was held with a wide range of Stakeholders on 23 January 2015. Invitations were sent to a total of 75 persons in November 2014 with follow-up invitations in December 2014 and in January 2015. The affiliation of the invited persons was apportioned as follows:

- Water Research Commission: 1 person
- WRC Project Reference Group: 1 person (all other reference group members were invited in capacity as industry or regulator)
- Golder Associates: 2 persons
- Environmental lawyer: 2 persons
- Chamber of Mines: 4 persons
- Gold mining sector: 8 persons
- Coal mining sector: 13 persons
- Platinum mining sector: 9 persons
- Other mining sectors: 3 persons
- Department Water and Sanitation: 12 persons
- Department Mineral Resources: 11 persons
- Department Environment Affairs: 9 persons

A total of 23 persons attended the workshop, apportioned as follows:

- Water Research Commission: 1 person
- WRC Project Reference Group: 1 person
- Golder Associates: 2 persons
- Environmental lawyer: 2 persons
- Chamber of Mines: 3 persons
- Gold mining sector: 1 person
- Coal mining sector: 4 persons
- Platinum mining sector: 4 persons
- Other mining sectors: 0 persons
- Department Water and Sanitation: 6 persons
- Department Mineral Resources: 0 persons
- Department Environment Affairs: 0 persons

Extensive discussions were held at this workshop regarding the draft final report and the comments and recommendations made at this workshop have been considered and incorporated, where possible, into this final project report.

CHAPTER 6: THE DESIRED RISK ASSESSMENT FRAMEWORK

The conclusions of the literature review (complete literature review is attached as Annexure A) previously undertaken can be summarised as follows:

1. The evaluation and prediction of post-closure water management impacts and the identification of appropriate management measures that should be implemented to address these impacts must be based on the classical risk assessment process.
2. Successful management of post-closure water management impacts and risks is based on rigorous implementation of a correct specified process and not through compliance with some arbitrary definition of what constitutes an acceptable risk.
3. Successful management of post-closure water management impacts and risks will require unique solutions for each mine that result from the rigorous application of a universally valid process.
4. The risk assessment process must be transparent and must demonstrably address the key questions and concerns of affected stakeholders.
5. All risk assessment and impact prediction exercises have inherent uncertainty but this acknowledgement of uncertainty is not a flaw in the process, it simply requires that this uncertainty be understood and defined and that it be catered for in the development of management measures to deal with post-closure water management impacts.
6. The Best Practice Guidelines G4: Impact Prediction and G5: Water Management Aspects for Mine Closure do contain and describe the correct process that should be followed to ensure that post-closure water management risks are properly understood and addressed.

While various risk assessment models and frameworks exist and a number of these were discussed in the literature review, most approaches have common elements that are best captured in the family of standards relating to risk management that have been codified by the International Organisation for Standardization (ISO) and issued as ISO 31000.

The key requirements of a good risk assessment have been defined as the following:

- Transparency in data and models (ability to replicate)
- Rigorous expert peer reviews
- Opportunity for stakeholder comment and explicit response to those comments
- Responsiveness to informational needs of the regulator

All these requirements are incorporated into the closure planning and impact prediction methodology set out in BPG G4 and G5.

6.1 RISK ASSESSMENT/MANAGEMENT PROCESS IN TERMS OF ISO 31000

The International Organization for Standardization (ISO) is a worldwide federation of national standards bodies. ISO prepared its 31000 standard, “Risk Management – Principles and Guidelines” (ISO, 2009) and supporting standards in recognition that all types of organizations need to address factors and uncertainties that challenge their objectives (i.e. risks). This risk management framework is the context within which the impact prediction and closure planning process should be undertaken. The principles shown in the Figure below are principles that resonate with those presented in the BPGs. The risk assessment process is also aligned with that described in the BPGs and the steps shown in the process below can be considered to be equivalent to the BPG Impact Assessment process as follows:

Establish the context = define impact assessment /closure objectives

Risk Identification = define the questions that need to be answered in the impact assessment

Risk Analyses = undertake the impact prediction (develop conceptual model; design and implement site characterisation process; select prediction code; define code input parameters; undertake predictions; produce results)

Risk Evaluation = assess outcome of impact prediction and decide which risk mitigation measures should be implemented

Risk Treatment = implementation of risk mitigation measures

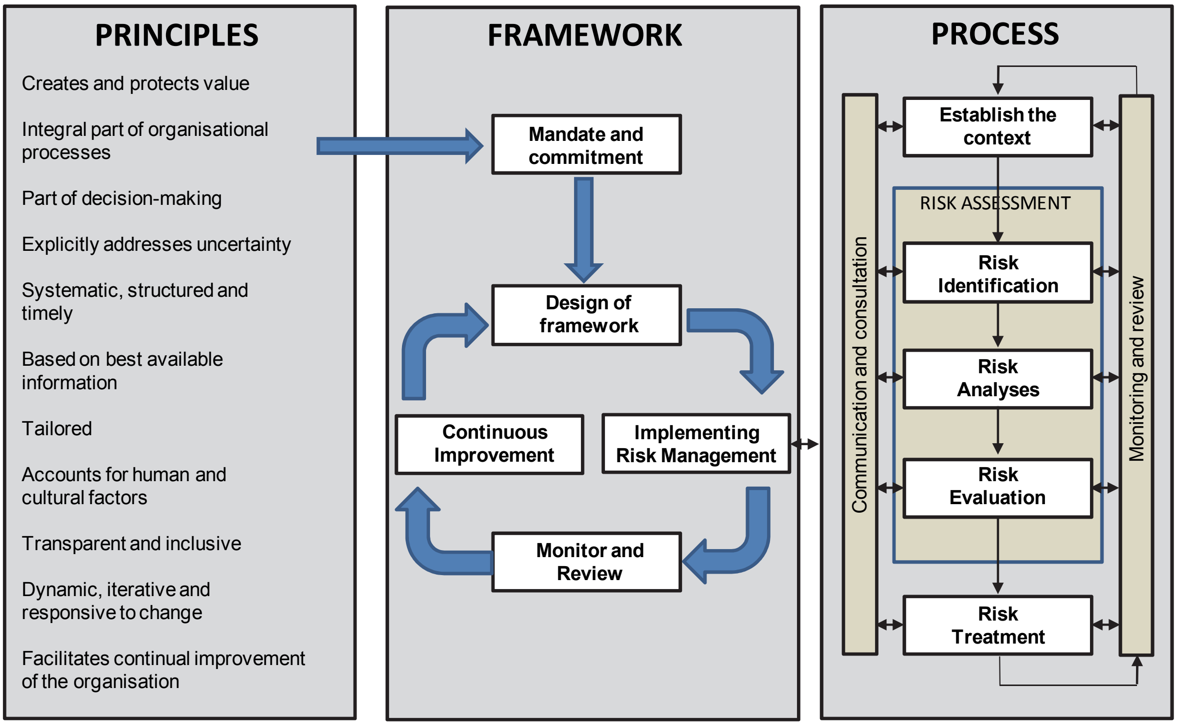

Figure 4: ISO Risk Framework

The ISO 31000 risk management framework is also adopted by the Australian Government (2006) in its recommendation on how mine closure planning should be undertaken.

6.2 WHAT IS AN ACCEPTABLE RISK?

There are a number of approaches that could be followed to determine when an assessed risk is acceptable and when it is not and mitigation measures should be considered. The different approaches range from imposition of arbitrary limits, economic cost-benefit assessments to political decisions (Hunter and Fewtrell, 2001).

The general consensus in the literature is that the "acceptability" of a risk is a judgement decision properly made by those exposed to the hazard or their designated health officials. It is not a scientifically derived value or a decision made by outsiders to the process (Kelly, 1991). Kelly, 1991 concludes with the following statement:

"The solution to developing better criteria for environmental contaminants is not to adopt arbitrary thresholds of "acceptable risk" in an attempt to manage the public's perception of risk, or develop oversimplified tools for enforcement of risk assessment. Rather, the solution is to standardize the ***process*** *by which risks are assessed and to undertake efforts to narrow the gap between the public's understanding of actual versus perceived risk."*

This approach is consistent with the methodologies set out in the DWS BPG G4 and G5 where the emphasis is placed on developing a rigorous *process* and methodology that must be followed in undertaking a mine closure assessment.

CHAPTER 7: MINE CLOSURE OBJECTIVES AND IMPACT PREDICTION QUESTIONS

7.1 BACKGROUND

Mine closure is essentially about rehabilitating the mine to a point where the regulatory authorities are willing to sign off on a mine closure approval and thereafter, the risk essentially passes to the State. As a consequence, in many countries, the procedures applied in mine closure are increasingly aligned with best practice principles. The global mining industry has already reached a consensus concerning restoration of mining areas to a stable environmental state, physically, chemically and ecologically, so as to minimise potential environmental and health risks.

The derivation of the appropriate questions that need to be answered in a closure impact prediction exercise must derive from an understanding of what the objectives of the mine closure process are. While there are many different ways of stating these objectives and while it is also necessary to formulate site-specific closure objectives that take account of site-specific conditions, the objectives of closure planning can generically be stated as follows:

- To reduce or eliminate adverse environmental effects once the mine ceases operations
- To establish physical and biological conditions which meet regulatory requirements
- To ensure the closed mine does not pose an unacceptable risk to public health and safety

7.2 STAKEHOLDERS IN SETTING CLOSURE OBJECTIVES

There are a number of stakeholders that have a legitimate claim to being involved in the setting of mine closure objectives. It has been recommended that the number of stakeholders should be kept relatively small to remain focussed and effective and may include representation from the following groups as appropriate:

- Local community
- Organised labour
- Government agencies
- Non-government organisations

7.3 THE MINING LIFE CYCLE

While the mining life cycle can be divided into different phases in different ways, the following definition of life-cycle phases is used in this document:

1. Exploration and prospecting
2. Mine planning (ranging from pre-feasibility through to detailed and final planning)
3. Construction and commissioning
4. Mining operations
5. Last five years of mining operations before planned mine closure
6. Mine decommissioning (ending with approval of mine closure by regulators)
7. Post-closure management

While it is obvious that closure-related considerations become more important as mines progress along the life cycle path towards mine closure, there are in fact, mine closure considerations that need to be considered during most of the abovementioned life cycle phases as described in the following section.

7.4 KEY QUESTIONS RELATING TO WATER MANAGEMENT AND MINE CLOSURE

The correct definition of key questions that need to be asked and answered in the mine closure planning process with regard to water management issues is critical. The formulation of the questions defines the manner in which the conceptual model is defined, how the site characterization programme should be designed and implemented and the type of impact prediction codes that need to be used. The questions that will be asked in South Africa will often be very different to those asked in other countries as the questions must take account of the particular regulatory approach in the country. Whereas many mining countries are primarily interested in whether or not acidic conditions will develop with their associated elevated metal concentrations, South African regulators also have a need to determine water quality in a broader context (e.g. sulphate levels, sodium levels, etc.).

A key principle in deciding when a mining activity should trigger closure-related questions, impact predictions and assessments is the longevity of the action in question. It is proposed that whenever an action is contemplated that will have effects that will persist till mine closure and beyond closure, such actions should be preceded by a risk assessment process that aims to quantify the potential long-term risks and impacts of such an action (together with alternative actions that could achieve a similar desired outcome for the mine) with the aim of identifying and implementing that action that has the most beneficial long-term risk (and cost) profile. This principle is, in essence, aligned with the principles of maximising pollution prevention opportunities, minimising life-cycle costs of actions, and adoption of the precautionary principle in the absence of reliable data.

A key principle underpinning this approach is that mine closure planning is about using the risk assessment and impact prediction process as a management decision tool to provide the information that can be used to consciously choose the best option for any action that will have an impact beyond mine closure. This means that mine closure planning and the impact prediction methodology should not only be seen as tools to predict the long-term consequences of past actions, but that their application should be viewed as a proactive means of reducing post-closure risk and costs. This approach can be applied to maximum benefit for new mines that are in the planning phase, but opportunities do also exist for existing mines that are already in an advanced stage of the overall mine life cycle.

The key questions that have been developed for each of the mine life-cycle phases are shown in the figure below (this figure is shown at a larger scale in Annexure B).

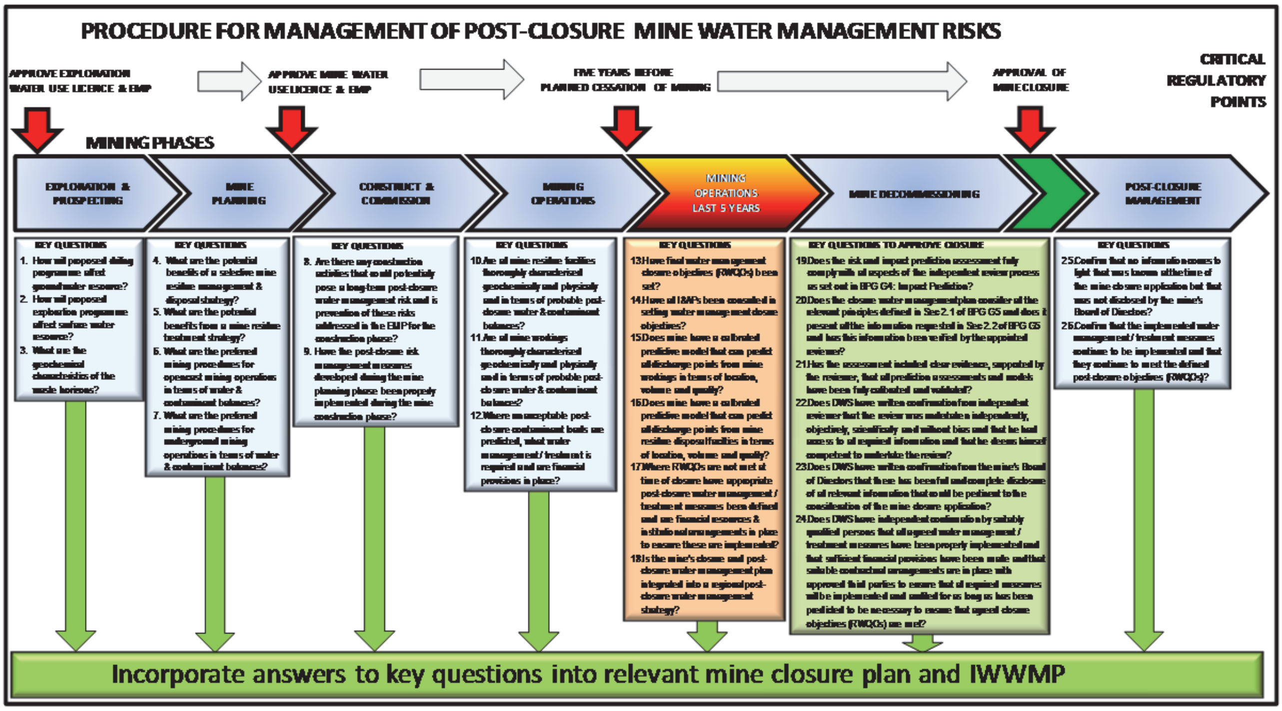

Figure 5: Key Post-Closure Water Management Questions for each Phase of the Mine Life Cycle

7.4.1 Key questions in the exploration and prospecting phase

It needs to be recognised that there are a number of closure-related issues that need to be considered in the exploration and prospecting phase of a mine if the post-closure risk to the water resource is to be minimised. Key questions that should be asked and answered by way of an appropriate risk assessment and impact prediction exercise are the following:

1. **How will the proposed drilling programme affect the integrity of the groundwater resources in the area where prospecting and exploration is intended to take place?** This question should be answered by developing an appropriate conceptual groundwater model of the area before any drilling commences, using this conceptual model to guide the drilling programme, defining data that should be collected during the exploration phase to refine the conceptual groundwater model and defining and implementing appropriate management measures to ensure that the long-term integrity of the local aquifers and groundwater resources is preserved after exploration activities have ceased, regardless of whether or not mining proceeds.

2. **How will the proposed exploration programme affect the surface water resources in the area where prospecting and exploration is intended to take place?** This question should be answered by developing a detailed development and rehabilitation plan, before any site development takes place, to ensure that, in addition to addressing operational water impacts during the exploration phase itself, that no lasting changes are made that affect the surface water resources after the exploration phase has been completed. In this context, particular attention will need to be paid to ensuring that surface disturbances and access routes are planned to enable complete rehabilitation to the pre-exploration state.

3. **What are the geochemical characteristics of the waste horizons that will be generated should the planned mine proceed and how should this mine residue be managed?** This question should be answered by ensuring that the drilling programme also takes samples of the material that will eventually find its way into mine residue deposits and submits these samples to an appropriately designed geochemical analytical programme in accordance with BPG G4. The services of a suitably-qualified geochemist will be required to advise whether samples need to be analysed immediately or whether they can be preserved appropriately for later analysis when a decision is taken to proceed to the mine planning phase. It would not be necessary to develop mine residue handling strategies during the exploration stage, but it is critical to take the samples that will be needed to generate the data needed to develop the mine residue handling strategies should the project proceed to the mine planning phase.

7.4.2 Key questions in the mine planning phase

Mines that enter the mine planning phase will be faced with considering alternatives for a wide range of features and actions associated with the planned mine. The interest in this phase of the mine life cycle with regard to mine closure and water management relates only to those actions that will persist throughout the life of the mine and which may potentially have impacts and risks beyond mine closure. The actions of interest will relate to the actual mining operations and the mine residue management options that will be implemented. It is also accepted that there is a relatively high level of uncertainty regarding many aspects of the future mining operations at the mine planning phase and that the type of risk assessment and impact prediction that can be undertaken at this stage will of necessity be of a "screening-level" and based on a precautionary and conservative set of assumptions in lieu of solid and reliable data. Nevertheless, there are important questions that need to be asked and answered during the mine planning phase as described below.

1. **What are the potential benefits that could be obtained from implementing a selective mine residue management and mine residue disposal strategy?** The samples of the potential waste horizons that were taken during the exploration and prospecting phase should, if this was not already done, now be subjected to detailed static and kinetic geochemical characterization as dictated by a suitably qualified geochemist using guidelines set out in BPG G4. Depending on the number of samples

available, it may be appropriate to send a randomly selected subset of the samples for analysis and then determine the variability and consequently statistical confidence in the samples that were analysed before deciding whether additional or all samples should be analysed. If there are clear and important differences in the long-term pollution potential of the different waste horizons then there should be consultation with the mine planning team to determine whether there are practical ways to separate the higher pollution potential mine residues from the lower pollution mine residues during mining, such that these mine residue streams can be disposed onto different mine residue disposal facilities with the aim of reducing long term risk and management cost of the complete mine residue inventory. This approach will only have the potential to provide benefits if the mine residue streams do differ significantly with regard to their pollution potential. Provided that there are sufficient waste horizon samples available from the exploration and prospecting phase, this assessment could potentially be undertaken quantitatively with a high degree of confidence. The assessment should also clearly specify on-going monitoring and analytical programmes for mine residues as they are generated during the mine operating phase in order that assessments can be updated and calibrated at a later stage.

2. **What are the potential benefits that could be obtained from implementing a mine residue treatment strategy to remove/reduce the pollution potential of the most reactive mine residue streams?** In the event that question 1 above does indicate that a portion of the mine residues that will be generated from the mining operation has a higher pollution potential than the average mine residues, then there may potentially be an advantage to selectively treat this mine residue (e.g. removal of the sulphides) prior to its disposal either on its own or combined with the other mine residues. such an assessment would be a combination of a risk and impact prediction assessment on the different mine residue disposal strategies with and without treatment, compared with the costs of constructing a plant to treat the mine residues and then dispose of, manage and close the resultant treated mine residue disposal facilities compared with the cost to dispose of, manage and close the untreated mine residue disposal facilities. Such an assessment would be undertaken at a screening level or semi-quantitative level, depending on the ability to accurately specify the characteristics of the treated mine residue.

3. **Based on evaluation of a most likely operational and post-closure pit water and contaminant balances, what are the preferred mining procedures for any planned opencast mining operations?** There are different ways in which the opencast mining operations could be planned and mined within different groundwater regimes that could have an impact on the location of post-closure decant points, volumes of decant and quality of decant. These issues need to be assessed on a screening level basis (i.e. limited data and conservative assumptions) in order to provide expected long-term pollution profiles for predicted contaminants of concern for the different mining and dewatering options being considered. The outcomes of such an assessment should be considered as one of the inputs into the mine planning process, by way of defining closure and post-closure cost estimates for the different options.

4. **Based on evaluation of a most likely operational and post-closure mining void water and contaminant balances and risks of surface subsidence, what are the preferred mining procedures for any planned underground mining operations?** The extent to which practical alternatives can be considered and assessed from the perspective of impact on mine closure risks is largely related to the depth of underground mining. Relatively shallow underground mining (such as is often found with coal mines) has the potential to have major impacts on the aquifers depending on the type of mining undertaken (e.g. bord and pillar versus total extraction) and alternatives can be quantified in terms of their long-term impacts on the water resource. Hydraulic connections with opencast mine voids and other natural features should also be explicitly assessed. The assessment of the risks associated with various underground mining techniques will generally be evaluated at a screening level due to high levels of uncertainty regarding the actual underground layout at the point of mine closure.

7.4.3 Key questions in the mine construction and commissioning phase

While the mine planning phase should have adjusted the planned operations, where necessary, to give attention to potential post-closure risks and to choose alternatives that pose the lowest post-closure water management risk, it is essential to ensure that these measures are properly and effectively implemented during the construction phase. It is also essential to ensure that the construction activities themselves do not cause long-term post-closure risks and it is therefore critical to ensure that the construction EMP addresses these risks and that its implementation is properly managed. There are therefore important questions that need to be asked and answered during the mine construction phase as described below.

1. **Are there any construction activities that could potentially pose a long-term post-closure water management risk and is prevention of these risks addressed in the environmental management plan (EMP) for the construction phase?** The mine planning process should, if undertaken correctly, also produce an environmental management plan (EMP) for the undertaking of the construction activities. In developing this EMP, particular care must be taken to ensure that the actual construction activities do not result in potential impacts that could persist till and after mine closure. Examples of construction activities that could have post-closure water management activities would be the use of sulphide-bearing material for the construction of roads, dam walls, and levelling of areas for construction of infrastructure such as offices and beneficiation plant. Location of construction site offices, access roads and river crossings should also be planned to ensure that no long-term post-closure impacts or risks are associated with these facilities.

2. **Have the post-closure risk management measures developed during the mine planning phase been properly implemented during the mine construction phase?** Section 7.4.3 highlights a number of key issues that should be considered during the mine planning phase in order to minimise the post-closure water management risks and liabilities. It is necessary to institute management systems during the construction phase of the project to ensure that these decisions are implemented or, alternatively, if practical site conditions necessitate changes to the mine plan during the construction phase, that the necessary assessment of the proposed changes is undertaken to again ensure that the chosen alternative is acceptable from a post-closure water management perspective.

7.4.4 Key questions during the mine operations phase

Any extensions to underground or opencast workings or development or new mine residue disposal facilities that are contemplated during the mine operations phase should be subjected to the same questions and risk assessments and impact predictions as described in Section 7.4.2 above. The difference would be that the assessment should be capable of being undertaken on a quantitative basis as opposed to a screening level basis as there should be good data sourced from historical mining operations that can be used in predicting the impacts of future mining operations. Activities that should trigger mine closure related risk and impact prediction assessments before being approved would therefore include the following:

- planned disposal of mine residues onto new or existing (but not previously used by the mine) surface mine residue deposits or into mining voids
- opening of new opencast or underground mining operations

Mines that already find themselves in the mine operations phase without having had the opportunity to ask the questions listed in Sections 7.4.1 and 7.4.2 above will have less opportunity to identify and apply pro-active pollution prevention management actions to some of the elements of their mining operations insofar as mining operations are already in place and existing mine residue disposal facilities are also already in place. However, key questions that should be asked during this phase are the following:

1. **Are all existing mine residue facilities thoroughly characterised in terms of their physical and geochemical heterogeneity and their probable post-closure water balances?** The operational phase of the mine provides the opportunity to undertake the necessary physical and geochemical characterisation of all existing mine residue disposal facilities that will persist to mine closure and beyond. The characterisation would be undertaken by taking appropriate samples (normally using drilling or augering techniques) of the existing facilities in order to subject such samples to geochemical characterisation in line with the guidelines set out in BPG G4. Appropriate water balances will also need to be developed for the mine residue deposits in order to be used, together with the geochemical data,

to construct kinetic geochemical models capable of predicting the current behaviour of these facilities. These predictive models should also be configured such that they are capable of predicting the beneficial effects of various closure and rehabilitation measures that would be considered for closure of the facility in terms of volume and quality of discharges for as long a period as is required to demonstrate that the impact of the seepage on the water resource is acceptable. The results from the evaluation of rehabilitation and closure measures should be used to develop appropriate financial provisions for the closure and post-closure management of these facilities. The assessments should also include the development of monitoring programmes that are aimed at collecting representative samples of new mine residue that continues to be deposited on the disposal facility and also collecting samples of seepage water that can be used to calibrate and validate the model. The objective should be to have fully calibrated geochemical prediction models for all mine residue facilities by the time the mine reaches the stage where it only has 5 years of operating life left.

2. **Are all mine workings (opencast and underground) thoroughly characterised in terms of their physical and geochemical heterogeneity and their probable post-closure water balances?** It must be assumed that all mine workings will decant into the ground and/or surface water resource at some point after mine closure unless it can be shown otherwise by appropriate modelling in accordance with the guidance provided in BPG G4 and BPG G5. There is therefore a need to construct detailed water balances around the mine voids that include all flow inputs and outputs for the operational and post-closure phase in order that the model can still be calibrated while the mine is in operation and flow measurements can still be made at key points - this is often not possible once the mine starts closing certain of its mining operations and access is no longer safe or possible. Where the risk of decant after mine closure is confirmed, it then becomes necessary to move towards a full geochemical characterisation of the mining void, based on the understanding that the geochemistry of the orebody and the waste horizons left behind in the mine void and seldom homogenous. An appropriate sampling programme must therefore be designed by a suitably qualified geochemist that is aimed at collecting and analysing samples in accordance with guidelines set out in BPG G4 and demonstrating that the sampling density is adequate to give an appropriate level of confidence based on the actual variability in key parameters found in the mine void. The results of the geochemical sampling programme must be coupled with the water balance to develop a kinetic geochemical model capable of predicting volumes and qualities of decant at all predicted decant points for as long a period as is required to demonstrate that the impact from these decants is acceptable. The assessment must also include a monitoring programme that needs to be implemented to collect data that can be used to calibrate and validate the predictive model. The objective should be to have fully calibrated geochemical prediction models for all mine workings by the time the mine reaches the stage where it only has 5 years of operating life left.

3. **Where unacceptable contaminant loads are predicted, what water management and treatment alternatives would be required to treat these loads to an acceptable level and are the financial provisions for such water management/treatment included in the mine's closure financial provisions?** If either the mine residues or mine workings assessed in terms of questions 1 and 2 above are predicted to produce a volume and quality (load) of contaminants that exceeds the load that can be assimilated to still meet the receiving water quality objectives (RWQOs), then some form of water treatment may be necessary to treat these discharges for as long as these discharges do exceed the RWQOs. BPG G5 provides a procedure and approach that should be followed to specify what degree of treatment needs to be provided for and how the financial provisions for such treatment should be determined.

It must be emphasized that while mines will only be required to compile provisional mine closure plans during that part of the operating phase that is further than five years from closure, this time should be used productively to ensure that all predictive models are developed and calibrated and that a reasonably confident assessment of the measures required at closure and post-closure can be made and financially provided for. It is too late to only define final closure and post-closure measures 5 years before actual mine closure if good provisional assessments have not been made previously. It is generally not feasible for a mine to generate the funds to provide for new closure and post-closure management activities within the last 5 years if reasonable estimates and provisions have not been made in the preceding years.

7.4.5 Key questions at five years before planned mine closure

At the point where the current mine plan indicates that the mine will cease operations and commence with decommissioning and closure activities within five years, an important shift occurs with regard to the mine closure planning process from the water management perspective. This point will also be reached should the mine at any other time suddenly find itself with less than five years of operating life left, e.g. should there be a dramatic fall in commodity prices or ore grades or any other factor that unexpectedly makes the mine's operations uneconomical.

At this point, the mine closure plan which has been in a continuous evolving provisional plan stage throughout the life of mine, needs to be converted into a final and approved mine closure plan and post-closure water management plan.

It has previously been emphasized in Section 7.4.4 above that the mine should essentially have final, complete and calibrated predictive models for all the mine workings and the mine residue disposal facilities at this point and that good estimates of closure and post-closure management measures and associated costs should be in place with finances already available in the mine's closure funds. The conversion of the provisional mine closure plan to a final mine closure plan should therefore not result in any radical changes to the plans or the financial provisions. The purpose of conversion to a final closure water management plan is to obtain finality on the RWQOs that the mine will need to meet and to enable the mine to then make final decisions on closure and post-closure measures to be implemented to meet the RWQOs. Certain parts of the mine can then also proceed to final decommissioning, with time then being available in the last five years of operation to collect monitoring data to demonstrate that predictive models are accurate and reliable and that specified closure management actions are in fact capable of meeting the specified RWQOs.

In order to facilitate this process, the following key questions need to be asked and answered at this stage in the mine's life cycle and incorporated into the final mine closure water management plan.

1. **Have the final closure objectives (RWQOs) with regard to water management been defined and set?** These objectives need to be set by the Department of Water and Sanitation and while provisional closure planning can proceed with provisional RWQOs, the final closure and post closure water management plan requires DWS to provide the mine with final RWQOs.

2. **Have all interested and affected stakeholders been consulted in the setting of these final closure water management objectives?** Interested and affected stakeholders have a right to be involved in the setting of final closure water management objectives, including the RWQOs. While most mines will have regular interactions with their identified stakeholder groups on operational environmental issues, there is a specific need to involve these stakeholders in defining and agreeing on the post-closure water management objectives.

3. **Has the mine developed and calibrated a predictive model that is capable of predicting all points of discharge from the mine workings (opencast and/or underground) in terms of location, volume and quality for all contaminants of concern for a period of time until such discharges are acceptable in terms of agreed RWQOs?** The requirements regarding such a predictive model has been extensively discussed in Section 7.4.4. Question 2 and if the mine has not undertaken this work appropriately during the earlier operating phase of the mine, then it becomes critical to ensure that this work is done and completed as soon as possible in full compliance with the guidelines presented in BPG G4 and BPG G5. Failure to do so would constitute a significant risk to the regional water resources as the risk of the mine reaching the end of its operations without proper provision for post-closure water management risks and impacts is then high.

4. **Has the mine developed and calibrated a predictive model that is capable of predicting all points of discharge from the mine residue disposal facilities (coarse and fine and disposed of on surface and/or underground) in terms of location, volume and quality for all contaminants of concern for a period of time until such discharges are acceptable in terms of agreed RWQOs?**

The requirements regarding such a predictive model has been extensively discussed in Section 7.4.4. Question 1 and if the mine has not undertaken this work appropriately during the earlier operating phase of the mine, then it becomes critical to ensure that this work is done and completed as soon as possible in full compliance with the guidelines presented in BPG G4 and BPG G5. Failure to do so would constitute a significant risk to the regional water resources as the risk of the mine reaching the end of its operations without proper provision for post-closure water management risks and impacts is then high.

5. **Where RWQOs are not met at the time of mine closure, have appropriate post-closure water management/treatment measures been specified, designed and costed by a suitably qualified person and have financial resources and institutional arrangements been made to implement and finance these measures for as long as they are predicted to be required, i.e. until the RWQOs can be met without such measures being in place?** The requirements regarding such specification and financial provisions for post-closure water management and treatment facilities has been discussed in Section 7.4.4. Question 3 and if the mine has not undertaken this work appropriately during the earlier operating phase of the mine, then it becomes critical to ensure that this work is done and completed as soon as possible in full compliance with the guidelines presented in BPG G5. Failure to do so would constitute a significant risk to the regional water resources as the risk of the mine reaching the end of its operations without proper provision for post-closure water management risks and impacts is then high. It would also be required for the mine to have implemented the specified water management/treatment measures and to collect performance data for at least 3 years to use to demonstrate that the implemented measures are capable of meeting the agreed RWQOs, before submitting an application for mine closure.

6. **Is the mine's closure and post-closure water management plan integrated into a regional post-closure water management plan?** Wherever a mine is located directly adjacent to other mines (operational or defunct), there is a need to develop the mine's closure and post-closure water plan within the context of a regional post-closure water management plan. Where this has not been done, it will be difficult, if not impossible, to assess the validity and sustainability of the mine's closure and post closure water management plan.

7.4.6 Key questions at the point of considering approval of mine closure

At the point where the mine has implemented the management measures contained in the approved mine closure and final post-closure water management plan, the mine would then approach the Department of Water and Sanitation (through the Department of Mineral Resources) to approve the granting of mine closure. At this point, it is assumed that the mine will have followed the procedures set out in BPG G4 and BPG G5 and the appropriate questions that need to be asked are those that are stipulated in BPG G5. The requirements that need to be met with regard to these questions are described in BPG G5.

1. Does the risk and impact prediction assessment fully comply with all aspects of the independent review process as set out in BPG G4: Impact Prediction?

2. Does the closure plan consider all the relevant principles described in Section 2.1 of BPG G5 and does it present all the information requested in Section 2.2 of BPG G5 in a clear written report and has all such information been verified by the appointed reviewer?

3. Has the assessment included clear evidence, supported by the independent reviewer, that all impact prediction assessments and models have been fully calibrated and validated using information collected from a verification monitoring programme?

4. Does DWS have written confirmation from the appointed reviewer that his/her review was undertaken independently, objectively, scientifically, without bias or favour to any party, that he/she was given full access to all information required to undertake the review and that he/she deems him/herself competent to have undertaken the review?

5. Does DWS have written confirmation, from a duly appointed representative of the mine's Board of Directors, that the mine closure application is based on full and complete disclosure of all information that could in any way be pertinent to the consideration of the mine closure application and that no potentially damaging information has been withheld?

6. Does DWS have confirmation, through an independent assessment by suitably qualified persons, that all the stipulated and agreed water management actions and measures (including any water treatment plants that may be required) have been properly implemented and that sufficient/adequate financial provisions have been made and that suitable contractual arrangements have been entered into with approved third parties to ensure that all the required operational, maintenance and financial measures will be implemented and audited for as long as has been predicted to be necessary to ensure that the agreed closure objectives are met?

7.4.7 Key post-closure questions

After mine closure has been approved, residual water management/treatment measures that may need to be implemented for a specified number of years will be managed by third parties agreed to at the point of approval of mine closure.

1. **Confirm that no information comes to light that was known at the time of mine closure application but that was not disclosed (in reference to Question 7 in Section 5.4.6 above).** If it does come to light that information was withheld during the closure application process that resulted in the Department of Water and Sanitation approving mine closure under false pretences, then the Department will need to consider options for recourse as provided for in the National Water Act.

2. **Are the implemented water management/treatment measures continuing to be implemented and do they continue to meet the defined RWQOs?** This should be undertaken by way of regular independent audits, to be funded from the financial provisions made by the mine for post-closure water management, with audit reports to be submitted to the DWS and the mining company.

7.4.8 Development of a post-closure water management plan checklist

The above key questions have been included into a graphical format as shown in Figure 5 above. Each of these questions has been expanded on in some detail as shown in Annexure B.

CHAPTER 8: DESCRIPTION OF UNCERTAINTIES

8.1 BACKGROUND

Management decisions are based on available information regarding pertinent conditions, objectives, costs and societal needs. There is never a complete understanding and a critical part of any post closure water management plan is identifying and dealing with uncertainty. For this reason, it is important to provide all possible outcomes or interpretations of monitoring and material characterization, not just the presently most probable or manageable hypothesis. Similarly when developing mitigation plans, it is important to document the uncertainties and show how this will be monitored and managed (Price, 2005).

Sensitivity analysis and risk assessment should be conducted at every stage of the closure planning process to determine the sufficiency of available information and the impact of possible inaccuracies on the overall environmental risk and liability. The results of sensitivity analyses and risk assessment can be used to determine monitoring requirements and to establish where additional safety factors or contingency protection measures may be necessary.

Probabilistic modelling is the best - if not only - technique for organizing and incorporating all available information on risks and uncertainties so that a good risk-informed decision can be reached (Pergler and Freeman, 2008). It is of course necessary to ensure that the probabilistic modelling is properly undertaken and that it is based on using the correct conceptual and mathematical model and input data sets that adequately reflect the true variability of the data. A probabilistic approach to quantifying uncertainty is also supported by the ICMM, 2008.

8.2 UNCERTAINTY IN GEOCHEMICAL CHARACTERIZATION PROGRAMMES

Uncertainty issues in the use of the geochemical toolbox are discussed extensively in Maest *et al* (2005) and their discussion is summarised in the sections below.

A very relevant research project aimed at quantifying uncertainties in geochemical sampling and analyses was undertaken for the WRC (Chihobvu *et al*., 2011). This report addresses this deficiency in geochemical sampling and analyses and proposes two methodologies (i) for quantifying uncertainties in geochemical sampling and analysis as a function of sample size and analysis and (ii) for determining the optimum sample size to ensure data quality.

The statistical analysis approach was adopted as the best method for sample size determination. The approach is based on the premise that "the size of the study sample is critical to producing meaningful results". The size of the required samples depends on a number of factors including purpose of the study, available budget, variability of the population being sampled, acceptable error and required confidence level.

The methodology for estimating uncertainty is a fusion of existing methodologies for quantifying measurement uncertainty. The methodology takes a holistic view of the measurement process to include all the processes involved in obtaining measurement results as possible components/sources of uncertainty. Like the statistical analysis approach, the methodology employs basic statistical principles in estimating the size of uncertainty associated with a given measurement result. The approach identifies each component of uncertainty; estimates the size of each component and sums the contribution of each component in order to approximate the overall uncertainty value associated with a given measurement result.

It is proposed that for mine closure risk and impact predictions, sample size should be selected to demonstrate a confidence level of 90-95%. This means that sufficient samples must be taken, analysed and statistically interpreted to demonstrate that there is a 90-95% confidence that the true mean value of the parameter being assessed lies within the range of values determined from the sampling. Procedures for undertaking the statistical analysis are provided in Chihobvu *et al*., 2011.

Key issues that could affect uncertainty and that should be considered in designing and undertaking a sampling and analytical programme are described in the literature review and key points are reproduced below.

1. Compositing of samples is only recommended for mined material that is consistent in size and composition, for example, existing tailings material that is known to be from a consistent ore type and a single process.
2. Geochemical characterization should be conducted throughout the active life of the mine and used to continually evaluate potential environmental impacts.
3. Site-specific measurements of temperature, particle-size distributions, available sulphide and neutralization mineral surface areas, spatial variability of sulphide-bearing rock, hydrological factors such as preferential flow, and the availability of oxygen should be determined for all waste units, especially waste rock and leach dumps. Mineralogical analysis, including mineral availability, should be completed before laboratory testing begins. To the extent possible, field-scale testing or laboratory columns, with minimal changes in grain size distribution compared to the actual mined material, should be conducted as supplements to or replacements for laboratory characterization testing, especially for waste rock. Site-specific estimates of scaling factors between laboratory and field conditions should be determined and used in predictive modelling studies.
4. Static ABA tests cannot be used to quantify acid generation and neutralization under field conditions and should only be used as an initial screening technique to estimate the total amount of acid-generating and acid-neutralizing material present in rock that is representative of the samples collected. Evaluation of mineralogy, including available weathering surface area for sulphides and carbonates, may be a more accurate approach than ABA testing for estimating the acid generation potential of mined materials.
5. Evaluation of mineralogy is a necessary step for determining the neutralization potential of mined materials. If using ABA testing, some general guidelines include: for most mineralogies, the original Sobek method will overestimate neutralization potential; use NAG testing only as a screening method for estimating neutralization potential; assuming siderite is not a dominant carbonate mineral, Lapakko and modified Sobek methods are the most reliable and reasonably conservative tests for estimating NP.
6. Mineralogy should be thoroughly examined as part of the environmental characterization process, with special attention paid to identifying the types of metal sulphides, silicates, and carbonates in mined materials and the surface area of these minerals available for reaction. In many cases, this will involve mineralogical examination that is more detailed and sophisticated than simple bulk powder X-ray diffraction. If siderite is a dominant carbonate, the NP tests should be modified to ensure that siderite is not included in NP. As a check on NP, use mineralogical NP (based on the amount of calcium and magnesium carbonates present) for samples of lithologies of interest. Use of total sulphur for AGP may result in slight overestimations of AGP, but using total S would result in more protective and supportable management decisions. However, if there is a substantial amount of non-acid producing sulphates or organic sulphur, they should be subtracted from the total sulphur value.
7. For rocks with low S content and/or low NP, standard ABA testing must be supplemented early in the mining process with additional information on mineralogy, availability of acid-producing and neutralizing material, and kinetic tests to determine the relative weathering rates of sulphides and neutralizing minerals.
8. Static ABA tests and NP/AP ratios should only be used as initial screening tools for samples to be used for kinetic testing and as estimates of the total amount of acid-generating and neutralizing material present. Knowledge of mineralogy is essential in interpreting ABA results. To estimate medium- and longer-term acid-generation and metal-leaching potential, static test results must be supplemented with mineralogical, mineral availability, and kinetic testing data.
9. The use of un-weathered materials in leach tests should be avoided. Short-term leach tests may have limited use as a scoping tool if weathered rock is used, but the results should only be applied to short-term leaching of mined materials after they have been weathered in the field. Involving an experienced geochemist in testing design and analysis will minimize misinterpretation of test results. Taking short-term leach test results from long-term kinetic tests (e.g. “first flush” results from humidity cell or column tests) would eliminate the need for separate short-term leach tests and would better link short-term and

long-term predictions for leaching of contaminants. In addition, releases can then be quantified on a per unit mass basis if short-term leach results are taken from kinetic testing.

10. Humidity cell testing should not be used to predict weathering rates for waste rock or wall rock or other types of heterogeneous, large-grain size material unless the results are expressed in terms of available mineral surface area. This requires that the surface area of specific minerals in the kinetic-test samples be known and – to permit scaling up to field conditions – that the surface area of minerals in the actual waste be known or well estimated. Column testing with no or minimal reduction of particle size or field techniques, such as mine wall washing, will provide results that will be more representative of field conditions. Samples must be well characterized in terms of mineralogy and mineral availability before and after tests are conducted.
11. The objectives of kinetic testing should be clearly stated. If the objective is to determine if the sample will produce acid, kinetic tests should be conducted for longer than 20 weeks, unless earlier results indicate that acid will be produced. The length of the test should depend on the sample composition. Mineralogy (including available surface areas) should be examined initially and after the test and used to help determine if the sample could eventually produce significant amounts of acid or contaminants. For kinetic test samples with static test NP:AP>1 that have not produced acid within one year, test lengths should be longer than one year.
12. For larger grain size material, such as waste rock, larger columns should be used for kinetic testing, using a ratio of column diameter to largest particle size of six or greater. To reduce grain size somewhat, the material can be broken by hand, for example, using a hammer, if necessary, so that the breakage would occur along faces that would naturally be exposed to weathering.
13. To the extent possible, field kinetic tests should be conducted as a supplement to laboratory kinetic testing. Mine proponents and regulators should acknowledge that the results of kinetic testing, unless the tests are conducted in the field, will not represent dynamic hydrologic and weathering conditions such as snowmelt and precipitation. Results from kinetic tests conducted under oxygenated conditions can be used to model the effect of different temperatures on sulphate production using experimental data on the effect of temperature on activation energies for the reactions (e.g. Ritchie, 2003).
14. Humidity cell tests should not be used to represent leaching characteristics of materials under low-oxygen or reducing conditions. Continuous flow column tests or batch tests can be used to estimate the behaviour of mined materials under low oxygen conditions.

8.3 UNCERTAINTY IN IMPACT PREDICTION MODELLING

Substantial uncertainty is inherent in determining many of the parameters that are required for modelling water-quality evolution at mining sites, especially hydrologic parameters such as hydraulic conductivity and recharge. Uncertainties in hydrologic modelling may be very large as a result of the inherent range in hydraulic conductivity and other hydrologic parameters, and the effects of these uncertainties on net water-quality predictions (via mass flux) need to be addressed in the uncertainty evaluation. The uncertainty may derive from incomplete characterization or incomplete knowledge of the geochemical and hydrogeological conditions at the site.

Methods used to evaluate or account for model uncertainty include Monte Carlo analysis, stochastic methods, and evaluating a range of model parameters to develop a range of deterministic outcomes (e.g. a range of water quality in a given receptor). These methods account for the fact that, rather than being well described by a single value as required in the model, parameters are better described with a probability distribution (i.e. a mean, variance, skewness, etc.).

Model uncertainty should be acknowledged in predicting water quality at mining sites, and some methodology (conducting sensitivity analyses using a range of values as input parameters, Monte Carlo approaches) should be employed to evaluate the effect of uncertainty on model output. For example, a desired confidence level could be determined (e.g. 95%), and this confidence level on environmental data could be used throughout the model. These approaches will be useful only if the uncertainty derives from site variability in parameters but will not address uncertainties in the conceptual model. Uncertainties in the conceptual model can be addressed by collecting as much site-specific hydrogeochemical data as possible and keeping an open mind to rethinking the original conceptual model. This approach is adopted in BPG G4 and is captured in the BPG G4 impact prediction methodology reproduced in Figure 1 in this report.

Key issues that could affect uncertainty and that should be considered in designing and undertaking an impact prediction modelling assessment are described in the literature review and key points are reproduced below.

1. If separate computer codes are to be used for different processes or spatial or temporal domains, there must be a careful evaluation of how those codes are coupled so that the output will be useable. Site conceptual models and modelling efforts should include the effect of varying water quantity on water quality. Often, prediction should be evaluated using both coupled and discrete-process codes to help determine processes that control critical model results, such as the movement of constituents through a waste rock dump.
2. To the extent possible, while still recognizing the uncertainty, predictions must be extended to the timeframe required by the regulatory context (such as 100 or more years for financial assurance determination purposes). However, timeframes for model predictions should not end at an arbitrary cut-off point (based on regulatory guidance or precedent, for instance), but rather should be based on the physical conditions of the modelled system. For example, pit lake chemistry could be modelled until steady state water quality is reached or certain ecological thresholds are exceeded. Models should be used to predict the timing and magnitude of impact from mine residue deposits even if these impacts are far into the future.
3. Codes developed by a group or company that are not available for sale or distribution outside of that company should not be used in predicting water quality at mining sites for mine closure applications. These codes cannot be verified or tested by those outside of the company. It is uncertain whether such codes accurately simulate the processes that are important for predicting water quality at the mine site. They may have “bugs” that have not been identified by wide code use. Furthermore, because the code itself is not available, it is not possible for a reviewer to reproduce the model simulations. In the same vein, any code that is so expensive that it is not feasible for a reviewer to purchase or lease the code should be avoided. Codes used for prediction of water quality at mining sites should be available for purchase and use by anyone. Similarly, models created using available codes but that do not provide an understandable record of all inputs and approaches should not be accepted for use in mine closure impact predictions.
4. Predicted contaminant transport rates in the vadose zone and groundwater are highly influenced by hydrologic parameters for geologic units in the models. Pump tests and lithologic descriptions may provide initial hydraulic and transport parameters, but these must be fine-tuned by calibration. The uncertainty in hydraulic parameters should be acknowledged, and an effort should be made to account for uncertainty in the model predictions.
5. After a modeller parameterizes the hydrogeological units, each unit typically is treated as completely homogeneous in the model. Within a hydrogeological unit, aquifer properties and geochemical characteristics are effectively averaged over the unit. Hydrogeologically complex areas such as those with fractures or variable mineralization may require more units than more homogeneous areas. Alternatively, a range of aquifer properties and geochemical characteristics can be used for a single unit.
6. In arid environments, potential evaporation is greater than precipitation. However, this does not mean that there will be no infiltration or recharge to groundwater. Even in arid or semi-arid environments, infiltration can occur during precipitation events and be transferred to depths in waste piles beyond the evaporative zone, resulting in infiltration. The timing and nature of precipitation events are key determinants of whether water will infiltrate the surface of the facility or evaporate. The wetting front will move downward into the waste pile over time, bringing with it solutes dissolved from the waste material. The code used to simulate infiltration and percolation of meteoric water into mine facilities such as waste rock dumps must be sophisticated enough to account for infiltration resulting from individual storm events.
7. Many hydrologic models assume uniform soil properties in geologic materials and are unable to simulate macro-pores, preferential flow, and fractures in the vadose or saturated zones, or in a groundwater aquifer. In many mining areas, the subsurface is composed of fractured bedrock. In many

cases, the fractured rock is assumed to behave as an "equivalent porous medium." This may be adequate for some sites, but could also result in inaccurate predictions of flow and contaminant migration. The inability to model preferential flow represents a major shortcoming in water quality predictions that must be acknowledged. Additional research is needed in this area if predictions are to be considered at all accurate or useful in determining potential for impacts and identifying mitigations to address such impacts.

8. Analytical data used to characterize groundwater, surface water, leachate, or pore water chemistry may not include all the important and necessary analytes. For example, if major cations and anions are not included, charge balances cannot be calculated, and a good charge balance is one indication that the laboratory analysis is adequate. A full analytical suite should be used for analysis of leachate from kinetic and short-term leach testing, and any identified constituents of concern should be included in the model. If thermodynamic data for an important constituent of concern is not present in the code, the modeller should consider modifying the database to include that constituent or selecting a code that has thermodynamic data for that/those constituents. If modelling is conducted using a limited water quality database, the user should state explicitly that the results do not adequately consider reactions involving the missing constituents.
9. For some minor and trace constituents, analytical detection limits can be higher than concentrations that could pose a risk to human health or the environment. Detection limits should be substantially lower than the most protective and relevant water-quality standards.
10. Extrapolation of data applicable to short-term conditions to longer-term conditions will add to uncertainty of longer-term water-quality predictions. Well-designed long-term kinetic leaching tests should be conducted on representative materials that pose a potential threat to water quality, and results from these tests (including how leachate concentrations change over time) can be used as inputs to hydrogeochemical models.
11. Distribution coefficients, or Kd values, describe the tendency of dissolved constituents to adhere to solid surfaces (e.g. soils and aquifer materials) and are only relevant to equilibrium conditions (Stumm and Morgan, 1996), yet they have been used extensively to model fate and transport of kinetically controlled reactions in aquifers. Kd values are often taken from the literature rather than conducting site-specific experiments on adsorption/desorption reactions in alluvial and bedrock aquifers. Their improper use in hydrogeochemical models can produce errors in the prediction of contaminant transport rates in groundwater and of recovery times. Site-specific information on the transport of contaminants in aquifers and mined materials should be used as inputs to predictive models.
12. Steady-state pH values and concentrations from humidity-cell tests are often used as input data for geochemical reaction path or mass balance models. These inputs are used to predict future water quality based on laboratory or field-scale experiments. However, differences in weathering rates and reactants produced under field and laboratory conditions can cause large differences between experimental and actual conditions, especially if reactive surface areas are not included in the model. Applying an across-the-board scaling factor (e.g. 10^{-3} or 10^{-4}) to account for higher oxidation rates in laboratory tests (compared to field conditions) is not warranted without examining the longer term leaching behaviour of the wastes. If appropriate long-term kinetic testing has been conducted, steady-state concentrations can be used without scaling factors, or site-specific scaling factors can be applied.
13. The timing of precipitation events and other types of climatic processes can affect water chemistry. During dry periods, weathering products (secondary minerals) from the oxidation of sulphide minerals will accumulate in test piles, mine units, and unmined materials. Storm precipitation following a dry period will flush these accumulated products from the piles and result in high concentrations of solutes and generally low pH values, while more continuous rain will result in a more constant volume of acid and other contaminants and lower concentrations in surface water and groundwater (Jambor *et al.*, 2000; Maest *et al.*, 2004). Sampling of mined materials, field-scale characterization tests, and water quality and quantity sampling must at least initially be conducted to capture the variability in seasonal and climatic conditions. A sensitivity analysis using linked end-members of the environmental data (i.e. concentrations and flows most likely to occur under, for example, high and low flow conditions) will better bracket actual field conditions than an average or median value.

CHAPTER 9: THE IMPACT PREDICTION PROCESS

The prediction of water quality at mine sites is a challenging topic because of its technical complication and inherent uncertainties. Much of the uncertainty related to predicting water quality at mine sites derives from inadequate or inaccurate conceptual models, hydrologic and geochemical characterization data, and input data to hydrogeochemical models (Maest *et al*., 2005). Factors that contribute to making this prediction complicated include the following:

- knowledge of the dissolution chemistry of minerals present in the material being assessed at the micro-scale, together with the secondary reactions among dissolution products, gas phases and solid surfaces
- knowledge of the mineral surface areas available for reaction
- knowledge of the kinetics of reaction rates in a complex chemical mix
- knowledge of the confidence with which results from laboratory tests on small samples over short time periods can be extrapolated to large mining features over long time scales (decades or centuries)
- knowledge of future climatic conditions (temperature, rainfall, etc.)
- knowledge of the variability of these factors with the large scale mining features being assessed
- knowledge of the essential characteristics of the management actions to be undertaken, how these vary spatially and temporally and how these may be affected by future human actions (maintenance or lack thereof, wilful damage, etc.)

The solution to the above lies in the following:

- good conceptual model that adequately describes the situation being assessed
- sound risk assessment technique (six step feedback loop over the source-pathway-receptor continuum)
- sound sampling and analytical techniques with revision to verify confidence limits in data
- quantification of uncertainties along the whole assessment path
- selection of correct mathematical model able to address the real questions and consider the key variables, run in a probabilistic framework
- use of suitably qualified persons to undertake assessment and evaluate outcomes in order to accurately define upper and lower bounds of confidence in outcomes
- monitoring and collection of key data to allow verification and validation of predictions

Although applications of mathematical modelling in mine water quality prediction is still a relatively recent development, it is finding increasing regulatory acceptance in North America, Australia and certain European countries (Younger and Sapsford, 2004).

The modelling toolbox consists of a number of tools that need to be utilised in the correct manner and sequence as follows:

- Development of a conceptual model
- Selection of appropriate predictive codes
- Collection of data for modelling inputs
- Code verification and model calibration
- Estimation of uncertainty

Selection and use of the most complex hydrogeochemical code to predict water quality at a mine site does not necessarily provide realistic predictions. As noted by Nordstrom (2004), the sophistication of software has outdistanced our capacity to evaluate, constrain, and test the software. Selection of a computer code to develop a prediction of water quality should be based on factors such as:

- modelling objectives;
- capability of the code to simulate important processes affecting water quality at the mine site, as described by the site conceptual model(s);

- ability of the code to simulate spatial and temporal distribution of key input parameters and boundary conditions;
- availability of the code and its documentation to the public; and
- ease of use of the code, including availability of pre- or post-processors and graphical interfaces

The overall objectives of the modelling project and the availability of supporting data should be considered in selecting a code. The code or codes chosen to predict water quality should be representative of the site (as reflected in the site conceptual model) and be applied at a level of complexity that is appropriate for the available data and the regulatory decisions that must be made. Some of the issues to consider when selecting a code include:

- What are the objectives and endpoints of the modelling
- What specific processes at the mine site will influence water quality, and what codes are capable of simulating these processes
- Whether reactions are better represented by equilibrium or kinetic codes (or both)
- Whether to use coupled or separate water quantity and quality codes
- The type and quality of environmental data available (or that could be collected) versus the type of data needed for the code
- Importance of colloids, microbiology, and transport by bacteria to resulting water quality
- Presence of graphical interfaces in codes and ease of use
- Availability of the code to others

Younger and Sapsford, 2004 in reviewing the international literature on "acid mine drainage prediction tools" found that the most serious omission in most protocols is a clear focus on understanding where water moves from/to in the subsurface environment which encloses a given site. They further conclude that "the literature is replete with thousands of pages of minutely-argued text concerning the intricacies of 'acid-base accounting' and 'humidity-cell tests' and y*et al*most devoid of serious discussions of the hydrological pathways which are the *sine qua non* for pollution impacts to actually occur.

Excellent guidance on the capabilities and limitations of different predictive codes is provided in Chapter 7 (Section 7.2) of Maest *et al* (2005). It is important to remember that the primary purpose for the geochemical assessment is to guide management decisions (Price, 2005).

International best practice in undertaking impact predictions of long-term water pollution from mine sites, as is required in support of a mine closure and post-closure water management plan has been extensively summarised in the literature review that forms part of this research project. A clear conclusion from the literature review is that the methodology described in BPG G4 is completely in line with current international best practice and there is no need to make any significant changes to the methodology in BPG G4. Conversely, it can be stated that any impact prediction assessment undertaken for a mine closure scenario that does not comply with the basic methodology set out in BPG G4 should be required to provide very extensive motivation, supported by the appointed external reviewer, as to why the deviation from accepted best practice should be considered appropriate and acceptable.

The complete impact prediction methodology developed in BPG G4 is summarised in Figure 2 of this report and is described fully in BPG G4. Use of BPG G4, together with the literature review completed as part of this project will ensure that impact predictions are undertaken in accordance with best practice and that the outcome thereof will be credible.

CHAPTER 10: USE OF SUITABLY QUALIFIED PERSONS

The technical studies that need to be undertaken as part of a closure impact prediction exercise are highly complex, require extensive practical experience in developing accurate site conceptual models, use complex mathematical codes, require solid judgement in interpreting results and require the experience to be able to justify and motivate assumptions, methodologies and outcomes to a wide audience, including regulators, IandAPs and the appointed review specialists. Persons that have this type of experience are referred to as "suitably qualified persons' and their role is critical in the closure impact prediction project.

The most complex tools that need to be applied in the impact prediction project are the geochemical models. The major processes that such tools are required to model include mineral dissolution and precipitation; aqueous inorganic speciation and complexation; solute adsorption and desorption; ion exchange; oxidation-reduction or redox reactions; transformations; gas uptake or production; organic matter speciation and complexation; evaporation; dilution; water mixing; reaction during fluid flow; reaction involving biotic interactions; and photoreaction. These process need to be evaluated in saturated and unsaturated conditions; dry and wet hydrological cycles; surface and groundwater systems, winter and summer.

While these geochemical models have the ability to give very good estimations of evolving water chemistry in many mining scenarios, these models have a dangerous sophistication for computing almost any type of possibility without adequately constraining what is possible (Nordstrom, 2004). Expert judgement is therefore particularly important in identifying the appropriateness of assumptions in applying a model and constitutes a bigger problem than that of model formulation (Nordstrom, 2004).

An impact prediction exercise for a typical mine closure will require a range of suitably qualified persons that cover the following disciplines: geochemistry; hydrogeology; hydrology; civil engineering (for definition of typical water management measures such as covers); mine water treatment; statistical evaluation and others. Project management and review of such a team of experts requires persons that have at least a sound working knowledge and experience of most, if not all, the above disciplines.

CHAPTER 11: POST-CLOSURE WATER TREATMENT ISSUES

Most post-closure ARD mitigation facilities or structures must be designed, constructed, operated and financed in a manner that allows them to perform indefinitely. Successful long-term performance requires pro-active detection and resolution of problems prior to significant environmental impacts (Price, 2005). This requires:

- a conservative design;
- ability to handle future geochemistry, hydrology, ecology, etc.;
- monitoring, maintenance, repair, replacement and contingency plans;
- regularly updated operating manuals and databases for monitoring results; and
- the financial resources to conduct the above

In terms of the Environment Canada: Environmental Code of Practice for Metal Mines (2009), at sites where it is determined that long-term treatment of wastewater will be necessary during post closure, a long-term wastewater treatment plan should be developed and implemented. This plan should include the following elements:

- identification of roles and responsibilities of persons to be involved in operation and maintenance of the treatment system;
- identification of the type of treatment system to be used;
- identification of any by-products from the treatment system, such as treatment sludge, and management plans for the disposal of those by-products;
- identification of routine maintenance activities to be conducted on the treatment system and the frequency;
- identification of monitoring to assess ongoing performance of the treatment system and the frequency;
- identification of reporting requirements for internal management and regulatory agencies; and
- description of contingency plans to address any problems associated with the treatment system

Consideration should be given to the implementation of a passive treatment system. In some cases, these systems may have lower maintenance requirements than traditional treatment systems, although all systems do require some degree of ongoing maintenance (Environment Canada, 2009). The potential for passive treatment options is also recognised by the Australian Government (2006).

Where there is a need for long-term treatment of wastewater from mines during mine closure and post closure, a long-term treatment plan should be developed. Due to changes in wastewater volume and possible changes in the chemical composition of wastewater after the end of the mine operations phase, treatment systems in place during mine operations may not be appropriate during mine closure and post closure.

The need for post-closure water treatment arises when the application of pollution prevention measures is insufficient in enabling the mine to meet its post-closure water quality performance objectives. Pollution prevention opportunities can be maximised by ensuring that mine closure planning happens at the earliest possible stage in the mine life cycle. If closure planning is postponed until the middle or end of the mineral extraction phase, it may be too late to use certain pollution prevention approaches (Environmental Law Institute, 2000).

In British Columbia, Canada, the primacy of pollution prevention is also recognised and the provincial Acid Rock Drainage Policy, which guides its approval of reclamation and closure plans provides that "The primary objective of a metal leaching and acid rock drainage programme is prevention. This will be achieved through prediction, design and effective implementation of appropriate mitigation strategies".

In some cases, regulations have become exceedingly wary of potential post-closure water pollution issues and the State of Wisconsin (USA) adopted a moratorium on the mining of sulphide ores until companies could present evidence of successfully closed mines that did not generate acid. The US Bureau of Land Management has proposed regulations that would require operators to "minimise water pollution (source control) in preference to water treatment" (Environmental Law Institute, 2000).

Unfortunately South Africa also does not have a good record of early detailed closure planning and early identification and implementation of pollution prevention options. Fourie and Brent, 2008 conclude that due to uncertainties in the process required for effective mine closure and the reluctance of the regulator to approve mine closure that mines are resorting to strategies where they "focus more on inexpensive means of just complying with the 'esthetical nuisance' [of mine closure] rather than strategising to solve long-term effects".

While it is clear that pollution prevention options are preferred and should be optimally implemented in an effort to prevent a post-closure situation where residual long-term water treatment is required, the reality is that avoidance of a need for water treatment is not always attainable.

In cases where post-closure water treatment is required, the determination of the precise water treatment requirements is an additional step that occurs once the necessary impact prediction modelling has been undertaken. In order to determine water treatment requirements, the following information inputs are required:

1. Well-defined and agreed water quality objectives that need to be met at the identified and agreed critical receptors, either for the ground water and/or the surface water.
2. Predictive modelling for the mine site under consideration that provides information on the volume and quality of discharges at all identified discharge points, within a probabilistic framework (i.e. maximum, minimum and average) for a period of time until the discharge meets water quality objectives .
3. Hydrological and/or groundwater transport and quality models that can use the data from the predictive modelling for discharge sources and predict actual water quality at the identified critical receptors for best, worst and most probable case scenarios.
4. In cases where the predicted post-closure water quality at the critical receptors is shown to exceed the water quality objectives that were agreed for these receptors, then data must be available to indicate what the discharge source water quality/volume should be to ensure that compliance is still achieved under worst case scenarios.

With these data inputs, the determination of appropriate water management/treatment options and their capital and operating costs can readily be undertaken by a water treatment specialist.

As highlighted in Section 2.2.4 above, BPG G5 does provide some guidance on the methodology that should be followed in defining the nature of water treatment required and the basis on which such treatment systems should be designed and costed. Figure 3 that is shown in Section 2.2.4 is reproduced below in order to facilitate further discussion thereof.

A critical paragraph from BPG G5 that relates to Figure 6 is reproduced below.

*Where the need for water management and treatment actions is envisaged after mine closure, appropriate arrangements must be made for financing and managing the water management/water treatment operations for the designated period of time (in terms of the MPRDA and various regulations defined in R527) after mine closure. In this scenario, and as shown schematically in Figure 6A below, the financial provision must cater for the possibility that the worst case scenario (as determined by probabilistic modelling – see **BPG G4: Impact Prediction**) may develop. It may also be necessary to enter into contractual arrangements with approved third parties (as provided for in the MPRDA). Other examples of impact predictions are shown in Figure 6B and 6C where perpetual and no post-closure water treatment requirements are shown as examples.*

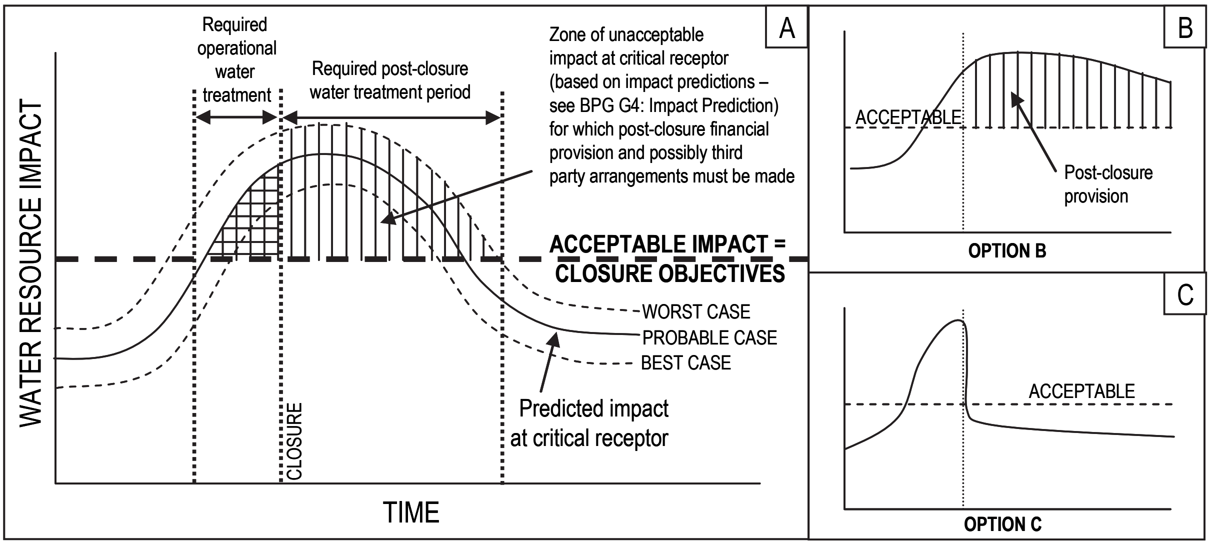

Figure 6: Potential for post-closure water treatment financial provision

Figure 6 contains a concise representation of all the issues that need to be considered in defining the extent of water treatment that needs to be provided for in the post-closure phase.

The first step would be the prediction of long term water quality within a probabilistic framework (in line with BPG G4) that allows for the prediction of a most probable water quality profile as well as best case and worst case scenarios which then needs to be plotted on a timeline with reference to the water quality value that is deemed acceptable. This prediction is for the situation without any water treatment. A number of such predictions and plots would need to be prepared for each of the identified contaminants of concern and each would go through the same process.

Figure 6A indicates graphically that during the operational phase of the mine, the water quality also exceeds the acceptable limits. However, during the operational phase, the mine only provides for treatment from the actual scenario (deemed equivalent to the most probable case prediction). However, in making provision for the post-closure scenario, the degree of treatment that needs to be designed for is to bring the water quality down from the predicted worst case scenario down to the acceptable limit. The time period over which treatment is required is also assumed to be the longest possible time period associated with the predicted worst case scenario. The financial provisions for post-closure water treatment must then cater for this worst case water quality for the worst case period of time.

In Figure 6B above it is clear that for the whole period of prediction, the water quality remains above the acceptable limit and in such a case, provision would need to be made for perpetual water treatment. Figure 6C represents a situation where all the pollution prevention measures implemented as part of mine closure have succeeded in ensuring that predicted post closure water quality is immediately within the acceptable limits and in this scenario no post-closure water treatment is required. Figure 6C therefore represents the most desirable situation for the mine and all other stakeholders. Figure 6A most probably represents a scenario where natural processes within the mine or mine residue disposal facility eventually consume all the pollution-generating material, giving rise to a steady improvement over time until a point is reached where discharge water quality is acceptable without treatment. Application of pollution prevention options have the potential to either reduce the time over which treatment is required or to reduce the amount of contaminant that needs to be removed by treatment - both resulting in reduced post-closure water treatment costs and lower post-closure risks.

CHAPTER 12: CONCLUSIONS

If the procedures and methodology described in this document are followed and all the critical questions are answered by way of undertaking assessments aligned with the procedures set out in BPG G4 and BPG G5 and as expanded upon in this document, then there should be very little new information or surprises at the time that the mine requires approval from the Department of Water and Sanitation for closure. The Department of Water and Sanitation will have an information trail that leads from the start of the mine up till closure for all new mines and will also have a clearly defined set of questions (and desired answers) for mines that are already in operation and that enter this process at some advanced stage in the mine life cycle.

The additional benefit to the mines is that the questions that are being asked and the studies that need to be undertaken to answer the questions, are fundamentally aimed at identifying and maximising the opportunity for the implementation of pollution prevention strategies. The old maxim that "prevention is better than cure" most certainly applies to mine water management too, and the investment of time and resources into answering the questions will provide payback in terms of reduced costs for the mine closure and post-closure water management plan and the surety that the final application for mine closure can be approved by the Department.

Most importantly, by following the procedures and methodology described in this report and the BPGs G4 and G5, the mine will have undertaken the appropriate risk management process to understand, manage and minimise its long term exposure to risk and liability associated with post-closure water impacts.

If the questions defined in this document are answered using the methodology set out in the relevant BPGs then there is no technical/scientific reason for the Department of Water and Sanitation to not approve the post-closure water management plan at the end of mine life.

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ANNEXURE A: LITERATURE REVIEW OF INTERNATIONAL BEST PRACTICE REGARDING POST-CLOSURE WATER MANAGEMENT

A1 INTRODUCTION AND BACKGROUND

The Department of Water and Sanitation recently produced a series of Best Practice Guidelines that give specific guidance on procedures to be adopted in the development of mine closure plans (BPG G5) and in the prediction of future impacts that are associated with mine closure (BPG G4).

While these Best Practice Guidelines provide clear methodologies for undertaking the assessments that are required to support a mine closure application, it remains the responsibility of the State (DWS) to ensure that the risk of unforeseen long-term water pollution problems arising after closure has been granted, is absolutely minimized, taking into account financial realities and practicalities and sustainability of water management measures. In exercising this responsibility, DWS officials are required to provide guidance and decision making with regard to the following key technical issues in the impact prediction and closure application process:

- agreement on the acceptable levels of confidence for the prediction that will limit the State's liability to acceptable levels;
- agreement on the statistical representivity of the datasets used in the prediction and their suitability for addressing the issues that pertain to the particular closure application;
- agreement on the definition and descriptions of uncertainty inherent in the predictions and acceptance that the defined uncertainty meets the requirements of the regulator; and
- agreement on the suitability and adequacy of financial provisions to cater for uncertainties and risks for post-closure water management and treatment

The Best Practice Guidelines do not provide any practical guidance on how the above issues should be addressed and these are left to the discretion of DWS officials that assess the mine closure application. The above issues are technically complex issues to address and agree on and failure to reach such agreement will prevent the finalisation of impact predictions and mine closure applications. Furthermore, agreement on the wrong criteria for the above issues could expose the State (and taxpayers) to unacceptable liabilities with regard to long-term impacts on the water resource.

This literature review aims to carefully analyse the risk elements incorporated in the Best Practice Guidelines BPG G4 and BPG G5 and to then establish international practice in dealing with these issues to serve as background for developing appropriate mechanisms that can be applied in South Africa.

A2 RISK ISSUES IN THE BEST PRACTICE GUIDELINES

The two most important Best Practice Guidelines issued by the DWS that have a bearing on risk issues associated with mine closure are BPG G4: Impact Prediction and BPG G5: Water Management Aspects for Mine Closure. Key risk-related issues raised in these two important BPGs are summarised below as these provide the guidance to the scope to be addressed in this literature review.

A2.1 BPG G4: IMPACT PREDICTION

This BPG provides a recommended approach that should be followed by mines when making predictions of future impacts arising from management actions that have historically been undertaken or are currently being undertaken. Such predictions of future impact could potentially be undertaken for a range of situations, including that which is the interest of this literature review, i.e. mine closure.

The concepts of risk are captured within the general impact prediction principles set out in Chapter 2 of the BPG, specifically the following:

- The traditional and established risk assessment methodology (source term, pathway and receptor) must be used in order to develop an appropriate conceptual model of the scenario to be evaluated – ensure that this step is discussed with and agreed to with all persons who will be reviewing the results of the assessment.
- Understand the need for proper data collection and that confidence in prediction is dependent on quality of data and use of correct tools.
- Understand and define the uncertainty inherent in the impact prediction, based on composite uncertainties of the data collection process, the assumptions made, and the limitations of the tools used.

Chapter 3 of the BPG is titled: "Risk-based Approach to Impact Prediction" and provides guidance on the risk assessment methodology that should be followed in undertaking an impact assessment. Some key statements made in this chapter are highlighted below.

The risk-based approach to impact prediction is favoured by DWS and is consistent with policies and approaches that are subscribed to by DWS in the review and approval of water use licence applications. It is recognized by DWS that any prediction of future impacts has inherent uncertainty which means that there is always a risk that the prediction proves to be incorrect due to the occurrence of some unforeseen future event.

However, in order to accept the risk-based approach and the consequences that go with it, this BPG sets out very specific requirements that must be complied with in order to ensure that the risk is a manageable one. For this reason, the BPG also defines a specific methodology and requires the concurrent involvement of an independent reviewer whenever the impact assessment is used as part of a mine closure application. The defined methodology also requires specific consideration and definition of uncertainties within the assessment process.

*The general principle inherent in the mine closure risk assessment methodology is that the mine must take responsibility for all risks that can be foreseen, by way of a post-closure financial provision, DWS accepts the risks associated with unforeseen events, provided that the impact prediction process complies with the requirements set out in this BPG and in **BPG G5: Water Management Aspects for Mine Closure**.*

The most basic risk assessment methodology is based on defining and understanding the three basic components of the risk, i.e. the source of the risk (source term), the pathway along which the risk propagates, and finally the target that experiences the risk (receptor).

*It needs to be recognized that **source terms** are mining features that are dynamic in nature and that exhibit a variable quality over time, due to changes in hydrology and to changes in the chemistry as sulphide minerals or neutralizing minerals become depleted or vary in reactivity, or as secondary minerals precipitate or redissolve as conditions change. An impact assessment that defines the source term as a static constant feature over time is unlikely to be realistic and would be inappropriate for anything other than the most basic screening level assessment.*

As with the source term, the first step in defining the pathway would be to take cognizance of the questions that need to be answered and to then construct a suitable detailed conceptual model that defines the various pathways of interest and the variables and factors that need to be considered when assessing these pathways. It will normally be important to understand which hydrological conditions will result in the worst case scenario for the receptor of interest and to understand the statistical frequency with which such scenarios could occur.

The critical receptor should be clearly defined in the conceptual model and should then be agreed upon with the affected parties and DWS before the risk assessment and impact prediction is undertaken. The agreement on the guidelines and quality objectives that should apply at the critical receptor must involve DWS officials in addition to other water users where appropriate.

Chapter 5 of the BPG is titled: "Key Impact Prediction Questions" and provides guidance on the type of questions that the impact prediction exercise should be able to answer during different life-cycle phases of the mine. Examples of key questions are the following:

What is the long-term impact of all waste residue deposits (fine and coarse waste) on the water resource (surface and groundwater) in terms of volumes and quality of drainage over the life of mine and post-closure?

What final rehabilitation should be undertaken for the different waste residue deposits in order to meet long-term risk management objectives for the water resource?

Will the mine void (pit or underground mine) decant after mine closure? If yes, where, when, how much and at what quality over time?

What are the drainage volumes and quality for all contaminants of concern for all source terms that pose a potential risk of impacting on the water resource – such profiles to show predictions at least 100 years into the future, or longer if longer periods are required to quantify the impact, as recommended by the specialist and agreed to by the independent reviewer and DWS.

What will the long-term impact be at the critical receptor for the contaminants of concern?

What additional water management (e.g. covers, infiltration reduction measures, etc.) or treatment measures need to be instituted to reduce the contaminant loads from the various source terms or to intercept the pathways in order to ensure that the critical receptor is not adversely impacted?

Finally, Chapter 7 of the BPG is titled: "Principles of Uncertainty" and provides guidance on understanding, describing and quantifying the uncertainties inherent in the impact prediction. Key statements on this topic are reproduced below.

It must be clearly understood that uncertainty is inherent in any prediction exercise and does not represent a fatal flaw with the methodology. Any future prediction of water impacts is based on assumptions about future rainfall, data values that are approximations of reality and tools that attempt to describe natural processes as mathematical formulae. While it is accepted that uncertainty is inherent in any prediction, the important issue is that the specialist undertaking the prediction must be able to describe and define the uncertainty in the prediction, in order that margins of safety can be built into management options and/or financial provisions.

Types of uncertainty mentioned in BPG G4 Chapter 7 include: sampling uncertainties; sample storage and preparation uncertainties; analytical uncertainties; assumption and estimate uncertainties; hydrological uncertainties; extrapolation uncertainties; mathematical modelling uncertainties; and model coupling uncertainties.

The BPG G4 also provides some discussion on the use of sensitivity analyses and probabilistic modelling as tools to defining uncertainty.

Finally, Chapter 7 has the following to say about the issue of defining acceptable confidence limits:

The definition of acceptable confidence limits and an acceptable degree of uncertainty is a difficult yet important task. From the regulator's perspective, the acceptable confidence limit refers to the mine closure situations where the objective of mine closure is to transfer risk and liability to the State. The confidence limits indicate the probability that the end result will be outside the boundaries defined in the impact prediction exercise, e.g. for a 90% confidence limit, the chance of the real life situation at a future date being outside the predicted boundaries is 10%. Once this has been defined, the appropriate margins of safety for developed management actions and financial provisions can be identified.

A2.2 BPG G5: WATER MANAGEMENT ASPECTS FOR MINE CLOSURE

This BPG provides considerable detail on the methodologies and approach that should be followed to gain an understanding of the post-closure water management risks and how to make provision for managing these risks.

This BPG makes the following comments In Chapter 2 relating to risk assessment and risk issues:

A2.2.1 Technical process principles

Risk-based approach

This implies consideration of several issues, including:

- *Demonstrable conservatism must be built into any assumptions that need to be made in lieu of appropriate data sets (precautionary principle). These assumptions should be clearly documented and motivated.*
- *A risk-based assessment should be undertaken by a suitably qualified person(s) with the necessary qualifications and experience to ensure the results are credible and unbiased.*
- *Wherever quantitative environmental risk assessments or impact predictions are made, the mine should, through prior consultation with the authorities, obtain agreement on the modelling techniques and tools to be used. This will ensure that such techniques are acceptable to the authorities, and that the results will be acceptable – see* ***BPG G4: Impact Prediction****.*
- *The surface residue deposits that remain after mine closure can never be maintained in a completely reducing environment and must be considered to pose a potential water related risk until shown otherwise by way of a suitable semi-quantitative or fully quantitative geochemical assessment – see* ***BPG A2: Water Management for Mine Residue Deposits****.*
- *Underground and opencast mine workings will fill up either partially or completely with water over time (slow or fast depending on geohydrological setting) and this water will be contaminated (either for a limited time or in perpetuity). A key element influencing the risk that these processes pose to the water resource is whether or not this contaminated water will decant into the underground aquifers or into the surface water resource and to what extent the natural water resource can assimilate this contamination. The mine workings must, therefore, be considered to pose a potential water related risk until shown otherwise by way of a suitable semi-quantitative or fully quantitative geohydrological and geochemical assessment – see* ***BPG A5: Water Management for Surface Mines*** *and* ***BPG A6: Water Management for Underground Mines****.*
- *In certain mining regions (e.g. near dolomitic compartments), mine dewatering activities and placement of surface residue deposits pose a long-term risk with regard to formation of sinkholes, which in turn pose safety, water resource and land use risks that need to be assessed.*
- *An understanding is required that mine closure is not about greening, but rather long-term pollution control and risk/hazard management. This involves consideration of a range of issues, and a range of possible management strategies.*
- *A risk-based approach includes a cradle to grave assessment on waste or waste streams, that is, from the point where they are generated, to their final disposal or reuse.*
- *Lastly, a risk-based approach will include the risk of failure of systems or management strategies. The consequences of such failure should be taken into account and the necessary contingency and/or emergency measures should be addressed either in the management measures and/or in the financial provisions.*

Communication and public participation

- *All interested and affected parties (IAPs) should be involved in the development of the risk-based strategy. While the timing and extent of this will vary from site to site, it is a key aspect that a risk communication component is included.*
- *Inherent in a risk based approach is that a clear paper trail is required so that others can understand the method whereby risks have been quantified. As indicated previously, all relevant assumptions should be documented.*

A2.2.2 DWS decision-making process principles

The very nature of risk-based management actions and strategies is that there is always a risk that some unforeseen long-term pollution problem develops. The primary departure point that DWS will be bearing in mind when undertaking or reviewing a closure application for a mine site where water pollution is believed to be a potential risk element, is that approval and granting of closure poses an increased risk to the State (and therefore the citizens of South Africa) of attracting liabilities previously only attributable to the mine. It is the responsibility of the State (DWS and DMR) to ensure that the risk of unforeseen long-term water pollution problems arising after closure has been granted, is absolutely minimized, taking into account financial realities and practicalities and sustainability of water management measures.

In order to ensure that this risk is minimized to an acceptably low level, DWS will review a closure plan or closure application in terms of its compliance with the principles set out below.

1. *There must have been consultation and agreement with DWS (see authorisation levels in DWS operational guidelines) and other Stakeholders on closure objectives for the mine and the mine closure plan must have demonstrated that it complies with these agreed closure objectives.*
2. *There must be full disclosure by the mine of all the data, facts, assumptions and any other relevant information that will or could potentially have a bearing on the decision to approve or to reject the closure application. Failure to fully disclose such information could result in the automatic rejection of the closure application. Discovery of such failure to fully disclose after closure has been approved could result in DWS applying corrective measures in terms of Section 19 of the NWA.*
3. *The risk assessment and impact predictions (see **BPG G4: Impact Prediction**) must be fully documented in a comprehensive technical report that sets out the detailed methodology that must, as a minimum, include the following information:*
    - *detailed description of the objectives of the assessment and the technical questions that were set to be answered in the assessment*
    - *detailed conceptual model for the individual components (source terms) and the integrated facility for which closure is being applied and the manner in which it interacts with the environment (i.e. all relevant impact pathways and critical receptors);*
    - *full disclosure and documentation of all data and assumptions used, with all assumptions to be motivated and properly referenced – such references to be made available to the State upon request;*
    - *statement on the statistical representivity of the dataset and its suitability for addressing the issues that pertain to the particular closure application;*
    - *detailed description of sampling techniques applied, analytical techniques used, data assessment techniques used and mathematical models used;*
    - *discussion on how the issue of uncertainty in data and assessment techniques has been accounted for in the predictions on future environmental impact and what confidence can be placed in the predictions;*
    - *detailed definition of verification monitoring programme to collect data for future (typically 3-5 years after prediction was made) validation of predictions and, in the case of an actual closure application, the results of the validation exercise confirming the accuracy and reliability of the predictions of future impact.*
    - *findings of all peer reviews done as part of the process (see **BPG G4: Impact Prediction** on the precise role and input required from an independent reviewer), as well as how the findings were addressed;*
    - *detailed documentation of all IAP consultations and how these consultations have been incorporated into the closure process to demonstrate real commitment to IAP involvement;*
    - *details of all post-closure impacts and management and maintenance measures that have been proposed to mitigate and manage such impacts to the point where they are within the limits set and agreed for the critical receptor(s);*
    - *financial provision for construction, operation and maintenance of post-closure water management measures where required and for as long as predicted to be required; and*
    - *third party involvement (if any) in post-closure and contractual agreements.*

4. *The study must be undertaken by suitably qualified persons using appropriate public-domain mathematical models and assessment techniques that are generally accepted in the scientific community as being suitable for the assessment being undertaken. While proprietary models can, with suitable motivation, be used for assessments undertaken by mines for non mine-closure situations, this is not the case where mine closure is being sought. The requirement for public domain models is to ensure that the performance of the model in undertaking the assessment at hand can be independently validated and that a suitably qualified third party could review the input files used and recreate the predictions independently, if deemed necessary. The procedures set out in* ***BPG G4: Impact Predictions*** *should be applied.*

In all cases, the closure application must be evaluated taking into account the site-specific circumstances and the sustainability of the management measures put in place to address the long-term (post closure) environmental impacts.

A2.2.3 Key questions in the DWS decision-making process

From DWS's perspective, based on the realistic assumption that DWS will not have the in-house expertise to properly review a detailed and integrated impact prediction assessment that incorporates integration of numerous hydrological, geohydrological and especially geochemical modelling exercises, the key questions that must be answered when considering a mine closure plan and/or mine closure application, are the following:

1. *Does the assessment fully comply with* ***all*** *aspects of the independent review process as set out in* ***BPG G4: Impact Prediction****?*
2. *Does the closure plan consider all the relevant principles described in Section 2.1 and does it present all the information requested in Section 2.2 (of BPG G5) above in a clear written report and has all such information been verified by the appointed reviewer?*
3. *Has the assessment included clear evidence, supported by the independent reviewer, that all impact prediction assessments and models have been fully calibrated and validated using information collected from a verification monitoring programme?*
4. *Does DWS have written confirmation from the appointed reviewer that his/her review was undertaken independently, objectively, scientifically, without bias or favour to any party, that he/she was given full access to all information required to undertake the review and that he/she deems him/herself competent to have undertaken the review?*
5. *Does DWS have written confirmation, from a duly appointed representative of the mine's Board of Directors, that the mine closure application is based on full and complete disclosure of all information that could in any way be pertinent to the consideration of the mine closure application and that no potentially damaging information has been withheld?*
6. *Does DWS have confirmation, through an independent assessment by suitably qualified persons, that all the stipulated and agreed water management actions and measures (including any water treatment plants that may be required) have been properly implemented and that sufficient/adequate financial provisions have been made and that suitable contractual arrangements have been entered into with approved third parties to ensure that all the required operational, maintenance and financial measures will be implemented and audited for as long as has been predicted to be necessary to ensure that the agreed closure objectives are met?*

Provided that a clear YES answer can be given to the abovementioned six questions, then DWS will be in a position to consider the mine closure plan and/or mine closure application and to make an informed and motivated decision that can be forwarded to the mining proponent and can then prepare a record of decision.

Importantly too, provided the above 6 questions have been answered with an unambiguous YES and provided that no future information comes to light that shows that the above questions were not truthfully answered, the approval of mine closure by DWS, will constitute an acceptance by DWS that it accepts any future risks associated with the closed mine and that it will not utilise the NWA to seek redress from the *mining company. This undertaking falls away in the event that it comes to light that any of the 6 questions were not answered truthfully.*

The risk that DWS is prepared to accept in approving a mine closure application is the risk of the genuinely unforeseen events. The principles and procedures set out above and in the remainder of this document are aimed at ensuring that the technically correct process is followed, that suitably qualified persons are engaged, that appropriate independent review procedures are followed and that there is full disclosure of all pertinent information. This process will then culminate in the development of appropriate management actions to address predicted post-closure impacts and the provision of appropriate financial resources to implement these actions (i.e. polluter pays principle). However, it is accepted that, despite following the abovementioned procedures, the possibility exists that some unforeseen event could occur which results in a greater post-closure impact than that which was predicted. In such a case, provided the procedures in this BPG have been followed and there was full disclosure of all relevant information by the mine at the time of the closure application, then DWS accepts the risk and responsibility of managing such unforeseen impact.

A2.2.4 Financial provisions for post-closure water management

Finally, Chapter 8 of BPG G5 makes a number of key statements relating to risk and the need for financial provisions for post-closure water management. Chapter 8 of BPG G5 is reproduced in its entirety below.

In many mine closure situations, there is a risk of an unacceptable post-closure risk to the water resource, as determined by an appropriate risk assessment and impact prediction (see ***BPG G4: Impact Prediction****). In such situations, there will be a need to determine the financial provisions required to fund both the capital cost of appropriate water management measures and the operating costs associated therewith. In cases where the water management measures are required for a number of decades, provision may also be required to reconstruct the appropriate measures after their design life has been exceeded.*

While the DMR has prepared a guideline for determining financial provisions, there is no standardized formula or factor that can be applied to determining what the financial provisions for water management should be, as each mine site will have very site specific requirements. The generic approach that would underpin the determination of the water management financial provisions is as follows:

1. *Determine objectives for the water resource (i.e. set acceptable levels of impact or risk to the identified critical receptor) that the mine would need to meet on closure.*
2. *Undertake a quantitative risk assessment and impact prediction exercise (see* ***BPG G4: Impact Prediction****) for the base case situation (application of standard minimum best practice measures) and determine whether or not the water management closure objectives would be met.*
3. *If not, undertake a second round of quantitative assessments (see* ***BPG G4: Impact Prediction****) for a range of defined and agreed alternative management measures (give preference to pollution prevention and passive measures with minimum long-term maintenance requirements – see* ***BPG H2: Pollution Prevention and Minimisation of Impacts****) and determine whether any of these options meet the agreed water management closure objectives. If an option can be identified that meets the closure objectives, determine the capital and operating costs for that management option and include it into the mine's financial provisions.*
4. *If, even after application of an appropriate water management option, the agreed water management closure objectives are not met, then provision must be made for interception of the source of water contamination (diffuse and point sources) and treatment of the intercepted water in order that the closure objectives can be met – see* ***BPG H4: Water Treatment****.*
5. *The duration of the required water treatment measures will depend on the outcome of the quantitative impact assessment that is undertaken and will need to coincide with the duration over which the closure objectives will not be met. An example is shown in Figure A1 below.*
6. *Determine the capital and operating costs for the full period over which the water treatment needs to be applied and incorporate this into the closure financial provisions.*

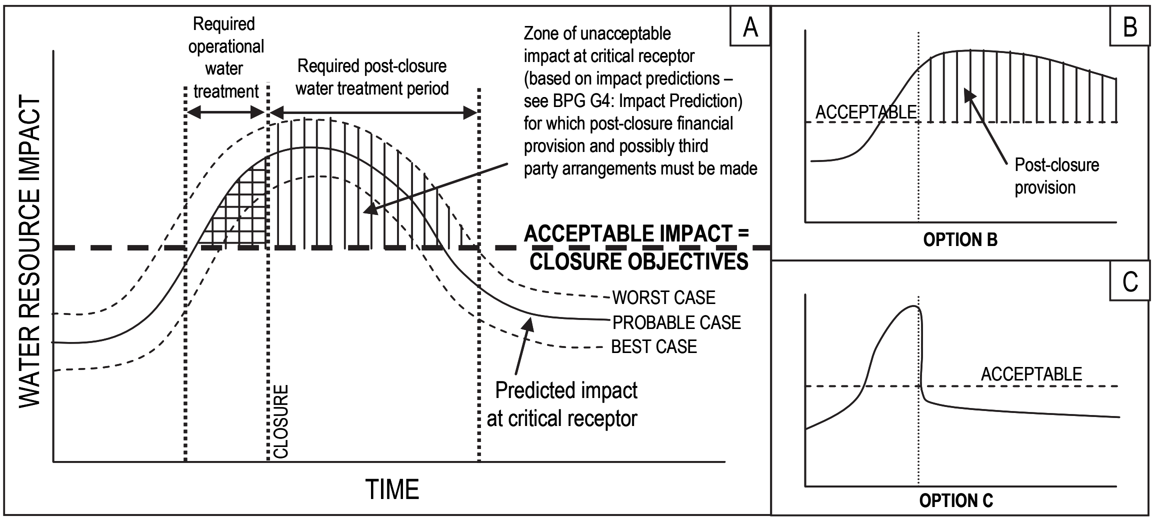

Figure A1: Potential for post-closure water treatment financial provision

*The assessments that need to be undertaken to determine the need for water management and/or water treatment measures would need to be undertaken in full compliance with the procedures set out in **BPG G4: Impact Prediction**. In particular, it will be necessary to ensure that the peer review process specified for mine closure-related assessments is complied with and that the specialist team undertaking the assessments incorporate persons with the appropriate skills and expertise in water management and treatment options.*

With the scarcity of water in South Africa and the future implementation of the Waste Discharge Charge System, mine closure management options that result in the interception and evaporation of contaminated water are not acceptable, and management measures should be implemented to eliminate this water use. The worst case scenario is that the intercepted water will need to be pumped to a water treatment plant and treated and provision for this eventuality must then be incorporated into the mine closure financial provisions. <u>In cases where there are regional interconnections between mines, or there is a combined impact or use of a combined water treatment plant an apportionment of financial liability for any cumulative or combined water treatment need must be made to the satisfaction of the regulatory authorities</u>.

*Where the need for water management and treatment actions is envisaged after mine closure, <u>appropriate arrangements must be made for financing and managing the water management/water treatment operations for the designated period of time</u> (in terms of the MPRDA and various regulations defined in R527) after mine closure. In this scenario, and as shown schematically in Figure 1 A above, the <u>financial provision must cater for the possibility that the worst case scenario</u> (as determined by probabilistic modelling – see **BPG G4: Impact Prediction**) <u>may develop</u>. It may also be necessary to enter into contractual arrangements with approved third parties (as provided for in the MPRDA). Other examples of impact predictions are shown in Figure 1 B and 1 C where perpetual and no post-closure water treatment requirements are shown as examples.*

A2.3 SUMMARY OF KEY ISSUES RAISED IN BPGS

Review of the extracts form BPG G4 and G5 which have been reproduced in Sections 2.1 and 2.2 above, indicate that there are a number of key issues that need to be explored and clarified to ensure that there is no ambiguity with regard to the requirements for mine closure. It is also clear that application of the risk-based approach to impact prediction requires the mine to reach agreement with DWS (and often with broader stakeholders too) on the following key issues:

1. The conceptual model that is being proposed as being appropriate for the risk assessment and impact prediction from the particular mine site.

2. The tools that will be used for site characterisation and for predictive modelling of source terms, pathways and effects on receptors.
3. Location of critical receptor(s) and what the acceptable water quality criteria for these receptors should be.
4. Assurance that demonstrable conservatism has been built in where assumptions are made in lieu of actual data.
5. Statistical representivity of data sets
6. That suitably qualified persons are undertaking the assessment and the review.
7. The key questions that need to be answered in the impact prediction exercise.
8. Agreeing on what the "foreseen risks" are.
9. The confidence limits that are deemed to be acceptable to the particular situation being assessed by way of defining and describing uncertainties in the assessment process.
10. Need to incorporate the risk of failure of systems

With regard to the issue of post-closure water treatment, the BPG G5 requirements can be summarised as follows:

11. A prescribed risk assessment process must be followed (as set out in BPG4)
12. Interception and evaporation of discharges is not a preferred option.
13. The possibility of regional interactions and the need for regional water management/treatment options must be considered.
14. Where post-closure water treatment is required, the extent of treatment must be determined using probabilistic modelling and must cater for the worst case scenario.

Points 1-9, 11 and 14 are all related to following the correct risk assessment and impact prediction process as using the correct process will automatically ensure that all these issues are addressed. Point 10 is a statement that needs to be addressed and agreement needs to be reached with DWS as to what failure events need to be catered for. Point 12 is a policy statement and Point 13 is a practical issue that needs to be addressed within the broader context of regional closure strategies.

A3 OBJECTIVES AND SCOPE OF THE LITERATURE REVIEW

A clear definition of the objectives of the literature review can be derived from the problem statement as defined in the project proposal and by considering the key issues as summarised in Section A2.3 above. The problem statement in the project proposal is as follows:

DWS officials are required to provide guidance and decision making with regard to the following key technical issues in the impact prediction and closure application process:

1. *agreement on the acceptable levels of confidence for the prediction that will limit the State's liability to acceptable levels;*
2. *agreement on the statistical representivity of the datasets used in the prediction and their suitability for addressing the issues that pertain to the particular closure application;*
3. *agreement on the definition and descriptions of uncertainty inherent in the predictions and acceptance that the defined uncertainty meets the requirements of the regulator; and*
4. *agreement on the suitability and adequacy of financial provisions to cater for uncertainties and risks for post-closure water management and treatment*

Point 1 will be addressed if the process described in BPG G4 is fully complied with and, most importantly, once data has been tabled to demonstrate that the recommended model verification and calibration procedures have been undertaken. The solution to this dilemma lies in following the scientifically correct process and not through arbitrary stipulation of a number such as 90% confidence limit. The correct approach is to present a thorough technical report that clearly demonstrates compliance with the technical procedures set out in BPG G4 and the additional clarification on key technical points provided in this literature review.

Point 2 will be addressed if the mine proponent complies with the requirements set out in BPG G4 and in this literature review on how the geochemical assessment and predictive modelling toolboxes should be used. Specific guidance needs to be provided on the correct procedure that should be followed to determine the statistical confidence that can be placed in the collected data and to confirm that the correct sampling density has been undertaken to account for variability in measured parameters.

Point 3 will be addressed by ensuring that the proponent follows the prescribed rigorous assessment procedure set out in BPG G4 and G5 which is based on international best practice and which, if followed properly, will give the assurance that the risk of a flawed prediction and conclusions is negligible. The external review throughout the process is a key component of this assurance. Additional discussions on sources of uncertainty and recommendations on how to define and limit this uncertainty is provided in this literature review.

Point 4 will also be addressed by demonstrating compliance with the procedures set out in BPG G4, together with the additional detail provided in this literature review. The inputs of water treatment specialists will also be required to define the appropriate water treatment technology and to establish capital and operating costs for this technology.

In summary, consideration of the information provided in Section A2.3 above and the discussion presented on the above 4 points, enables the definition of the appropriate scope and content of the literature review.

- Risk assessment process that supports impact prediction – Section A4
- Definition of questions to be answered in a mine closure water impact prediction assessment – Section A5
- Description of uncertainties along the whole assessment path – Section A6
- The mine site conceptual model – Section A7
- Sampling and analytical techniques and their statistical representivity – Section A8
- Selection and application of correct predictive modelling techniques able to address the real questions and consider the key variables, run in a probabilistic framework – Section A9
- Use of suitably qualified persons to undertake assessment and evaluate outcomes in order to accurately define upper and lower bounds of confidence in outcomes – Section A10
- Monitoring and collection of key data to allow verification and validation of predictions – Section A11
- Agreement on what the foreseen risks should include – Section A12
- Specific issues relating to post-closure water treatment – Section A13

A4 THE RISK ASSESSMENT PROCESS FOR IMPACT PREDICTION

A4.1 BACKGROUND

Risk assessment techniques are today widely accepted as the most robust manner in which technically complex problems should be tackled in a systematic manner, leading to identification of key priority risk issues that should receive priority attention in a risk mitigation plan. The risk assessment process is applied in areas of mine exploration, ore body evaluation, financial modelling and decision making, safety and health management and environmental management and decision making.

Use of the risk assessment approach in closure planning to evaluate risk and cost benefit in both engineering and environmental terms is widely accepted in the mining industry globally (ICMM, 2008; ANZMEC, 2000, Australian Government, 2006 and others). It is stated that the advantages of a risk-based approach to closure planning lie in the quantification of subjective factors and the analysis of uncertainty related to both design performance and cost (ANZMEC, 2000).

To this end, a family of standards relating to risk management have been codified by the International Organisation for Standardization (ISO) and issued as ISO 31000. The general scope of ISO 31000 is not developed for a particular industry group, management system or subject matter field, but is rather aimed at providing a best practice structure and guidance to all operations concerned with risk management (Anon, 2012).

Risk assessment is a step in a risk management procedure. Risk assessment is the determination of quantitative or qualitative value of risk related to a concrete situation and a recognised threat (also called hazard) (Anon, 2012). Quantitative risk assessment requires calculations of two components of risk; the magnitude of the potential effect and the probability that the effect will occur.

According to Graham, 2009, the key requirements of a good risk assessment are the following:

- Transparency in data and models (ability to replicate)
- Rigorous expert peer reviews
- Opportunity for stakeholder comment and explicit response to those comments
- Responsiveness to informational needs of the regulator

All these requirements are incorporated into the closure planning and impact prediction methodology set out in BPG G4 and G5.

A4.2 RISK ASSESSMENT/MANAGEMENT PROCESS IN TERMS OF ISO 31000

The International Organization for Standardization (ISO) is a worldwide federation of national standards bodies. ISO prepared its 31000 standard, “Risk Management – Principles and Guidelines” (ISO, 2009) and supporting standards in recognition that all types of organizations need to address factors and uncertainties that challenge their objectives (i.e. risks). The standard defines various principles regarding the integration of risk management into organizations’ processes and the expectations for risk management evaluations. The consistent use of risk management requires a management framework to embed, support, and improve the processes throughout the organization. The implementation of a risk management approach is, in turn, supported by a structured process that includes establishing the context (e.g. the specific objectives and decisions, internal and external factors to consider, and decision-making criteria), assessing the risks, selecting options, monitoring results and revising actions and processes, and communicating with various stakeholders. The relationship between the principles, framework, and risk management process are shown in the following figure.

This risk management framework is the context within which the impact prediction and closure planning process should be undertaken. The principles shown in the Figure below are principles that resonate with those presented in the BPGs. The risk assessment process is also aligned with that described in the BPGs and the steps shown in the process below can be considered to be equivalent to the BPG Impact Assessment process as follows:

Establish the context = define impact assessment /closure objectives

Risk Identification = define the questions that need to be answered in the impact assessment

Risk Analyses = undertake the impact prediction (develop conceptual model; design and implement site characterisation process; select prediction code; define code input parameters; undertake predictions; produce results)

Risk Evaluation = assess outcome of impact prediction and decide which risk mitigation measures should be implemented

Risk Treatment = implementation of risk mitigation measures

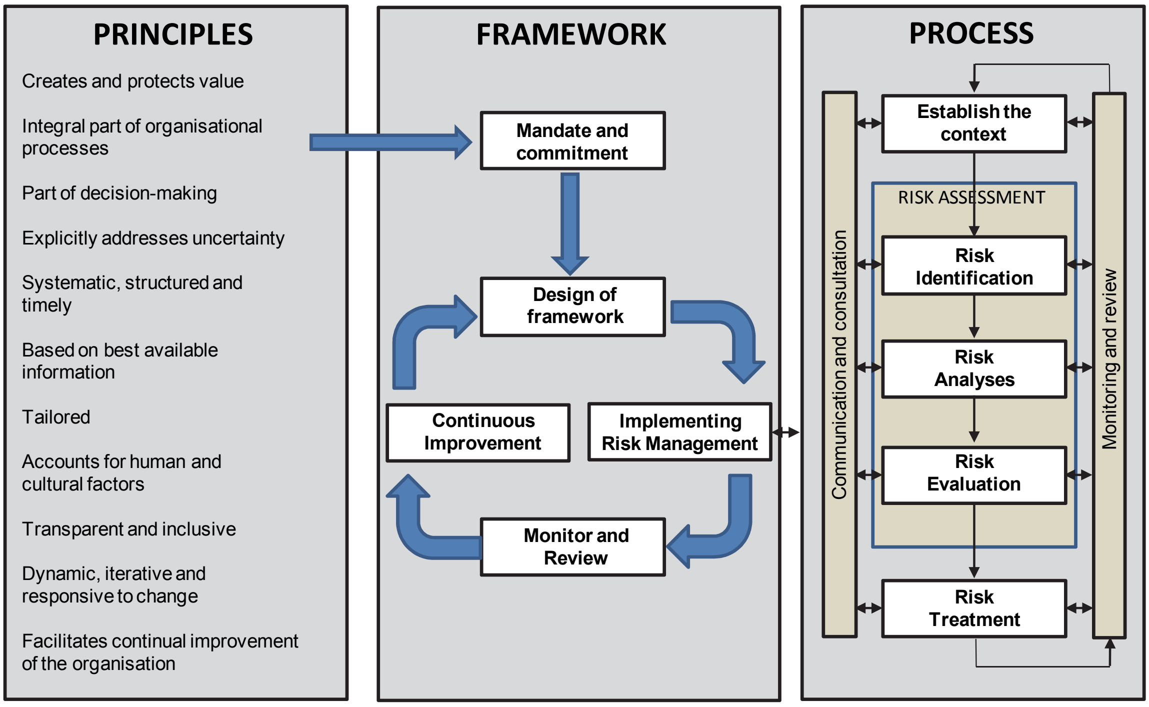

Figure A2: ISO risk framework

The ISO 31000 risk management framework is also adopted by the Australian Government (2006) in its recommendation on how mine closure planning should be undertaken.

A4.3 UNDERSTANDING RISK DECISION MAKING

The National Resource Council has performed several studies related to risk assessments and risk management as they apply to various government functions and public health concerns. In 1996, the Council documented (National Research Council, 1996) a study it had undertaken to address the following task statement:

"Risk characterization" is a complex and often controversial activity that is both a product of analysis and dependent on the processes of defining and conducting analysis. The study committee will assess opportunities to improve the characterization of risk so as to better inform Decision-making and resolution of controversies over risk. The study will address: technical issues such as the representation of uncertainty; issues relating to translating the outputs of conventional risk analysis into non-technical language; and social, behavioural, economic, and ethical aspects of risk that are relevant to the content or process of risk characterization."

The report offers seven principles to increase the likelihood of achieving sound and acceptable decisions. These principles are as follows:

1. Risk characterization should be a decision-driven activity, directed toward informing choices and solving problems.
2. Coping with a risk situation requires a broad understanding of the relevant losses, harms, or consequences to the interested and affected parties.
3. Risk characterization is the outcome of an analytic-deliberative process. Its success depends critically on systematic analysis that is appropriate to the problem, responds to the needs of the interested and affected parties, and treats uncertainties of importance to the decision problem in a comprehensible way. Success also depends on deliberations that formulate the decision problem, guide analysis to improve decision participants' understanding, seek the meaning of analytic findings and uncertainties, and improve the ability of interested and affected parties to participate effectively in the risk decision process.

The process must have an appropriately diverse participation or representation of the spectrum of interested and affected parties, of decision makers, and of specialists in risk analysis at each step.

4. The analytic-deliberative process leading to a risk characterization should include early and explicit attention to problem formulation; representation of the spectrum of interested and affected parties at this early stage is imperative.
5. The analytic-deliberative process should be mutual and recursive. Analysis and deliberation are complementary and must be integrated throughout the process leading the process benefits from feedback between the two.
6. Those responsible for a risk characterization should begin by developing a provisional diagnosis of the decision situation so that they can better match the analytic-deliberative process leading to the characterization to the needs of the decision, particularly in terms of level and intensity of effort and representation of parties.
7. Each organization responsible for making risk decisions should work to build organizational capability to conform to the principles of sound risk characterization. At a minimum, an organization should pay attention to organizational changes and staff training efforts that might be required, to ways of improving practice by learning from experience, and to both costs and benefits in terms of the organization's mission and budget.

The Council's report provided the following schematic representation of a risk decision process:

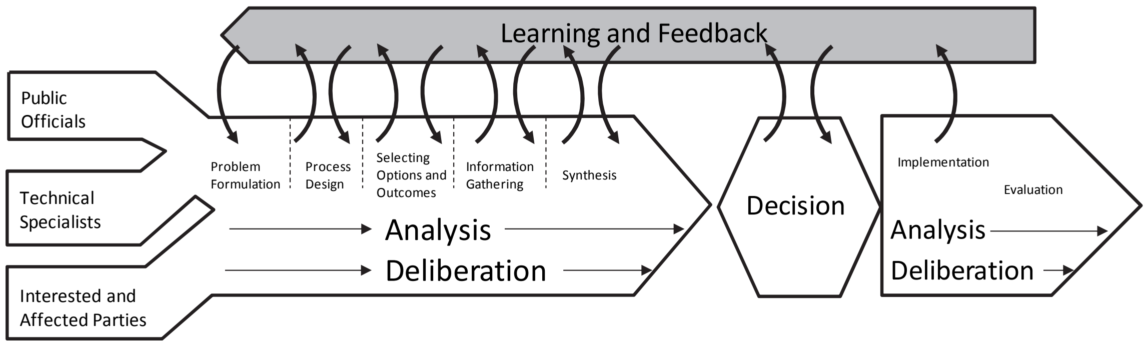

Figure A3: Risk decision process

A4.4 RISK GOVERNANCE FRAMEWORK

The International Risk Governance Council (IRGC) is a private, independent, non-profit foundation based in Geneva, Switzerland. It was founded in 2003 with a mission to support governments, industry, nongovernmental organizations, and other organizations in their efforts to deal with major and global risks facing society and to foster public confidence in risk governance. The IRGC was established to address widespread concern within the public sector, the corporate world, academia, the media, and society at large that the complexity and interdependence of an increasingly large number of risk issues was making it ever more difficult for risk managers to develop and implement adequate risk governance strategies.

They produced a white paper, entitled "Risk Governance – Towards an Integrative Approach" (IRGC, 2005) to describe a framework for an integrated, holistic, and structured approach for improving the ways risk is identified, assessed, managed, monitored, and communicated. The IRGC framework is depicted in the Figure below.

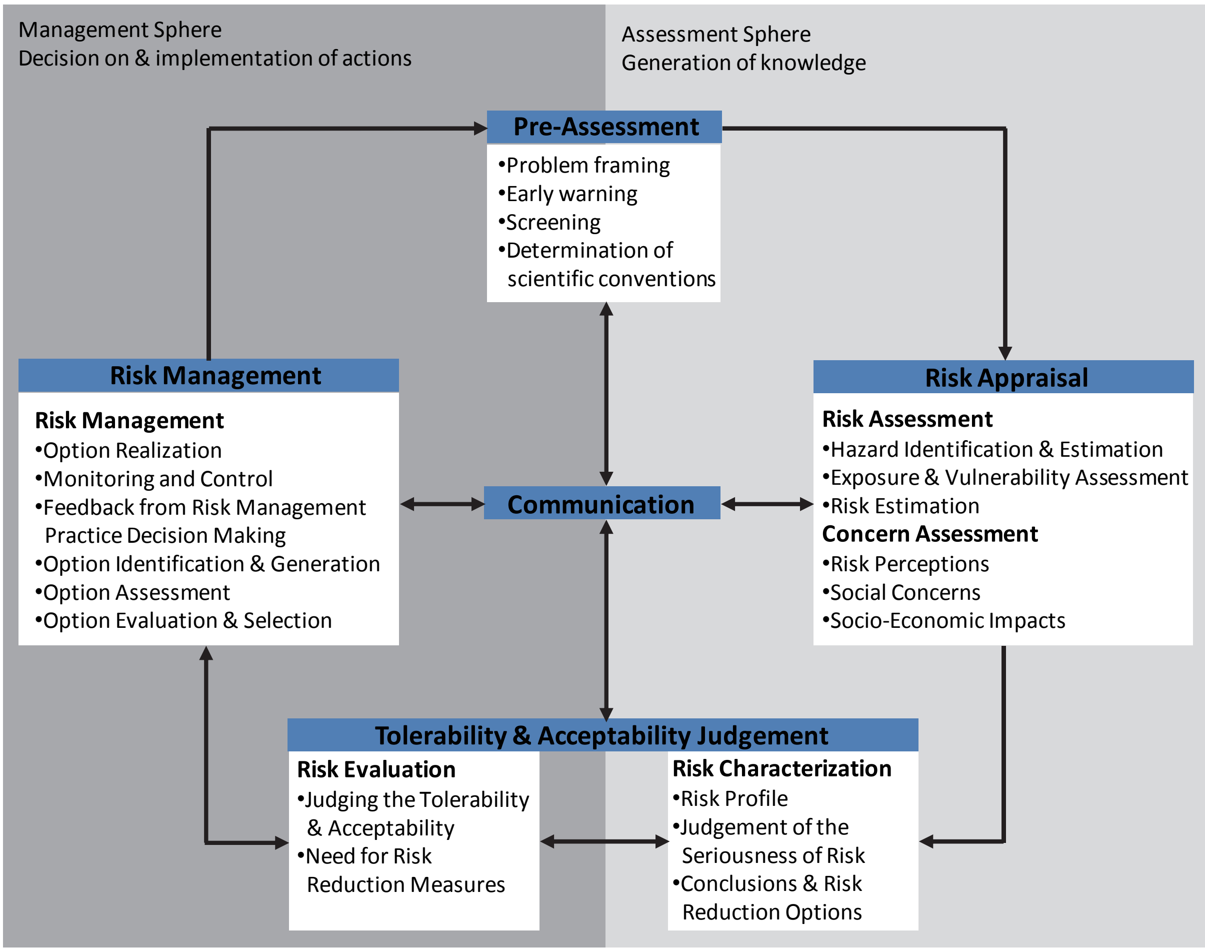

Figure A4: Risk governance framework

The IRGC risk governance framework and its sequence of pre-assessment, risk appraisal, risk characterization, risk evaluation and risk management is also discussed in a report by the Organization for Economic Cooperation and Development (OECD). The report, entitled “Risk and Regulatory Policy – Improving the Governance of Risk” (OECD, 2010) is one of a series of OECD reports on regulatory reforms. A premise of the report is that there is a gap between the level of risk that is aspired to by policymakers and the level that is achievable through regulation. In addition, the report acknowledges that since not all risks can be reduced to zero, tradeoffs in risk reduction measures are inevitable. The OECD studied areas for the improvement of risk governance through an analysis of the legal, procedural, and practical challenges for risk regulation.

A4.5 SUMMARY OF RISK MANAGEMENT FRAMEWORKS

There are many general descriptions of risk management processes or methodologies that include similar key points. A review of many of the frameworks and processes for risk management reveals that most share common steps or phases. Not surprisingly, these risk management frameworks are a variation of traditional decision-making models. The steps to a basic risk-based decision-making model are as follows:

- define the problem and the desired outcome
- research and identify options
- analyse alternatives
- make a decision, (i.e. choose an alternative)
- implement the decision
- monitor the results

A4.6 WHAT IS AN ACCEPTABLE RISK?

There are a number of approaches that could be followed to determine when an assessed risk is acceptable and when it is not and mitigation measures should be considered. The different approaches range from imposition of arbitrary limits, economic cost-benefit assessments to political decisions (Hunter and Fewtrell, 2001).

The concept of an acceptable risk is normally expressed as an increased risk in developing cancer or of death in a given population. For example, the risk of developing cancer associated with background levels of exposure to environmental contaminants is estimated at 10^{-3} to 10^{-2} (Travis, 1991). The lifetime risk of dying in a car accident is 2 in 100 (Travis, 1988).

The general consensus in the literature is that the "acceptability" of a risk is a judgement decision properly made by those exposed to the hazard or their designated health officials. It is not a scientifically derived value or a decision made by outsiders to the process (Kelly, 1991). Travis *et al*., 1987, attempted to answer the question of what is acceptable risk indirectly by quantifying the risk levels associated with 132 federal (US) regulatory decisions and thus determine a *de facto* level of acceptable risk. From this effort, they convincingly concluded that the *de facto* level of acceptable risk in federal regulatory decisions is approximately 10^{-4}. The risk of 10^{-4} is a shorthand description for an increased lifetime chance of 1 in 10000 of developing cancer due to lifetime exposure to a substance.

This is a significant variation from the often quoted standard of a 10^{-6} risk being defined as an acceptable risk. Kelly, 1991, very convincingly demonstrates that this value of 10^{-6} has no scientific basis and evolved out of a misunderstanding of an risk value initially set for an essentially zero risk for residues of animal drugs and how this value was then propagated into a criterion used to guide environmental clean-up programmes.

Kelly, 1991 concludes with the following statement: "The solution to developing better criteria for environmental contaminants is not to adopt arbitrary thresholds of "acceptable risk" in an attempt to manage the public's perception of risk, or develop oversimplified tools for enforcement of risk assessment. Rather, the solution is to standardize the *process* by which risks are assessed and to undertake efforts to narrow the gap between the public's understanding of actual versus perceived risk."

This approach is consistent with the methodologies set out in the DWS BPG G4 and G5 where the emphasis is placed on developing a rigorous *process* and methodology that must be followed in undertaking a mine closure assessment.

Cost-benefit considerations are important in deciding upon the merit of potential risk reduction measures and, in particular, in demonstrating that risks are as low as is reasonably practicable. In addition to the actual costs of any proposed measure, the associated benefits need to be judged in terms of both the relative reduction in risks and the resultant residual risk. The merit of allowing for cost-benefit arguments in determining actions to reduce risks has been recognised within the Environment Act 1995 (UK), which states (para. 39)

'Each new Agency –

(a) in considering whether or not to exercise any power conferred upon it by or under any enactment, or
(b) in deciding the manner in which to exercise any such power,
shall, unless and to the extent that it is unreasonable for it to do so in view of the nature or purpose of the power or in the circumstances of the particular case, take into account the likely costs and benefits of the exercise or non-exercise of the power in the manner in question.'

The use of risk criteria to assist the decision-making process associated with management of environmental risks has been referred to above. Any such criteria are only one of the factors used in this process. The operator needs to justify to the Competent Authority the criteria used to make risk management decisions under COMAH (Control of Major Accident Hazards). It is suggested that a general framework incorporating three broad categories of risk would form a suitable mechanism for helping this process. The three broad categories of risk may be summarised as:

- a lower level of risk beneath which risks are of minimal concern. These require continued monitoring to ensure they remain low;

- an intermediate level of risk between the above two regions within which risks require some further consideration but which do not necessarily require the instigation of risk reduction measures provided that it can be demonstrated that it is not practicable to reduce risks further (the area in which ALARP and BATNEEC considerations are particularly important); and

- an upper level of risk above which risks are priorities for further attention (for example, reviewing the assumptions and modelling used in the risk assessment, or implementing risk reduction measures). The action selected will depend on factors such as the relative costs, benefits and level of residual risk of the different approaches or of undertaking further risk assessments.

Based on the information presented in this section, it is proposed that the above-mentioned three broad risk categories could be given values as follows:

- lower level of risk beneath which risks are of minimal concern - 10^{-6}
- upper level of risk above which risks are priorities - 10^{-4}
- intermediate level of risk 10^{-4} to 10^{-6}

However, it should be reiterated that the recommended approach in assessing acceptable risk is to focus on the process rather than an arbitrary risk level.

A5 MINE CLOSURE OBJECTIVES AND IMPACT PREDICTION QUESTIONS

A5.1 BACKGROUND

As a general principle, it can be stated that the primary objective of successful mine closure is to ensure that the former mine site is restored to a condition where it no longer represents any kind of environmental, health or safety risk (Heikkinen *et al.*, 2008).

Mine closure is essentially about rehabilitating the mine to a point where the regulatory authorities are willing to sign off on a mine closure approval and thereafter, the risk essentially passes to the State. As a consequence, in many countries, the procedures applied in mine closure are increasingly aligned with best practice principles. The global mining industry has already reached a consensus concerning restoration of mining areas to a stable environmental state, physically, chemically and ecologically, so as to minimise potential environmental and health risks (MMSD, 2002).

The derivation of the appropriate questions that need to be answered in a closure impact prediction exercise must derive from an understanding of what the objectives of the mine closure process are. While there are many different ways of stating these objectives and while it is also necessary to formulate site-specific closure objectives that take account of site-specific conditions, the objectives of closure planning can generically be stated as follows (Queensland Mining Council, 2001):

- To reduce or eliminate adverse environmental effects once the mine ceases operations
- To establish physical and biological conditions which meet regulatory requirements
- To ensure the closed mine does not pose an unacceptable risk to public health and safety

A5.2 STAKEHOLDERS IN SETTING CLOSURE OBJECTIVES

There are a number of stakeholders that have a legitimate claim to being involved in the setting of mine closure objectives. The Queensland Mining Council (2001) recommends that the number of stakeholders should be kept relatively small to remain focussed and effective and may include representation from the following groups as appropriate:

- Local community
- Organised labour
- Government agencies
- Non-government organisations

ANZMEC (2000) also very clearly establishes and expands on the principle that all stakeholders should be able to have their interests considered during the mine closure process. The same principle is confirmed and expanded upon by the Australian Government (2006) and the ICMM (2008). The Australian Government guideline for Mine Closure and Completion (2006) specifically recommends that stakeholders should have an involvement in the development of success criteria (referred to as closure objectives in the South African BPGs) with monitoring and reporting on achievement thereof back to stakeholders.

The ICMM Planning for Integrated Mine Closure Toolkit (2008) also proposes very specific procedures (using specified tools) that should be considered to help create stakeholder ownership of the closure outcomes and ultimately help ensure successful closure. The role of stakeholders in defining required social closure outcomes is highlighted.

A very thorough and robust approach to fully engaging the local communities in mine closure planning (amongst others) is provided in the ICMM Community Development Toolkit, 2005. This toolkit provides and describes a set of 17 tools that fully cover all aspects of community involvement in a mining project. While these 17 tools are very comprehensively dealt with in the referenced ICMM document, they can be summarised as follows:

Assessment Tools

- **Tool 1 Stakeholder Identification -** for identifying all the people with an interest in the project or who may be affected by the project.
- **Tool 2 Social Baseline Study -** for drawing up a profile of the community surrounding the project area and its regional and national setting.
- **Tool 3 Social Impact and Opportunities Assessment -** for assessing the impacts, both positive and negative, that the project may have on host communities and how to manage them.
- **Tool 4 Competencies Assessment -** for determining the attributes your team has and whether other skills, knowledge, and understanding may be required.

Planning Tools

- **Tool 5 Strategic Planning Framework -** the process through which you (a) understand why you want to contribute to community development, (b) define and plan your development objectives and how to achieve them, and (c) determine how you will know when you have succeeded.
- **Tool 6 Community Map -** this is an exercise in which local people map out their community's physical layout. It is designed to start people recognizing that they are the experts about their own community and to get discussion and cooperation going.
- **Tool 7 Institutional Analysis -** this is an exercise to evaluate the variety, strength, and linkages of institutions within and around a community.
- **Tool 8 Problem Census -** this is to allow a full range of participants to decide upon priority development issues in the community rather than the views of only a few being noted. It is a workshop process that enables a broad range of community participants to define and explain the importance of obstacles to development in their community.

- **Tool 9 Opportunity Ranking -** this is a process to help community members decide which projects to start implementing first by sorting the projects according to priority and feasibility. This is accomplished by taking into account the locally available resources, skills, and capacities.

Relationships Tools

- **Tool 10 Stakeholder Analysis -** having identified the project's stakeholders (with tool 1), it is useful to analyse their level of interest in the project, whether they are very interested or only marginally interested.
- **Tool 11 Consultation Matrix -** after analysing the stakeholders, it is important to develop a system to ensure that they are consulted as often as they would like and at an appropriate level to their interest in the project.
- **Tool 12 Partnership Assessment -** a tool for analysing potential partners, their suitability for partnering with the organization, and what areas of mutual interest are shared in regional community development programs.

Program Management Tools

- **Tool 13 Conflict Management -** conflict Management is a means for identifying, understanding, and managing conflicts through resolution so that they do not disrupt the activities of the various stakeholders, especially where community development programs are concerned.
- **Tool 14 Community Action Plans (CAPs) -** the Community Action Plan (CAP) is a detailed plan for implementing solutions to the problems that have been identified during the participatory planning process. It will become the management plan both for the community and its development partners, and will be adjusted to suit circumstances and changing community priorities as time passes.

Monitoring and Evaluation Tools

- **Tool 15 Logical Framework -** this is a matrix that can be used for developing clear outputs and outcomes and that uses verifiable indicators to measure progress toward goals. It is a powerful system for program management and for monitoring and evaluation.
- **Tool 16 Indicator Development -** this is a process for choosing indicators for program evaluation that can measure up to transparent scrutiny from any quarter. These indicators are especially appropriate for use in the logical framework and Goal Attainment Scaling methods outlined.
- **Tool 17 Goal Attainment Scaling -** this is a useful means for measuring the degree to which outputs and outcomes are being met. It is particularly useful for social investment and community development projects where multiple stakeholders are involved and where there may be differing assessments about the degree of achievement of project goals. It enables evaluations to be made by a range of stakeholders and observers, not just so-called experts. Another major advantage is that the results can be presented in the form of simple graphs, which makes them more accessible to people unfamiliar with qualitative, social science measurements, such as financial and technical managers at a mining project.

As described in Section A4 dealing with risk management frameworks, the involvement of stakeholders is critical throughout the risk assessment process and appropriate mechanisms need to be implemented to obtain the meaningful input of these stakeholders. This process is, of course not without its challenges as communication of risk concepts to the general public requires the development of particular risk communication strategies.

A5.3 CRITICAL QUESTIONS RELATING TO WATER MANAGEMENT AND MINE CLOSURE

The correct definition of key questions that need to be asked and answered in the mine closure planning process with regard to water management issues is critical. The formulation of the questions defines the manner in which the conceptual model is defined, how the site characterization programme should be designed and implemented and the type of impact prediction codes that need to be used. The questions that will be asked in South Africa will often be very different to those asked in other countries as the questions must take account of the particular regulatory approach in the country. Whereas many mining countries are primarily interested in whether or not acidic conditions will develop with their associated elevated metal concentrations, South African regulators also have a need to determine water quality in a broader context (e.g. sulphate levels, sodium levels, etc.). Examples of key questions that could be formulated for a mine closure application are the following:

1. *What is the long-term impact of all waste residue deposits (fine and coarse waste) on the water resource (surface and groundwater) in terms of volumes and quality (pH, heavy metals, major cations and anions) of drainage for a period of 100 years after all rehabilitation work has been completed?*
2. *How do different waste residue deposit rehabilitation options compare in terms of their effect on long term volume and quality of drainage from such facilities?*
3. *Will alternative waste residue deposit rehabilitation options result in an impact on ground and/or surface water resources that meets the closure performance objectives that have been set? If not, what additional mitigation measures (e.g. seepage interception and treatment) would be required to meet the closure performance objectives?*
4. *Will the mine void (pit or underground mine) decant after mine closure? If yes, where, when, at what volume and at what quality over time?*
5. *What are the drainage volumes and quality for all contaminants of concern for all source terms that pose a potential risk of impacting on the water resource – such profiles to show predictions at least 100 years into the future, or longer if longer periods are required to quantify the impact, as recommended by the specialist and agreed to by the independent reviewer and DWA.*
6. *What will the long-term impact be at the critical receptor for the contaminants of concern?*
7. *What is the maximum contaminant loads (water quality and volume) that can be discharged from the mine post-closure to ensure that water quality objectives at the critical receptors can be safely met?*
8. *What additional water management (e.g. covers, infiltration reduction measures, etc.) or treatment measures need to be instituted to reduce the contaminant loads from the various source terms or to intercept the pathways in order to ensure that the critical receptor is not adversely impacted?*

The above are typical examples of questions that need to be answered when undertaking an impact assessment and risk assessment for a mine closure situation.

A6 DESCRIPTION OF UNCERTAINTIES

A6.1 Background

Management decisions are based on available information regarding pertinent conditions, objectives, costs and societal needs. There is never a complete understanding and a critical part of any post closure water management plan is identifying and dealing with uncertainty. For this reason, it is important to provide all possible outcomes or interpretations of monitoring and material characterization, not just the presently most probable or manageable hypothesis. Similarly when developing mitigation plans, it is important to document the uncertainties and show how this will be monitored and managed (Price, 2005).

Sensitivity analysis and risk assessment should be conducted at every stage of the closure planning process to determine the sufficiency of available information and the impact of possible inaccuracies on the overall environmental risk and liability. The results of sensitivity analyses and risk assessment can be used to determine monitoring requirements and to establish where additional safety factors or contingency protection measures may be necessary.

Contingency plans should include monitoring programmes to track performance and to ensure timely implementation of contingency measures. Another important part of contingency planning is ensuring that adequate resources are available.

Probabilistic modelling is the best - if not only - technique for organizing and incorporating all available information on risks and uncertainties so that a good risk-informed decision can be reached (Pergler and Freeman, 2008). It is of course necessary to ensure that the probabilistic modelling is properly undertaken and that it is based on using the correct conceptual and mathematical model and input data sets that adequately reflect the true variability of the data. A probabilistic approach to quantifying uncertainty is also supported by the ICMM, 2008.

The output from probabilistic modelling is again a probabilistic distribution of key output variables which needs to be evaluated by a person that has a sound understanding of which factors contribute and to which extent to the uncertainty of outcomes.

The degree of confidence in the models is severely limited in part because the models are so complex that they cannot be easily reviewed by regulatory staff and the public. Water quality predictions should always be re-evaluated over time at mines sites and compared to site-specific water quality information as it becomes available.

Predictive modelling of water quality at mine sites is an evolving science with inherent uncertainties. However, using the recommended approaches, predictive water quality modelling and site characterization information can be reliably used to design protective mitigation measures and to estimate the costs of future remediation of hard rock mine sites (Maest *et al*., 2005).

The fact that sampling errors are inherent in random data does not mean, however, that statistical manipulation can in any way overcome faulty environmental data. The quality of any statistical analysis as input to any risk assessment is no better than the quality of the data utilised. Furthermore, statistical considerations cannot be used to replace judgement and careful thought in analysing data. Statistics must be regarded as a tool or an aid to understanding, never as a replacement of careful thought (McBean and Rovers, 1998). The core message in this statement is that knowledge of uncertainty must be incorporated into the design of the assessment process and that uncertainty is not an issue that can be evaluated and addressed after the data collection process has been completed. This is also the reason why the section on uncertainty is dealt with early on in the literature review as knowledge of sources of uncertainty should drive the whole assessment process in order that the uncertainty can be minimised.

Sensitivity analysis, as it is applied to risk assessment, is an approach to determine which factors in a risk model (specific exposure pathways or making certain assumptions with respect to model parameters) influence risk most strongly. It provides a means of exploring, in a quantitative manner, the effect of a variety of “what-if” scenarios on the risk estimates. The basic approach is to allow for a subset of the input variables to vary within prescribed ranges and to determine how much the model output (usually risk) changes in response to changes in the values for each input variable. Of the several approaches to sensitivity analysis that are available, no single approach will serve as the best analysis for all modelling efforts. The best choice for a particular situation will depend on a number of factors, including the nature and complexity of the model and the resources available. For example, sensitivity ratios can be used where the ratio is equal to the percentage change in output (e.g. risk) divided by the percentage change in input for a specific input variable. Risk estimates are considered most sensitive to input variables that yield the highest ratios.

An alternative approach to quantifying uncertainty is presented by the ICMM (2008) by using the technique termed "knowledge platform mapping". In this approach, the knowledge inputs into a mine closure plan are assigned into seven knowledge classes ranging from "common knowledge" up to "focused proof", each with a different ranking ranging from 20 to 100. Each closure objective and the actions undertaken to achieve it are then characterised and given a ranking, with an overall average closure plan knowledge platform being determined. The objective is then to make sure that each review of the closure plan moves up to a higher knowledge platform. However, no guidance is given as to what knowledge platform level should be considered adequate for granting of mine closure.

A6.2 UNCERTAINTY IN GEOCHEMICAL CHARACTERIZATION PROGRAMMES

Uncertainty issues in the use of the geochemical toolbox are discussed extensively in Maest *et al* (2005) and their discussion is summarised in the sections below.

A very relevant research project aimed at quantifying uncertainties in geochemical sampling and analyses was undertaken for the WRC (Chihobvu *et al*., 2011). This report addresses this deficiency in geochemical sampling and analyses and proposes two methodologies (i) for quantifying uncertainties in geochemical sampling and analysis as a function of sample size and analysis and (ii) for determining the optimum sample size to ensure data quality.

The statistical analysis approach was adopted as the best method for sample size determination. The approach is based on the premise that “the size of the study sample is critical to producing meaningful results”. The size of the required samples depends on a number of factors including purpose of the study, available budget, variability of the population being sampled, acceptable error and required confidence level.

The methodology for estimating uncertainty is a fusion of existing methodologies for quantifying measurement uncertainty. The methodology takes a holistic view of the measurement process to include all the processes involved in obtaining measurement results as possible components/sources of uncertainty. Like the statistical analysis approach, the methodology employs basic statistical principles in estimating the size of uncertainty associated with a given measurement result. The approach identifies each component of uncertainty; estimates the size of each component and sums the contribution of each component in order to approximate the overall uncertainty value associated with a given measurement result.

The two methods were applied to Acid-Base Accounting (ABA) data derived from geochemical assessment for Environmental Risk Assessment of the West Wits and Vaal River tailings dams undertaken by Pulles and Howard de Lange Inc. on behalf of AngloGold Ltd. The study was aimed at assessing and evaluating the potential of tailings dams in the two mining areas to impact on water quality and implications of this impact in terms of mine closure and rehabilitation.

Findings from this study show that the number of samples needed is influenced by the purpose of the study, size of the target area, nature and type of material, budget, tolerable error and the confidence level required, among other factors. Acceptable error has an inverse relationship with sample size; confidence level and standard deviation have a positive correlation with sample size hence one can minimize error by increasing sample size. While a low value of acceptable error value and high confidence are always desirable, a tradeoff among these competing factors must be found, given the fact that funds and time are normally limited.

The findings also demonstrated that uncertainties in geochemical sampling and analysis are unavoidable. They arise from the fact that only a small portion of the population rather than a census is used to derive conclusions about certain characteristics of the target population. This is further augmented by other influential quantities that affect the accuracy of the estimates. Effects such as poor sampling design, inadequate sample size, sample heterogeneity and other factors highly affect data quality and representivity, hence measurement uncertainty. Among these factors associated with sampling, heterogeneity was found to be the strongest contributing factor toward overall uncertainty. This implies an increased proportion of expenditure should be channelled toward sampling to minimize uncertainty.

A6.2.1 General uncertainty issues

A6.2.1.1 Extent of environmental sampling (representativeness of field conditions)

Problem Statement: The extent of sampling of mined materials is often inadequate for representing the range of potential environmental impacts at a mine site, especially for mines with variable geology and mineralogy.

Recommendation: The variability in the potential to impact the environment should be examined initially by extensive geologic and mineralogical analysis of all mined materials and wastes. The extent of geological and mineralogical sampling should be commensurate with the extent of sampling for ore characterization. The observed degree of geological and mineralogical variability should then dictate the extent of sampling for environmental characterization.

A6.2.1.2 Compositing of samples

Problem Statement: Compositing of samples for environmental characterization leads to a lack of knowledge about where potential environmental problems can develop on the mine site.
Recommendation: Compositing of samples is only recommended for mined material that is consistent in size and composition, for example, existing tailings material that is known to be from a consistent ore type and a single process.

A6.2.1.3 Changes in geochemical characterization as mine evolves

Problem Statement: Geochemical characterization conducted before mining begins may not accurately reflect conditions after mining has progressed.
Recommendation: Geochemical characterization should be conducted throughout the active life of the mine and used to continually evaluate potential environmental impacts.

A6.2.1.4 Field/laboratory discrepancies

Problem Statement: Laboratory geochemical characterization tests are generally not representative of field conditions. Results from laboratory tests will generally overestimate field weathering rates and underestimate the length of contaminant generation from mined materials.
Recommendation: Site-specific measurements of temperature, particle-size distributions, available sulphide and neutralization mineral surface areas, spatial variability of sulphide-bearing rock, hydrological factors such as preferential flow, and the availability of oxygen should be determined for all waste units, especially waste rock and leach dumps. Mineralogical analysis, including mineral availability, should be completed before laboratory testing begins. To the extent possible, field-scale testing or laboratory columns, with minimal changes in grain size distribution compared to the actual mined material, should be conducted as supplements to or replacements for laboratory characterization testing, especially for waste rock. Site-specific estimates of scaling factors between laboratory and field conditions should be determined and used in predictive modelling studies.

A6.2.2 Uncertainty issues relating to static testing

A6.2.2.1 Effect of particle size

Problem Statement: Static ABA tests use crushed rock, which will overestimate the association of acid-producing and acid-neutralizing minerals under field conditions and overestimate the neutralizing, and possibly the acid-generation, potential of the samples.
Recommendation: Static ABA tests cannot be used to quantify acid generation and neutralization under field conditions and should only be used as an initial screening technique to estimate the total amount of acid-generating and acid-neutralizing material present in rock that is representative of the samples collected. Evaluation of mineralogy, including available weathering surface area for sulphides and carbonates, may be a more accurate approach than ABA testing for estimating the acid generation potential of mined materials.

A6.2.2.2 Effect of temperature, pH and test duration on neutralization potential estimates

Problem Statement: Neutralization potential tests that are conducted at elevated temperatures or that use pH endpoints of <6.0 will overestimate the amount of neutralization potential available under field conditions. For samples with low carbonate content, neutralization potential tests conducted for short time frames may underestimate the neutralization potential.
Recommendation: Evaluation of mineralogy is a necessary step for determining the neutralization potential of mined materials. If using ABA testing, some general guidelines include: for most mineralogies, the original Sobek method will overestimate neutralization potential; use NAG testing only as a screening method for estimating neutralization potential; assuming siderite is not a dominant carbonate mineral, Lapakko and modified Sobek methods are the most reliable and reasonably conservative tests for estimating NP.

A6.2.2.3 Effect of mineralogy and organic matter on neutralization and acid generation potential

Problem Statement: Mineralogy is the most important control on acid-generation and neutralization potential, yet until the last few years, mineralogy has rarely been confirmed as part of static or kinetic testing procedures. Lack of knowledge about the mineralogy of mined material can cause either overestimation or underestimation of net acid generation potential.
Recommendation: Mineralogy should be thoroughly examined as part of the environmental characterization process, with special attention paid to identifying the types of metal sulphides, silicates, and carbonates in mined materials and the surface area of these minerals available for reaction. In many cases, this will involve mineralogical examination that is more detailed and sophisticated than simple bulk powder X-ray diffraction. If siderite is a dominant carbonate, the NP tests should be modified to ensure that siderite is not included in NP. As a check on NP, use mineralogical NP (based on the amount of calcium and magnesium carbonates present) for samples of lithologies of interest. Use of total sulphur for AGP may result in slight overestimations of AGP, but using total S would result in more protective and supportable management decisions. However, if there is a substantial amount of non-acid producing sulphates or organic sulphur, they should be subtracted from the total sulphur value.

A6.2.2.4 Estimating NP and AP in low-S, low NP wastes

Problem Statement: Rocks with low sulphur content can produce acid, and rocks with low NP can buffer acid, yet standard ABA tests may not predict these results.
Recommendation: For rocks with low S content and/or low NP, standard ABA testing must be supplemented early in the mining process with additional information on mineralogy, availability of acid-producing and neutralizing material, and kinetic tests to determine the relative weathering rates of sulphides and neutralizing minerals.

A6.2.2.5 Interpretation of static testing results using NP/AP ratios

Problem Statement: NP/AP ratios are routinely used to predict the likelihood of acid generation at a mine site. Depending on the amount and availability of neutralizing material, material with even “safe” ratios (e.g. >3:1) may produce acid in the longer-term.
Recommendation: Static ABA tests and NP/AP ratios should only be used as initial screening tools for samples to be used for kinetic testing and as estimates of the total amount of acid-generating and neutralizing material present. Knowledge of mineralogy is essential in interpreting ABA results. To estimate medium- and longer-term acid-generation and metal-leaching potential, static test results must be supplemented with mineralogical, mineral availability, and kinetic testing data.

A6.2.3 Uncertainty issues relating to short-term leach testing

A6.2.3.1 Water : rock ratio, use of un-weathered materials and interpretation and use of short-term leach testing results

Problem Statement: Short-term leach tests are used routinely to determine the identity and concentrations of constituents of concern leaching from mined materials. Although the intent of the tests is to simulate short-term leaching conditions, the results of the tests are often misapplied to longer-term leaching. Two other issues that confound the interpretation and of the tests is the water : rock ratio and the use of un-weathered mined materials.
Recommendations: The use of un-weathered materials in leach tests should be avoided. Short-term leach tests may have limited use as a scoping tool if weathered rock is used, but the results should only be applied to short-term leaching of mined materials after they have been weathered in the field. Involving an experienced geochemist in testing design and analysis will minimize misinterpretation of test results. Taking short-term leach test results from long-term kinetic tests (e.g. “first flush” results from humidity cell or column tests) would eliminate the need for separate short-term leach tests and would better link short-term and long-term predictions for leaching of contaminants. In addition, releases can then be quantified on a per unit mass basis if short-term leach results are taken from kinetic testing.

A6.2.4 Issues related to kinetic testing

There are two distinct purposes for conducting kinetic tests: to predict the onset of acid drainage, especially in samples with equivocal results for static testing; and to generate data that can be used to model or predict water chemistry. For kinetic testing conducted before the early- to mid-1990's, the main purpose was to predict the onset of acid drainage. Today, most projects would require the development of a technical basis for estimating future water quality, and the prediction of the onset of acid drainage would come as a by-product of that analysis. The purpose of conducting kinetic testing must be understood by all parties, and then the details of how to conduct the test can be worked out for decision-making purposes.

A6.2.4.1 Effect of particle size and mineral availability

Problem Statement: With the exception of tailings, crushing is required for humidity cell tests, yet, especially for heterogeneous and larger grained material, such as waste rock, humidity cell test results will not accurately represent field conditions.
Recommendation: Humidity cell testing should not be used to predict weathering rates for waste rock or wall rock or other types of heterogeneous, large-grain size material unless the results are expressed in terms of available mineral surface area. This requires that the surface area of specific minerals in the kinetic-test samples be known and – to permit scaling up to field conditions – that the surface area of minerals in the actual waste be known or well estimated. Column testing with no or minimal reduction of particle size or field techniques, such as mine wall washing, will provide results that will be more representative of field conditions. Samples must be well characterized in terms of mineralogy and mineral availability before and after tests are conducted.

A6.2.4.2 Length of kinetic tests

Problem Statement: The minimum recommended length of time for kinetic testing is 20 weeks, but a number of practitioners of kinetic testing have shown that this time frame is inadequate for accurate prediction of the onset of acid drainage and/or metal leaching, especially in samples with higher neutralization potential.
Recommendation: The objectives of kinetic testing should be clearly stated. If the objective is to determine if the sample will produce acid, kinetic tests should be conducted for longer than 20 weeks, unless earlier results indicate that acid will be produced. The length of the test should depend on the sample composition. Mineralogy (including available surface areas) should be examined initially and after the test and used to help determine if the sample could eventually produce significant amounts of acid or contaminants. For kinetic test samples with static test NP:AP>1 that have not produced acid within one year, test lengths should be longer than one year.

A6.2.4.3 Effect of column size and shape

Problem Statement: Column testing of larger grain size material may result in incomplete contact of leachate with the sample material and inaccurate prediction of water quality unless the experiment is carefully designed and implemented.
Recommendation: For larger grain size material, such as waste rock, larger columns should be used for kinetic testing, using a ratio of column diameter to largest particle size of six or greater. To reduce grain size somewhat, the material can be broken by hand, for example, using a hammer, if necessary, so that the breakage would occur along faces that would naturally be exposed to weathering.

A6.2.4.4 Effect of temperature and weather conditions

Problem Statement: Laboratory temperatures and conditions deviate from field conditions, and these deviations may result in under- or overestimation of metal leaching and acid production rates and concentrations.
Recommendation: To the extent possible, field kinetic tests should be conducted as a supplement to laboratory kinetic testing. Mine proponents and regulators should acknowledge that the results of kinetic

testing, unless the tests are conducted in the field, will not represent dynamic hydrologic and weathering conditions such as snowmelt and precipitation. Results from kinetic tests conducted under oxygenated conditions can be used to model the effect of different temperatures on sulphate production using experimental data on the effect of temperature on activation energies for the reactions (e.g. Ritchie, 2003).

A6.2.4.5 Applicability of standard kinetic testing for materials under low oxygen or reducing conditions

Problem Statement: Humidity cell tests have been used, among other things, to estimate leaching characteristics of tailings material, some of which may be fully saturated under field conditions. Humidity cell tests are not designed to represent low-oxygen or reducing conditions.
Recommendation: Humidity cell tests should not be used to represent leaching characteristics of materials under low-oxygen or reducing conditions. Continuous flow column tests or batch tests can be used to estimate the behaviour of mined materials under low oxygen conditions.

A6.3 UNCERTAINTY IN IMPACT PREDICTION MODELLING

The inherent uncertainty in model predictions is rarely stated or recognized. Substantial uncertainty is inherent in determining many of the parameters that are required for modelling water-quality evolution at mining sites, especially hydrologic parameters such as hydraulic conductivity and recharge. Uncertainties in hydrologic modelling may be very large as a result of the inherent range in hydraulic conductivity and other hydrologic parameters, and the effects of these uncertainties on net water-quality predictions (via mass flux) need to be addressed in the uncertainty evaluation. The uncertainty may derive from incomplete characterization or incomplete knowledge of the geochemical and hydrogeological conditions at the site. Many authors have written about the necessity of quantifying uncertainty in model predictions (Beven, 1993 and 2000; Draper, 1995; Kundzewicz, 1995; Meyer and Gee, 1999; Neuman and Weirenga, 2003).

Methods used to evaluate or account for model uncertainty include Monte Carlo analysis, stochastic methods, and evaluating a range of model parameters to develop a range of deterministic outcomes (e.g. a range of water quality in a given receptor). These methods account for the fact that, rather than being well described by a single value as required in the model, parameters are better described with a probability distribution (i.e. a mean, variance, skewness, etc.).

Another aspect of uncertainty relates to estimating the efficiency of mitigation or remediation measures, which often cannot be completely quantified. The predicted water quality from a facility will in part determine what kind of mitigation measures will be taken. If the predictions aren't realistic, it is much harder to "retrofit" mine design than to make it right or prevent pollution in the first place. Adaptive management in the absence of predictions can be useful only if mitigations can be designed and implemented at a later date and be effective. Regulators will still need to rely on predictions for the initial design of the mine waste unit.

Model uncertainty should be acknowledged in predicting water quality at mining sites, and some methodology (conducting sensitivity analyses using a range of values as input parameters, Monte Carlo approaches) should be employed to evaluate the effect of uncertainty on model output. For example, a desired confidence level could be determined (e.g. 95%), and this confidence level on environmental data could be used throughout the model. The computer program Excel has add-ins that can be used to incorporate parameter distributions into a model for the evaluation of uncertainty. The add-ins include @Risk (available from www.palisade.com), and Crystal Ball (available from www.decisioneering.com). These approaches will be useful only if the uncertainty derives from site variability in parameters but will not address uncertainties in the conceptual model. Uncertainties in the conceptual model can be addressed by collecting as much site-specific hydrogeochemical data as possible and keeping an open mind to rethinking the original conceptual model (Bredehoeft, 2005).

A6.3.1 General uncertainty issues

A6.3.1.1 Coupling of models

Problem Statement: Water quantity and water quality must be jointly considered in predictions of water quality at mine sites. Often, the uncertainty and variability in water quantity and flow are not adequately considered in predictive modelling of water quality. Coupling of water quantity and quality (and different aspects of each) in a reactive-transport model has certain advantages in terms of ease of use but may result in loss of information in dealing with a complex chemical system.
Recommendations: If separate codes are to be used for different processes or spatial or temporal domains, there must be a careful evaluation of how those codes are coupled so that the output will be useable. Site conceptual models and modelling efforts should include the effect of varying water quantity on water quality. Often, prediction should be evaluated using both coupled and discrete-process codes to help determine processes that control critical model results, such as the movement of constituents through a waste rock dump.

A6.3.1.2 Timeframe for predictions

Problem Statement: Hydrologic and geochemical conditions change over time at a mine site. The timeframe over which predictions are made can vary considerably from site to site and for different predictions at the same site. Depending on the timeframe chosen, substantially different modelling results can be obtained.
Recommendation: To the extent possible, while still recognizing the uncertainty, predictions must be extended to the timeframe required by the regulatory context (such as 100 or more years for financial assurance determination purposes). However, timeframes for model predictions should not end at an arbitrary cut-off point (based on regulatory guidance or precedent, for instance), but rather should be based on the physical conditions of the modelled system. For example, pit lake chemistry could be modelled until steady state water quality is reached or certain ecological thresholds are exceeded. Models should be used to predict the timing and magnitude of impact from waste rock units even if these impacts are far into the future.

A6.3.1.3 Use of proprietary codes

Problem Statement: The use of proprietary codes prevents the independent examination by other consultants, regulators, and public interests and creates uncertainty about the legitimacy of modelling results.
Recommendation: Codes developed by a group or company that are not available for sale or distribution outside of that company should not be used in predicting water quality at mining sites. These codes cannot be verified or tested by those outside of the company. It is uncertain whether such codes accurately simulate the processes that are important for predicting water quality at the mine site. They may have “bugs” that have not been identified by wide code use. Furthermore, because the code itself is not available, it is not possible for a reviewer to reproduce the model simulations. In the same vein, any code that is so expensive that it is not feasible for a reviewer to purchase or lease the code should be avoided. Codes used for prediction of water quality at mining sites should be available for purchase and use by anyone. Similarly, models created using available codes but that do not provide an understandable record of all inputs and approaches should not be accepted for use by regulatory agencies.

In most cases, several widely-available, reasonably priced codes are available to simulate the relevant processes influencing water quality at mining sites. Some may argue that a specific proprietary code is necessary to simulate a specific process, and that no other more available codes simulate this process. In this case, the importance of the simulated process to the water- quality predictions should be carefully considered prior to selecting a proprietary code.

A6.3.2 Uncertainty issues relating to model inputs

A6.3.2.1 Hydrologic and hydrogeological inputs

Limited data on aquifer properties.
Predicted contaminant transport rates in the vadose zone and groundwater are highly influenced by hydrologic parameters for geologic units in the models. Pump tests and lithologic descriptions may provide initial hydraulic and transport parameters, but these must be fine-tuned by calibration. The uncertainty in hydraulic parameters should be acknowledged, and an effort should be made to account for uncertainty in the model predictions.

Improper representation of hydrogeological units.
After a modeller parameterizes the hydrogeological units, each unit typically is treated as completely homogeneous in the model. Within a hydrogeological unit, aquifer properties and geochemical characteristics are effectively averaged over the unit. Hydrogeologically complex areas such as those with fractures or variable mineralization may require more units than more homogeneous areas. Alternatively, a range of aquifer properties and geochemical characteristics can be used for a single unit.

Simulation of recharge.
In arid environments, potential evaporation is greater than precipitation. However, this does not mean that there will be no infiltration or recharge to groundwater. Even in arid or semi-arid environments, infiltration can occur during precipitation events and be transferred to depths in waste piles beyond the evaporative zone, resulting in infiltration. The timing and nature of precipitation events are key determinants of whether water will infiltrate the surface of the facility or evaporate. The wetting front will move downward into the waste pile over time, bringing with it solutes dissolved from the waste material. The code used to simulate infiltration and percolation of meteoric water into mine facilities such as waste rock dumps must be sophisticated enough to account for infiltration resulting from individual storm events.

Handling of preferential flow, macro-pores, and fractures in models.
Many hydrologic models assume uniform soil properties in geologic materials and are unable to simulate macro-pores, preferential flow, and fractures in the vadose or saturated zones, or in a groundwater aquifer. In many mining areas, the subsurface is composed of fractured bedrock. In many cases, the fractured rock is assumed to behave as an "equivalent porous medium." This may be adequate for some sites, but could also result in inaccurate predictions of flow and contaminant migration. The inability to model preferential flow represents a major shortcoming in water quality predictions that must be acknowledged. Additional research is needed in this area if predictions are to be considered at all accurate or useful in determining potential for impacts and identifying mitigations to address such impacts.

A6.3.2.2 Geochemical inputs

Completeness of water quality data used in modelling
Analytical data used to characterize groundwater, surface water, leachate, or pore water chemistry may not include all the important and necessary analytes. For example, if major cations and anions are not included, charge balances cannot be calculated, and a good charge balance is one indication that the laboratory analysis is adequate. A full analytical suite should be used for analysis of leachate from kinetic and short-term leach testing, and any identified constituents of concern should be included in the model. If thermodynamic data for an important constituent of concern is not present in the code, the modeller should consider modifying the database to include that constituent or selecting a code that has thermodynamic data for that/those constituents. If modelling is conducted using a limited water quality database, the user should state explicitly that the results do not adequately consider reactions involving the missing constituents.

Elevated detection limits.
For some minor and trace constituents, analytical detection limits can be higher than concentrations that could pose a risk to human health or the environment. Detection limits should be substantially lower than the most protective and relevant water-quality standards.

Incomplete characterization of medium- and long-term environmental behaviour of mined materials.
Extrapolation of data applicable to short-term conditions to longer-term conditions will add to uncertainty of longer-term water-quality predictions. Well-designed long-term kinetic leaching tests should be conducted on representative materials that pose a potential threat to water quality, and results from these tests (including how leachate concentrations change over time) can be used as inputs to hydrogeochemical models.

Use of distribution coefficient (Kd) values in transport models.
Distribution coefficients, or Kd values, describe the tendency of dissolved constituents to adhere to solid surfaces (e.g. soils and aquifer materials) and are only relevant to equilibrium conditions (Stumm and Morgan, 1996), yet they have been used extensively to model fate and transport of kinetically controlled reactions in aquifers. Kd values are often taken from the literature rather than conducting site-specific experiments on adsorption/desorption reactions in alluvial and bedrock aquifers. Their improper use in hydrogeochemical models can produce errors in the prediction of contaminant transport rates in groundwater and of recovery times. Site-specific information on the transport of contaminants in aquifers and mined materials should be used as inputs to predictive models.

Application of characterization data as source terms to reaction path/mass balance models.
Steady-state pH values and concentrations from humidity-cell tests are often used as input data for geochemical reaction path or mass balance models. These inputs are used to predict future water quality based on laboratory or field-scale experiments. However, differences in weathering rates and reactants produced under field and laboratory conditions can cause large differences between experimental and actual conditions, especially if reactive surface areas are not included in the model. Applying an across-the-board scaling factor (e.g. 10-3 or 10-4) to account for higher oxidation rates in laboratory tests (compared to field conditions) is not warranted without examining the longer term leaching behaviour of the wastes. If appropriate long-term kinetic testing has been conducted, steady-state concentrations can be used without scaling factors, or site-specific scaling factors can be applied.

Concentrations of contaminants that are affected by seasonal variability
The timing of precipitation events and other types of climatic processes can affect water chemistry. During dry periods, weathering products (secondary minerals) from the oxidation of sulphide minerals will accumulate in test piles, mine units, and unmined materials. Storm precipitation following a dry period will flush these accumulated products from the piles and result in high concentrations of solutes and generally low pH values, while more continuous rain will result in a more constant volume of acid and other contaminants and lower concentrations in surface water and groundwater (Jambor *et al*., 2000; Maest *et al*., 2004). Sampling of mined materials, field-scale characterization tests, and water quality and quantity sampling must at least initially be conducted to capture the variability in seasonal and climatic conditions. A sensitivity analysis using linked end-members of the environmental data (i.e. concentrations and flows most likely to occur under, for example, high and low flow conditions) will better bracket actual field conditions than an average or median value.

A7 THE MINE SITE CONCEPTUAL MODEL

The development of an accurate and appropriate conceptual model is the most critical first step in a successful impact prediction exercise and errors in this step are often the root cause of errors in modelling (Bredehoeft, 2005).

The conceptual model is usually a written summary that is supplemented with graphical representations of information derived from a combination of relevant background data, assumptions concerning parameters and boundary conditions and a range of modelling objectives or scenarios for numerical testing. Conceptual models are typically refined in an iterative manner as more data becomes available from field observations (Heikkinen *et al*., 2008). The term 'conceptual model' has a formal meaning in hydrogeology, having been defined by Bear and Verruijt, 1987 as 'a set of [rigorously justified] assumptions which represent our simplified perception of a real system'.

A conceptual model is therefore a qualitative description of the hydrology and chemistry of the site and their effects on mined and natural materials. It includes baseline conditions, sources (mining-related and natural), pathways, biological and physicochemical processes, mitigation measures, and receptors. A conceptual model report must include detailed specification of the key questions that need to be answered by the assessment/prediction project and then specify the toolbox that will be used to answer these questions.

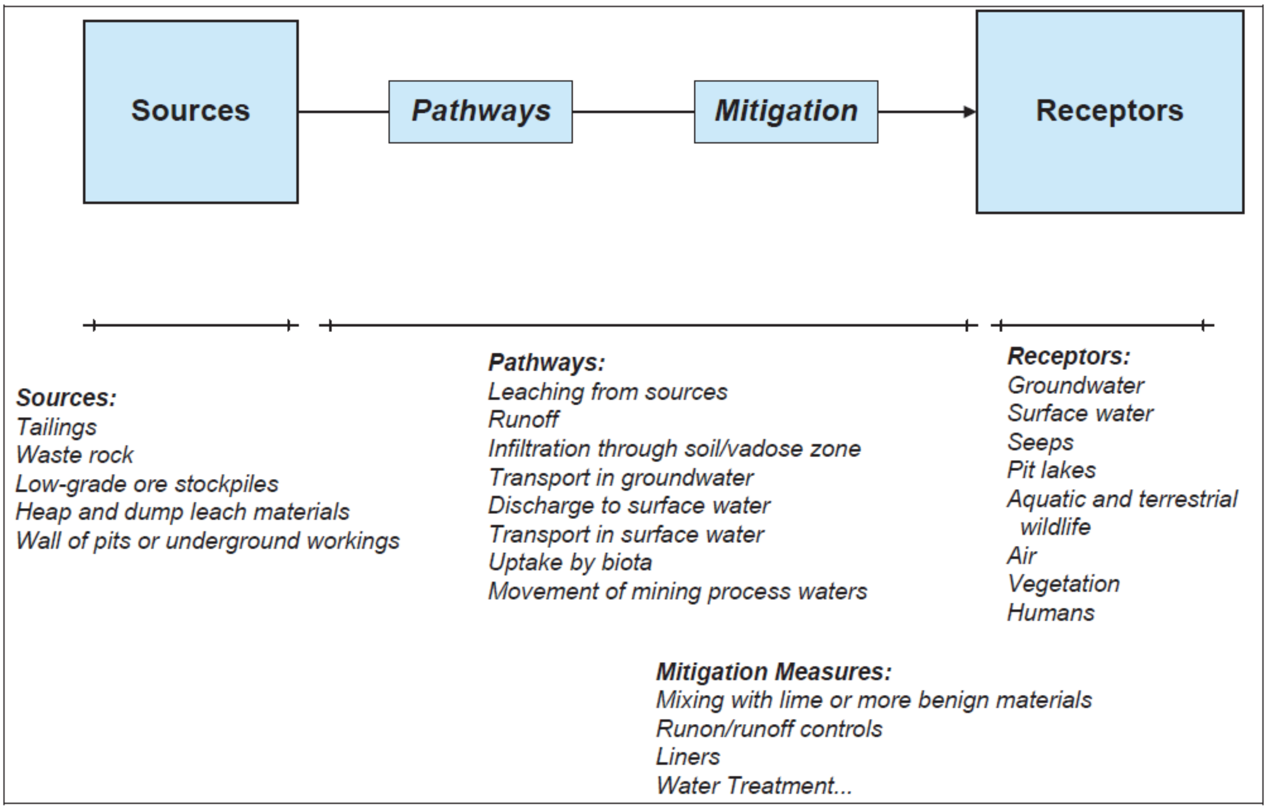

Figure A5: Generalised conceptual model of sources, pathways, mitigations and receptors at a mine site (Maest *et al.*, 2005)

The type of information needed for a site-wide conceptual model includes:

Baseline conditions

- Description of all geologic units (lithology/mineralogy)
- Spatial characteristics of geologic units (e.g. depth, thickness, locations)
- Physical, hydraulic, and geochemical characterization of any existing wastes or contaminant sources (including mineralogy, volumes, locations, physical characteristics, acid-drainage potential, contaminant-leaching potential)
- Location and quality of springs and seeps, including seasonal/temporal variability in water quality
- Existing groundwater and surface-water quality, including seasonal/temporal variability in water quality
- Hydrology and hydrogeology, including depth to groundwater, composition and location of unsaturated zone and aquifers/aquitards; spring and stream flow rates, recharge/ infiltration rates, groundwater flow directions and fluxes, gaining/losing reaches of stream, hydrologic parameters (hydraulic conductivity, porosity, permeability, etc.), seasonal/temporal variability of all hydrologic components, and the effect of man-made structures (e.g. dams, wells, intake structures) on water flows and levels
- Climatic conditions (precipitation, evaporation, climate type, seasonal/long-term climatic variability, dominant wind directions, typical storm events, temperature) for locations at or close to mine

Sources

- Location, volume, mass, chemistry of proposed mining-related sources

- Nature and extent of natural background sources

Pathways

- Possible travel paths from movement of contaminants from sources to receptors (e.g. air, infiltration, runoff, vadose zone, groundwater, transport in streams, transfer among solid and aqueous phases in groundwater and surface water)

Processes

- Hydrologic (e.g. advection/diffusion, dispersion, mixing, convection)
- Geochemical (e.g. sorption, precipitation, dissolution, redox)
- Air flow (e.g. movement of air into mined material/waste units)
- Biological (e.g. uptake of contaminants by wildlife, aquatic biota; oxidation/reduction of contaminants by bacteria)

Receptors

- Streams, springs, lakes, groundwater, wildlife, aquatic biota, human, etc.
- Location
- Quality and quantity (covered under baseline conditions)
- Interconnectedness of receptors

Mitigation

- Proposed mitigations for mine units
- Natural mitigation (e.g. dilution in surface water/groundwater, adsorption onto alluvial material)
- Description of performance and effectiveness of mitigation measures in terms of parameters that are relevant for the predictive modelling

While conceptual modelling should always proceed any attempt to mathematically any mining site (geohydrologically, hydrologically and geochemically), it is by no means always necessary that a conceptual model be converted into a mathematical model. Rather conceptual models are largely an end in themselves. They represent the current consensus on system behaviour, whether this be informed by direct interpretation of field and laboratory data alone, or whether these data have been further 'inverted' by mathematical modelling (Younger and Sapsford, 2004).

The mine site conceptual model should be developed in a staged approach in accordance with the following sequence of steps:

1. Site visit followed by collection and review of all relevant background existing information.
2. Development of initial conceptual model and documentation as an initial conceptual model report
3. Peer review of initial conceptual model report
4. Use of initial conceptual model to develop detailed site characterisation and sampling programme
5. Peer review of detailed site characterisation and sampling programme
6. Review of outcome of site characterisation results and review of initial conceptual model
7. Update of conceptual model and preparation of revised conceptual model report
8. Peer review of revised conceptual model report
9. Selection of mathematical code to be used and agreement with peer reviewer and regulator

A8 SAMPLING AND ANALYTICAL TECHNIQUES

A8.1 CHARACTERISTICS OF GEOCHEMICAL CHARACTERIZATION METHODS

See Table A1 below, taken from Maest *et al*., 2005 for a summary of the characteristics, advantages and limitations of the different types of geochemical characterization tests commonly applied. These issues are also extensively discussed in USEPA, 1994.

Table A1: Description of Geochemical Characterization Methods used to Estimate Water Quality

Characterization Tool	Test Names	Use in Water Quality Predictions	Advantages	Limitations
Geology and geophysics	Geologic mapping; sampling logging; petrographic and mineralogical analysis; ore assay; 3D block model of ore body and wastes; structural fracture density and orientation and rock competency information; geomorphology; geophysics	Information on rock type, mineralogy, and alteration type used to evaluate acid generation and neutralization capacity of site. Information on structure and fractures used to estimate porosity in competent bedrock. Geomorphology used for effects of landforms on hydrology and geochemistry. AVIRIS used for remote spectral imaging of minerals.	Provides information on ore reserves and potential pathways for transport of contaminants in subsurface.	Representativeness of samples; difficulty in defining structural and fracture information.
Whole rock analysis	Whole rock analysis	Determines total potential load of constituents to environment.	Can identify rock types with higher total levels of contaminants; can be used with CIPW normative calculations to determine likely mineralogy of sample.	Volatile elements such as As, Sb, Hg may be lost in HNO_3/ perchloric/HF acid digestion (use HCl/K chlorate instead); high S may precipitate insoluble sulphates and underestimate concentrations of Be, Pb, etc.
Paste pH	Paste pH	Determines potential effect of acid-forming salts in mine waste over short term.	Quick, inexpensive, easy to perform.	Provides no indication of long-term acidity/ neutralizing potential of soils/rocks.
Mineralogy/ microscopy/ microprobe /petrology	Optical microscopy; XRD; petrographic Analysis (reflected And transmitted light); SEM/EDS; electron microprobe; Sulphide Alteration Index; Rietveld analysis	IDs primary/secondary minerals alternation that could affect neutralization potential (NP) and acid generation potential (AGP); degree of alteration of minerals (e.g. Sulphide Alteration Index); type of sulphide minerals and crystal forms (e.g. framboidal) to help evaluate reactivity of minerals; availability of minerals for weathering reactions (liberation) that can affect AGP and contaminant leaching potential.	Provides information about AGP, NP, and availability of minerals for weathering; corroborates rock type information.	Not easy to understand results if not trained in geology; semi-quantitative at best; small sample size/ representativeness; no database for comparison of results; XRD: no information on grain size or condition, not good for identification of secondary minerals
Sulphur analysis (different forms of sulphur)	Total S, pyritic S, sulphide S, organic S, sulphate S	Potential of samples to generate acid; used in combination with ABA tests.	Distinguishes between forms of S with more (pyritic S, sulphide S) and less (organic S, sulphate S) acid generation potential.	Does not confirm identity of minerals that contain the sulphur; can overestimate (for jarosite, iron sulphates) or underestimate (for chalcopyrite, galena) sulphide content
Static testing	Acid-base Accounting (ABA) methods: Sobek Method	To evaluate overall amounts of acid generating and acid-neutralizing materials in a sample; to identify samples that need kinetic testing.	<u>General for Static testing:</u> Gives operationally defined estimate of total neutralizing and acid generating content of samples; well-established technique; relatively fast and inexpensive technique; less labour-intensive than identifying complete mineralogy.	<u>General for Static testing:</u> Provides no information on relative rates, availability, texture, or identity of AG and NP minerals; assumes NP and AG minerals are Completely available for weathering; can over- or underestimate AGP And overestimate NP (see below); testing can be time-consuming. <u>For Sobek Method:</u> Can overestimate AGP (use of Total S); can overestimate NP (boiling, pH endpoint)

Characterization Tool	Test Names	Use in Water Quality Predictions	Advantages	Limitations
Static testing	Other ABA And Neutralization Potential Procedures	As above .	Prevents overestimation of NP and AP that can occur using Sobek *et al*., 1978; confirms presence/ absence of bacteria (BCRC).	BC Research Test requires more equipment and takes longer to run than ABA; Variable estimates of NP: NP-Sobek>NPModified Sobek>NPBCRI Initial> NPLapakko
Static testing	NAG (Net acid generating)	As above. Widely used in SE Asia and Australia for management and screening tool.	Evaluates net acid-base balance; arrives quickly at estimated net value for AGP; uses simple laboratory equipment and reagents.	Does not distinguish between AP and NP; screening method only; use with caution in carbonaceous rocks (can produce acid in error) or in high sulphide rocks (elevated temperatures can drop pH)
Static testing	NCV (Net carbonate value)	As above. Used principally by Newmont.	Procedure can be conducted quickly; includes only carbonate minerals in NP if pyrolysis working as expected; good for screening level and operational testing tool.	Does not confirm presence of minerals that generate or consume acid; requires sophisticated instrumentation; can overestimate NP when siderite is main carbonate mineral.
Total Inorganic Carbon	TIC	Measures NP associated with carbonates.	Avoids inclusion of non-carbonate minerals in NP; less expensive than NP.	Only provides carbonate fraction of NP; can overestimate NP when siderite is main carbonate; can only complement total NP results.
Short-term leach tests	SPLP (Synthetic Precipitation Leaching Procedure, Method 1312) and modification by USGS	Measures readily soluble components of mine wastes (all leach tests). SPLP: developed to evaluate metal mobility in an engineered landfill subjected to acid rain. USGS modification used to measure fraction that controls rapid leaching.	Provides indication of extent of leaching of salts and readily dissolvable constituents from dried mine materials (for all short-term leach tests).	Provides no information on long-term leach rates; only simulates short term interaction with rain/ snowmelt; high liquid:solid ratio may underestimate leachability.
Short-term leach tests	TCLP (Toxicity Characteristic Leaching Procedure, Method 1311)	Use to determine if waste is hazardous under RCRA; to evaluate metal mobility in a sanitary landfill.	Applicable standards available.	Use of acetic acid not appropriate for mining applications; only simulates the release of contaminants to groundwater.
Short-term leach tests	MEP (Multiple Extraction Procedure, Method 1320)	Same as TCLP and SPLP.	Longer procedure than TCLP and SPLP.	Provides no information on long-term leach rates; only simulates short term interaction with rain/ snowmelt; high liquid:solid ratio may underestimate leachability.
Short-term leach tests	MWMP (Meteoric Water Mobility Procedure)	Same as for SPLP.	Commonly used in Nevada; uses larger sample size than SPLP and solution more similar to rainwater in western US; higher solid:liquid ratio than SPLP.	Similar to SPLP but weaker (less aggressive) than SPLP (uses only water).
Short-term leach tests	California WET (waste extraction test)	Same as for TCLP.	Commonly used in California; lower liquid:solid ratio and longer tests time than SPLP and TCLP.	Similar to EP Toxicity test, but sodium citrate makes test more aggressive; sodium citrate not appropriate for mining applications.
Short-term leach tests	EP Toxicity (Extraction Procedure, Method 1310)	Similar to TCLP.	Applicable standards.	Replaced by TCLP.

Characterization Tool	Test Names	Use in Water Quality Predictions	Advantages	Limitations
Short-term leach tests	(British Columbia Special Waste Extraction Procedure) And Modification	Similar to TCLP for normal procedure; similar to SPLP/MWMP for modification.	Similar to TCLP for normal procedure; similar to SPLP/MWMP for modification. Lower liquid:solid ratio than other short term leach tests.	Similar to TCLP for normal procedure; similar to SPLP/MWMP for modification.
Short-term leach tests	Sequential Extraction	To evaluate associations of constituents of interest, especially metals, with different solid phases (e.g. salts, loosely bound/ adsorbed, iron and manganese oxides/ hydroxides, inside mineral lattice); to determine how easily metals can be released to the environment	Understanding associations of metals with different phases of the solid will assist in understanding geochemical conditions under which they may be released to environment	Long procedure, many reagents, mostly research application, no applicable standards/ criteria.
Short-term leach tests	Modification of Shake Extraction of Solid Waste with Water	For extraction of tailings solids.	Can simulate conditions where the solid waste is the dominant factor in determining the pH of the extract; lower liquid:solid ratio than some other leach tests.	Test only approved for certain inorganic constituents, and is not applicable to organic substances and volatile organic compounds (VOCs).
Laboratory kinetic testing	Humidity cell tests (HCT)	To estimate longer term potential of fully oxygenated mined materials to generate/ consume acid and produce contaminated leachate; to estimate rates of sulphide oxidation and neutralizing mineral dissolution; to evaluate acid generation lag time; to determine relative reactivities of rocks of a given mineral assemblage as a function of solid phase compositional variation; to provide rates for modelling.	Standardized test; provides kinetic and steady-state leaching information and information on weathering rates of primary minerals (e.g. sulphides).	Additional size reduction, if used, causes discrepancies between laboratory results and field conditions; not appropriate for saturated mined materials (e.g. submerged tailings); if NP>AP, AG lag time for metal/acid production may be longer than test
Laboratory kinetic testing	Column tests	As above, but can simulate leaching conditions in variably saturated or oxygen-deprived conditions; to simulate effects of mixing mined material with lime/alkaline additions.	Closer to field conditions than HCT; can simulate different weathering/ saturation conditions and mitigations; simulates combined weathering of primary and secondary phases.	Channelling of leachate along preferential flow paths or sides of column; must examine mineralogy before and after tests for estimation of weathering rates of primary minerals
Field testing of mined materials	Multiple; waste rock or tailings test piles; wall washing; Minewall Approach	To estimate long term potential of mined materials to generate acid and contaminated leachate.	Tests are conducted under actual field conditions; can collect samples after transient events, such as thunderstorms and snowmelt.	For field test piles: requires consideration of sampling and sample handling for proper scaling to full-scale system (e.g. for particle distribution, chemical composition, water movement, rate of weathering, effect of climate, gas transport, etc.).

The limitations of the applicability of kinetic test results to actual field conditions are highlighted extensively by Younger and Sapsford, 2004 who note that it has repeatedly been found that field rates of pollutant release from mine wastes are typically two to three orders of magnitude less than laboratory determined rates for the same rocks. At least five major causes for this systematic lab-field discrepancy have been identified by Banwart *et al*., 2002, namely:

- Particle size effects
- Temperature effects
- Spatial variations in mineralogy
- Hydrogeological complexity and preferential flowpaths
- Oxygen availability.

A8.2 STATE-OF-THE-ART METHODOLOGY FOR GEOCHEMICAL CHARACTERIZATION OF MINED MATERIALS

The steps for state-of-the-art geochemical characterization of mined materials are described below and shown schematically in the Figure below. The rationale for the selection of these approaches is contained in the preceding sections. The full list of steps is most appropriate for proposed or expanding operations. Characterization of mined materials at inactive or abandoned mines sites would instead rely more on existing site- or unit-specific water chemistry (e.g. seep, pore water, pit water, surface water, or groundwater quality) or a smaller list of approaches. Detailed descriptions of each of the components of this approach are provided in Maest *et al*., 2005.

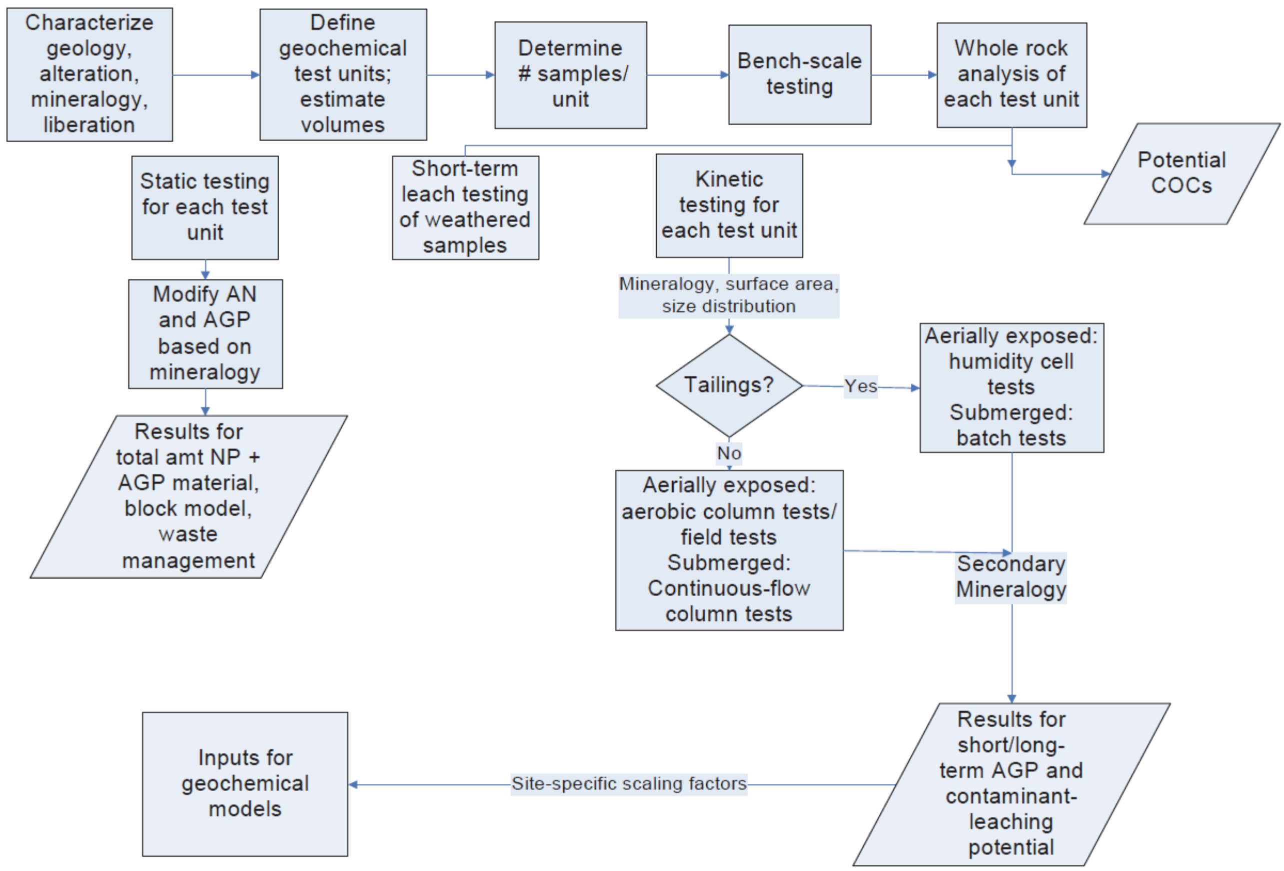

Figure A6: Steps for state-of-the-art characterization of mined materials (Maest *et al*., 2005)

A9 THE PREDICTIVE MODELLING TOOLBOX

A9.1 BACKGROUND TO PREDICTIVE MODELLING

The prediction of water quality at mine sites is a challenging topic because of its technical complication and inherent uncertainties. Much of the uncertainty related to predicting water quality at mine sites derives from inadequate or inaccurate conceptual models, hydrologic and geochemical characterization data, and input data to hydrogeochemical models (Maest *et al.*, 2005). Factors that contribute to making this prediction complicated include the following:

- knowledge of the dissolution chemistry of minerals present in the material being assessed at the micro-scale, together with the secondary reactions among dissolution products, gas phases and solid surfaces
- knowledge of the mineral surface areas available for reaction
- knowledge of the kinetics of reaction rates in a complex chemical mix
- knowledge of the confidence with which results from laboratory tests on small samples over short time periods can be extrapolated to large mining features over long time scales (decades or centuries)
- knowledge of future climatic conditions (temperature, rainfall, etc.)
- knowledge of the variability of these factors with the large scale mining features being assessed
- knowledge of the essential characteristics of the management actions to be undertaken, how these vary spatially and temporally and how these may be affected by future human actions (maintenance or lack thereof, wilful damage, etc.)

The solution to the above lies in the following:

- good conceptual model that adequately describes the situation being assessed
- sound risk assessment technique (six step feedback loop over the source-pathway-receptor continuum)
- sound sampling and analytical techniques with revision to verify confidence limits in data
- quantification of uncertainties along the whole assessment path
- selection of correct mathematical model able to address the real questions and consider the key variables, run in a probabilistic framework
- use of suitably qualified persons to undertake assessment and evaluate outcomes in order to accurately define upper and lower bounds of confidence in outcomes
- monitoring and collection of key data to allow verification and validation of predictions

Although applications of mathematical modelling in mine water quality prediction is still a relatively recent development, it is finding increasing regulatory acceptance in North America, Australia and certain European countries (Younger and Sapsford, 2004).

The modelling toolbox consists of a number of tools that need to be utilised in the correct manner and sequence as follows:

- Development of a conceptual model
- Selection of appropriate predictive codes
- Collection of data for modelling inputs
- Code verification and model calibration
- Estimation of uncertainty

Selection and use of the most complex hydrogeochemical code to predict water quality at a mine site does not necessarily provide realistic predictions. As noted by Nordstrom (2004), the sophistication of software has outdistanced our capacity to evaluate, constrain, and test the software. Selection of a computer code to develop a prediction of water quality should be based on factors such as:

- modelling objectives;
- capability of the code to simulate important processes affecting water quality at the mine site, as described by the site conceptual model(s);

- ability of the code to simulate spatial and temporal distribution of key input parameters and boundary conditions;
- availability of the code and its documentation to the public; and
- ease of use of the code, including availability of pre- or post-processors and graphical interfaces.

The overall objectives of the modelling project and the availability of supporting data should be considered in selecting a code. The code or codes chosen to predict water quality should be representative of the site (as reflected in the site conceptual model) and be applied at a level of complexity that is appropriate for the available data and the regulatory decisions that must be made. Some of the issues to consider when selecting a code include:

- What are the objectives and endpoints of the modelling
- What specific processes at the mine site will influence water quality, and what codes are capable of simulating these processes
- Whether reactions are better represented by equilibrium or kinetic codes (or both)
- Whether to use coupled or separate water quantity and quality codes
- The type and quality of environmental data available (or that could be collected) versus the type of data needed for the code
- Importance of colloids, microbiology, and transport by bacteria to resulting water quality
- Presence of graphical interfaces in codes and ease of use
- Availability of the code to others.

Younger and Sapsford, 2004 in reviewing the international literature on "acid mine drainage prediction tools" found that the most serious omission in most protocols is a clear focus on understanding where water moves from/to in the subsurface environment which encloses a given site. They further conclude that "the literature is replete with thousands of pages of minutely-argued text concerning the intricacies of 'acid-base accounting' and 'humidity-cell tests' and y*et al*most devoid of serious discussions of the hydrological pathways which are the *sine qua non* for pollution impacts to actually occur.

Excellent guidance on the capabilities and limitations of different predictive codes is provided in Chapter 7 (Section 7.2) of Maest *et al* (2005). It is important to remember that the primary purpose for the geochemical assessment is to guide management decisions (Price, 2005).

A9.2 COLLECTION OF DATA FOR MODELLING INPUTS

Site-specific inputs to computer codes are needed to make a model that will have relevance to a given mine site. The quality and representativeness of input data will affect the results of the models. Site-specific inputs to hydrogeochemical codes used to predict water quality are similar to certain information needed for conceptual models and can include:

- Spatial characteristics of geologic or geochemical units (e.g. depth, thickness)
- Hydraulic characteristics (e.g. hydraulic conductivity, porosity, storage characteristics) of mined materials, aquifers, and vadose zone)
- Water (leachate) quality and quantity of contaminant sources
- Rate of leaching of contaminants from mined materials
- Rate of pyrite oxidation
- Mineralogy of mined materials
- Reactive surface area of wastes
- Presence and type of bacteria
- Oxygen diffusion rates
- Partitioning of contaminants between soil/rock/waste/sediment and water
- Groundwater and surface water quality and temporal variability in quality
- Groundwater and surface water flow and temporal variability in flow
- Depth to groundwater and distance to surface water
- If a pit lake will form, pit lake bathymetry and dimensions

- Climate data (precipitation, temperature, wind speed, solar radiation, etc.)
- Information on mitigations.

In addition to site-specific data used as inputs to a code, data usually included in a code (e.g. thermodynamic data) should also be reviewed to ensure that the data are adequate for the intended purpose of the model and the site-specific conditions. Examples of data or parameters that can be included in hydrogeochemical codes include:

- Thermodynamic data, including thermodynamic data for secondary minerals, solid solutions, and aqueous species (e.g. iron, arsenic, selenium)
- Activity coefficient corrections capable of handling high-ionic strength solutions (e.g. Pitzer formulations)
- Reaction rate/kinetics data if non-equilibrium reactions are expected to be important
- Microbiological data - the rate of production of acid, sulphate, and metals is dependent on the presence of microbes such as *T. ferrooxidans*. Information on rates with and without microbes can be used in certain codes.
- Geochemical reactions (e.g. sorption).

The most challenging problem in all cases is specifying the reactive surface area of the minerals involved in the various pollutant release/attenuation reactions. It is possible to estimate this parameter at field scale by back-calculation of observed tracer release from minerals with well-constrained weathering rates (see Banwart *et al*., 2003). However, in many cases it will be necessary to work with assumed values and to account for the uncertainties which this inevitably introduces by means of sensitivity analyses.

A9.3 STATE-OF-THE-ART IN PREDICTIVE MODELLING

A generalized flow chart for state-of-the-art modelling of water quality at hard rock mine sites is shown in Figure A7. Using site-specific input data, hydrogeochemical modelling is conducted to determine potential concentrations at receptors or other points of interest. A numeric uncertainty analysis should be conducted using possible ranges of input values. Presenting potential contaminant concentrations at receptors as ranges rather than absolute values will better reflect the uncertainty inherent in predictive modelling. Detailed descriptions of each of the components of this approach are provided in Maest *et al*., 2005.

Modelling approaches for post-closure impact prediction will fall into the category of deterministic models which make the prediction on the basis of solving systems of equations that represent the various controlling factors in the reaction process (USEPA, 1994) rather than empirical models that are based on an assessment of trends and relationships in data sets.

A10 USE OF SUITABLY QUALIFIED PERSONS

The technical studies that need to be undertaken as part of a closure impact prediction exercise are highly complex, require extensive practical experience in developing accurate site conceptual models, use complex mathematical codes, require solid judgement in interpreting results and require the experience to be able to justify and motivate assumptions, methodologies and outcomes to a wide audience, including regulators, IandAPs and the appointed review specialists. Persons that have this type of experience are referred to as "suitably qualified persons' and their role is critical in the closure impact prediction project.

The most complex tools that need to be applied in the impact prediction project are the geochemical models. The major processes that such tools are required to model include mineral dissolution and precipitation; aqueous inorganic speciation and complexation; solute adsorption and desorption; ion exchange; oxidation-reduction or redox reactions; transformations; gas uptake or production; organic matter speciation and complexation; evaporation; dilution; water mixing; reaction during fluid flow; reaction involving biotic interactions; and photoreaction. These process need to be evaluated in saturated and unsaturated conditions; dray and wet hydrological cycles; surface and groundwater systems, winter and summer.

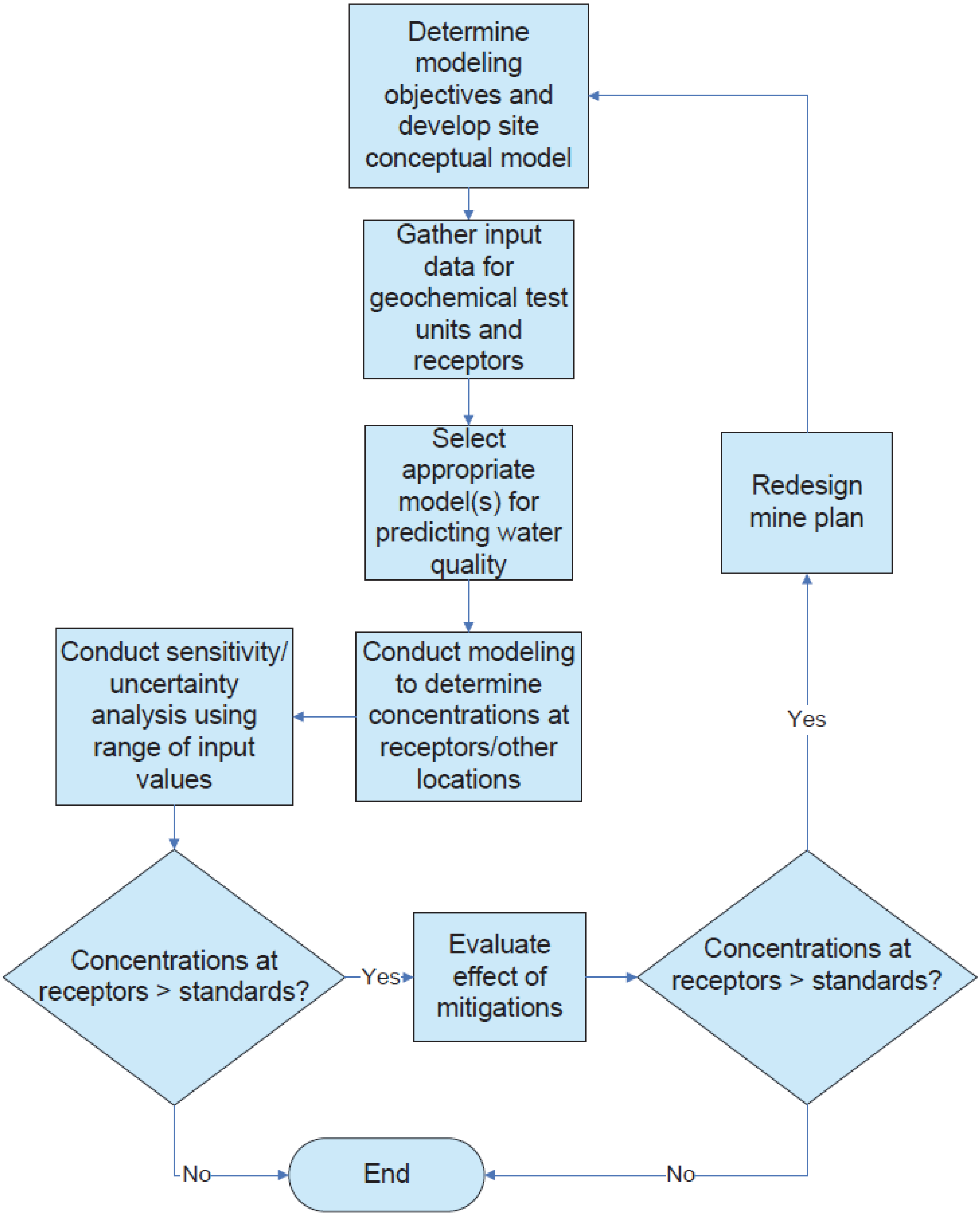

Figure A7: Steps for state-of-the-art predictive modelling at mine sites (Maest *et al.*, 2005)

While these geochemical models have the ability to give very good estimations of evolving water chemistry in many mining scenarios, these models have a dangerous sophistication for computing almost any type of possibility without adequately constraining what is possible (Nordstrom, 2004). Expert judgement is therefore particularly important in identifying the appropriateness of assumptions in applying a model and constitutes a bigger problem than that of model formulation (Nordstrom, 2004).

Generally, in risk analyses with little or no relevant historical data, expert judgment is required (Daneshkhah, 2004). How to use such judgment depends on which probabilistic method should be used to assess risk. If sufficient data are available, the estimation of parameters can be obtained based on analysis of the classical statistics approach only. But, if we have scarce data, the combined classical and Bayesian approach will be suggested which allows us to use expert judgment to establish subjective uncertainty measures associated with the true values of the parameters of interest.

It should be noticed that in both approaches, there are uncertainties associated with two levels: the occurrence of future events; and the true values of the probabilities and failure rates. In fact, the use of expert opinion from suitably qualified persons is a well-known way to obtain these estimates of uncertainty.

Expert opinions can provide useful information for forecasting, making decisions, and assessing risks. Expert judgment can be considered as an informed assessment or estimate, based on the experts' training and experience, about an uncertain quantity or quality of interest. Expert judgments are required in most steps of risk assessments: hazard identification, risk estimation, risk evaluation and analysis of options.

The use and elicitation of expert judgment is therefore subject to on-going research. So, it is important to clarify the meaning of the words expert and judgment which have been used in the risk communities. An expert is a person with special knowledge or skills in a particular domain. Some evidence that might be used as criteria for selecting expert(s) are: experience in performing judgements and making decisions, based on evidence of expertise, e.g. degrees, research, publications, positions and experience, awards, etc.; availability and willingness to participate; impartiality and inherent qualities like self-confidence and adaptability.

Judgment refers to inferences made in forming opinions. Thus, an expert judgment should be the inferential opinion of a domain specialist regarding an issue within the area of expertise. The judgment is obtained through a formal elicitation process (discussed below) that seeks to minimise biases (availability, anchoring and adjustment, representation, motivational biases, etc. (see Daneshkhah (2004) and references therein)) and to help the expert construct the subjective probability distribution. The use of expert judgment is subject to a developing set of rules which include:

- Experts are capable of expressing useful opinions as probability distributions. Usually these are what we would call uncertainty rather than variability, although sometimes both are confused.
- Effort must be made to reduce or account for the biases of experts. Overconfidence seems to be the most important of these for risk analysis.
- It should be noticed we want experts to look at the problem from very different point of views.

In a probabilistic risk assessment, expert opinion is used in two ways:

- To structure a problem. Experts determine which data and variables are relevant for analysis, which analytical methods are appropriate and which assumptions are valid. This input is critical in the construction of a site conceptual model
- To provide estimates. For example, experts may estimate failure or incidence rates, determine weighting for combining data sources, or characterize uncertainty.

A11 MONITORING, CALIBRATION and VALIDATION OF PREDICTIONS

A11.1 BACKGROUND

The monitoring programme that should be undertaken at a mine in support of mine closure must ultimately be able to demonstrate that the closure objectives either have been met, or that there is confidence that they will be met if the defined management actions are implemented. This confidence in a future outcome derives from confidence in a predictive tool that has been used to identify this future outcome and this is where model validation and calibration is critical.

A water-quality model is a simplified representation of the complex hydrologic and geochemical conditions at a mining site. The success of the model predictions will depend on how well the model represents the actual conditions and processes that influence water quality at the site. Verification of the modelling software and calibration of the selected model should be performed as part of hydrologic modelling.

“Verification” of the modelling software means that the code that is selected for the predictive modelling accurately solves the mathematical equations that describe the processes that the code simulates for conditions similar to those at the site in question. For hydrologic codes, the software is verified by comparison to analytical solutions for simple simulations, and this provides some assurance that the basic programming in the code is accurate.

Model calibration is the process of comparing site specific observations (e.g. stream flows, groundwater elevations, or pit lake concentrations) with model simulations. Calibration includes adjusting model parameters (e.g. hydraulic conductivity or porosity) so that the output from the model reproduces observed field conditions. After several years of site-specific data have been collected at the mine site, the model can be calibrated to a longer data record that will incorporate more temporal variability, and confidence in the model predictions can increase.

With the range of sophisticated computer codes available today our computational ability generally far exceeds our observational data on natural systems. Sophisticated computations, especially in the hands of the unskilled, have the possibility of achieving any preconceived result unless adequately constrained by empirical data (Nordstrom, 2004). More field data and related empirical observations are needed in order to provide the necessary constraints to achieve the legitimacy that is sought by the public and the regulators.

In impact prediction exercises, this problem of unconstrained predictions is addressed by undertaking the following:

- ensuring that simpler empirical test methods are also employed to provide reality checks against which model predictions can be tested;
- ensuring that suitably qualified persons are employed, as a minimum in managing the project, to ensure that good judgement is applied to all assumptions and methodologies employed;
- ensuring that a second independent suitably qualified person is appointed to act as project reviewer throughout the process;
- ensuring that post-prediction monitoring is undertaken and that the monitoring data is utilised to calibrate and validate the model.

A11.2 RESEARCH and FIELD TRIALS

The Australian Government (2006) clearly foresees the need to undertake site-specific research and field trials as part of the mine closure planning process.

In many cases when the mine closure plan is being developed, there may not be a clear methodology that can be applied to meet the closure goals, for example, developing a capping design for a waste rock dump to minimise oxidation and generation of acid rock drainage.

In these circumstances, specialist expertise is needed to develop a range of potential designs that could meet the long-term objectives. Evaluation of each design should include the materials to be used for the cover construction, modelling of the various inputs and outputs and prediction of long-term performance. The next steps are usually to develop trial cover systems - using the preferred two or three designs of lowest assessed risk - and monitor performance.

Cover design performance should be evaluated for at least three years. Data collected can be used to recalibrate the model and influence a final design for closure of the waste dump. In particular, the occurrence of extreme rainfall events or higher than average wet years, provide opportunities for rigorous testing of the design (Australian Government, 2006)

Research and trials can take several years to establish, monitor and modify before acceptable outcomes are achieved. It is critical that these trials are established long before the mine closes so that the knowledge from the trials can be incorporated into the final mine closure plans.

A11.3 MONITORING PROGRAMMES

Provision should be made in closure planning for an adequate period of maintenance and monitoring. Monitoring should be designed to demonstrate that closure objectives have been met and that the site is safe, stable and has achieved the land use objectives set during the planning process. It is unlikely that such conditions can be demonstrated in less than 5 years following cessation of mining (ANZMEC, 2000). Of particular importance is the development of support mechanisms for the maintenance and monitoring phase, when operational support (accounting, maintenance, etc.) is no longer readily available.

The need for maintenance recognises that not all closure strategies will be initially successful. All closure situations are unique, and although past experience and good planning can minimise the risks of failure, some remedial activity will usually be necessary.

Typical monitoring programs that support a mine closure program can include:

- baseline monitoring in the early mine life phases. This defines the values that need to be protected or re-established. For the purposes of rehabilitation, it should include the identification and establishment of un-mined reference areas during pre-mining mapping and surveys.
- monitoring, recording and understanding of all potential impacts during the operational phase of mining.
- documentation of the rehabilitation operations carried out - to confirm that agreed procedures have been implemented and to assist when interpreting the findings of later rehabilitation monitoring results.
- Initial closure monitoring conducted within one to two years of rehabilitation, to evaluate initial establishment success.
- long-term monitoring, commencing usually two to three years after rehabilitation, to evaluate the progress of rehabilitation towards fulfilling long-term closure objectives, and determine whether the rehabilitated ecosystem is likely to be sustainable over the long term.

A12 FORESEEN RISKS TO BE CONSIDERED

According to Heikkinen *et al.*, 2008, compliance with basic safety guidelines requires 1) that all structures (infrastructure, tailings and waste rock areas) remaining at the site are physically and chemically stable over the long-term, and 2) that any other legacy of mining operations, which might pose a safety risk (e.g. mine tunnels, steep slopes and embankments, decommissioned mining infrastructure and equipment), are either removed from the site, or rendered permanently inaccessible. Safety criteria are defined so as to ensure that risk mitigation procedures are sufficiently robust to cope with all conceivable geological and climatic contingencies. Therefore, closure strategies need to anticipate the likelihood of:

- extreme natural events (including intense rainfall, floods, storms, drought, wildfires, landslides and avalanches, and in some countries, volcanic eruptions and earthquakes);
- potential hazards of geological origin, such as erosion, collapse and subsidence and landslides
- environmental deterioration due to cumulative effects of successive floods or erosion over time;
- effects of climatic changes, such as variations in the frequency and intensity of extreme precipitation events and floods, and
- progressive deterioration in quality and loss of integrity of materials used in site management and remediation, including wooden, concrete and steel structures as well as clay liners and membranes and rock fill, as a consequence of weathering, or successive drying and wetting, or microbial attack and degradation.

Ideally the closure plan addresses closure risks at acceptable levels; however, there will always be a level of residual risk or uncertainty which requires further assessment and management. These include the success or failure of the chosen option, cost forecasting, and the risk that an event such as an earthquake, cyclone or unusually large rainfall may occur. For example, a particular water treatment process or dump design may have been identified to control the risks. Having developed the control (the closure plan), there will still be a residual risk that the water treatment - as planned - could fail, requiring additional measures. Failure could be due to changes in chemistry, damage from an extreme climatic event or changing regulations that may require stricter discharge limits. Even in cases of low severity and unlikely residual risk, analysis should still be carried out from a long-term risk management perspective. A risk-based closure plan will identify and assess residual risk and the outcomes will be included into the costing methodology (Australian Government, 2006).

A13 POST-CLOSURE WATER TREATMENT ISSUES

Most post-closure ARD mitigation facilities or structures must be designed, constructed, operated and financed in a manner that allows them to perform indefinitely. Successful long-term performance requires pro-active detection and resolution of problems prior to significant environmental impacts (Price, 2005). This requires:

- a conservative design;
- ability to handle future geochemistry, hydrology, ecology, etc.;
- monitoring, maintenance, repair, replacement and contingency plans;
- regularly updated operating manuals and databases for monitoring results; and
- the financial resources to conduct the above.

In terms of the Environment Canada: Environmental Code of Practice for Metal Mines (2009), at sites where it is determined that long-term treatment of wastewater will be necessary during post closure, a long-term wastewater treatment plan should be developed and implemented. This plan should include the following elements:

- identification of roles and responsibilities of persons to be involved in operation and maintenance of the treatment system;
- identification of the type of treatment system to be used;
- identification of any by-products from the treatment system, such as treatment sludge, and management plans for the disposal of those by-products;
- identification of routine maintenance activities to be conducted on the treatment system and the frequency;
- identification of monitoring to assess ongoing performance of the treatment system and the frequency;
- identification of reporting requirements for internal management and regulatory agencies; and
- description of contingency plans to address any problems associated with the treatment system.

Consideration should be given to the implementation of a passive treatment system. In some cases, these systems may have lower maintenance requirements than traditional treatment systems, although all systems do require some degree of ongoing maintenance (Environment Canada, 2009). The potential for passive treatment options is also recognised by the Australian Government (2006).

Where there is a need for long-term treatment of wastewater from mines during mine closure and post closure, a long-term treatment plan should be developed. Due to changes in wastewater volume and possible changes in the chemical composition of wastewater after the end of the mine operations phase, treatment systems in place during mine operations may not be appropriate during mine closure and post closure.

The need for post-closure water treatment arises when the application of pollution prevention measures is insufficient in enabling the mine to meet its post-closure water quality performance objectives. Pollution prevention opportunities can be maximised by ensuring that mine closure planning happens at the earliest possible stage in the mine life cycle. If closure planning is postponed until the middle or end of the mineral extraction phase, it may be too late to use certain pollution prevention approaches (Environmental Law Institute, 2000).

In British Columbia, Canada, the primacy of pollution prevention is also recognised and the provincial Acid Rock Drainage Policy, which guides its approval of reclamation and closure plans provides that "The primary objective of a metal leaching and acid rock drainage programme is prevention. This will be achieved through prediction, design and effective implementation of appropriate mitigation strategies".

In some cases, regulations have become exceedingly wary of potential post-closure water pollution issues and the State of Wisconsin (USA) adopted a moratorium on the mining of sulphide ores until companies could present evidence of successfully closed mines that did not generate acid. The US Bureau of Land Management has proposed regulations that would require operators to "minimise water pollution (source control) in preference to water treatment" (Environmental Law Institute, 2000).
Unfortunately South Africa also does not have a good record of early detailed closure planning and early identification and implementation of pollution prevention options. Fourie and Brent, 2008 conclude that due to uncertainties in the process required for effective mine closure and the reluctance of the regulator to approve mine closure that mines are resorting to strategies where they "focus more on inexpensive means of just complying with the 'esthetical nuisance' [of mine closure] rather than strategising to solve long-term effects".

While it is clear that pollution prevention options are preferred and should be optimally implemented in an effort to prevent a post-closure situation where residual long-term water treatment is required, the reality is that avoidance of a need for water treatment is not always attainable.

In cases where post-closure water treatment is required, the determination of the precise water treatment requirements is an additional step that occurs once the necessary impact prediction modelling has been undertaken. In order to determine water treatment requirements, the following information inputs are required:

1. Well-defined and agreed water quality objectives that need to be met at the identified and agreed critical receptors, either for the ground water and/or the surface water.
2. Predictive modelling for the mine site under consideration that provides information on the volume and quality of discharges at all identified discharge points, within a probabilistic framework (i.e. maximum, minimum and average) for at least 100 years into the future after mine closure.
3. Hydrological and/or groundwater transport and quality models that can use the data from the predictive modelling for discharge sources and predict actual water quality at the identified critical receptors for best, worst and most probable case scenarios.
4. In cases where the predicted post-closure water quality at the critical receptors is shown to exceed the water quality objectives that were agreed for these receptors, then data must be available to indicate what the discharge source water quality/volume should be to ensure that compliance is still achieved under worst case scenarios.

With these data inputs, the determination of appropriate water management/treatment options and their capital and operating costs can readily be undertaken by a water treatment specialist. There are two well - documented case studies of how key elements of the procedures and process described in this literature review and in the BPGs have been implemented at South African mines. The one case study refers to the assessment of alternative cover designs for a coal discard dump and the use of quantitative predictive modelling to provide the basis for decision-making on which cover option should be implemented (Swart *et al*., 1998). The second case study refers to the very detailed integrated assessment of a complete coal mine site, incorporating extensive underground workings, numerous interconnected opencast pits and coal discard facilities. This mine discharged through numerous discharge points into the headwaters of three different river catchments and the flow and quality was modelled in each of these river systems all the way down to identified critical receptors some kilometres downstream of the discharge points. Various water management mitigation measures were identified and also modelled and the results of these predictive assessments were used as the basis for selecting priority risk features of the mine and identifying priority management actions to be implemented. Where necessary, residual post-closure passive water treatment options were also identified (Hattingh *et al*., 2002).

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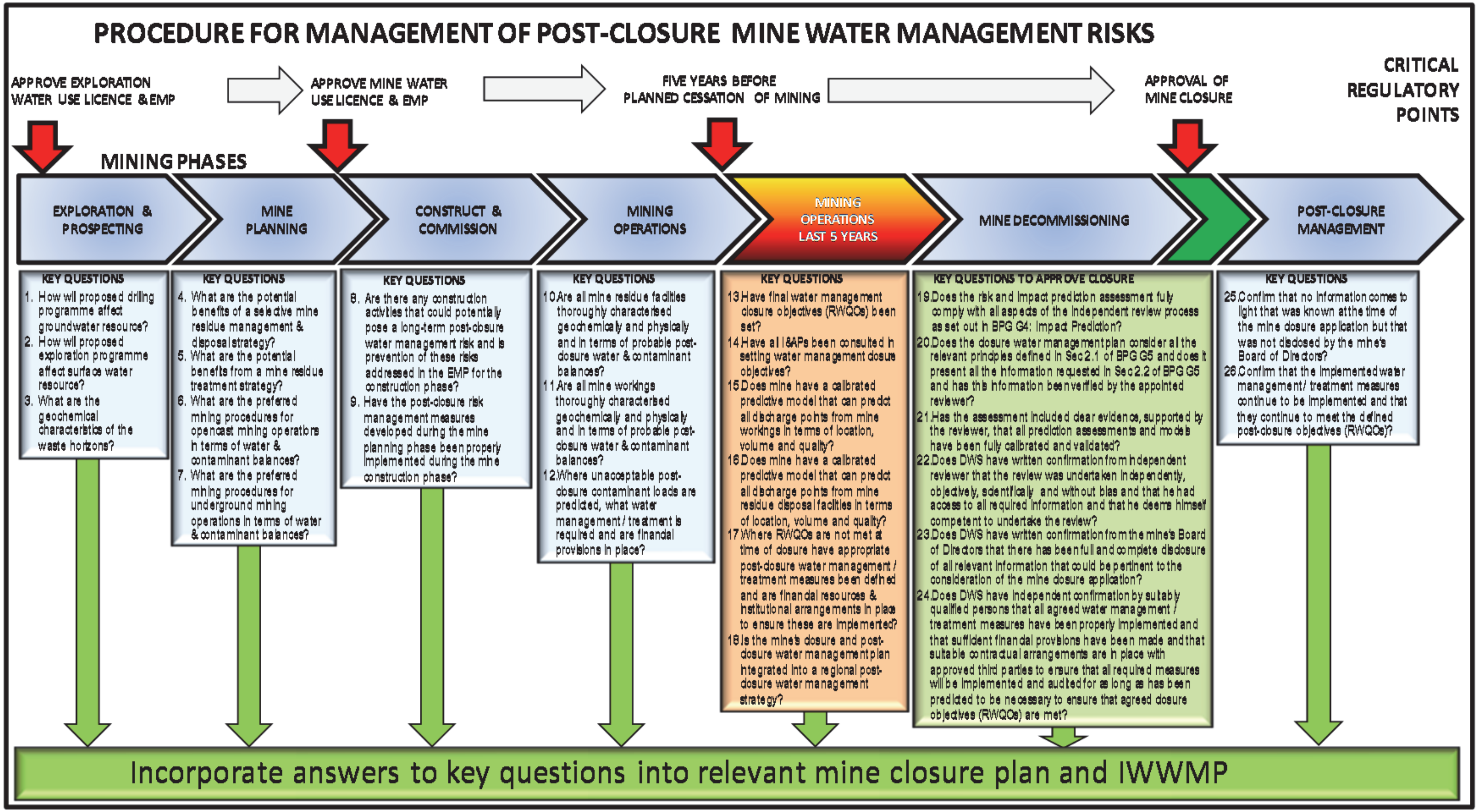
ANNEXURE B: GUIDELINE FOR THE MINING INDUSTRY FOR THE MANAGEMENT OF POST-CLOSURE WATER MANAGEMENT RISKS OVER THE FULL LIFE-CYCLE OF A MINING OPERATION

Guideline for the mining industry for the management of major post-closure water management risks over the full life-cycle of a mining operation

by
William Pulles

RECORD OF EVENTS THAT SHOULD BE MAINTAINED OVER THE LIFE –CYCLE OF THE MINING OPERATION IN ORDER TO DEMONSTRATE THAT THE CORRECT POST-CLOSURE WATER MANAGEMENT PLANNING PROCESS WAS EMPLOYED BY THE MINE AS A PRECURSOR TO THE APPROVAL OF A MINE CLOSURE APPLICATION AND TO GIVE THE MINE ASSURANCE THAT RISK MANAGEMENT MEASURES HAVE BEEN IDENTIFIED AND IMPLEMENTED AT ALL THE NECESSARY STAGES OF THE MINING PROJECT

NOTE: This guideline deals with the assessment and management of the major risks associated with mining projects that may affect post-closure risk and financial liability from a water management perspective. The primary focus is on risks associated with mine residue deposits and mine workings (underground and open cast)


PROCEDURE FOR MANAGEMENT OF POST-CLOSURE MINE WATER MANAGEMENT RISKS
APPROVE EXPLORATION WATER USE LICENCE & EMP
APPROVE MINE WATER USE LICENCE & EMP
FIVE YEARS BEFORE PLANNED CESSATION OF MINING
APPROVAL OF MINE CLOSURE
CRITICAL REGULATORY POINTS
MINING PHASES
EXPLORATION & PROSPECTING
MINE PLANNING
CONSTRUCT & COMMISSION
MINING OPERATIONS
MINING OPERATIONS LAST 5 YEARS
MINE DECOMMISSIONING
POST-CLOSURE MANAGEMENT
KEY QUESTIONS
1. How will proposed drilling programme affect groundwater resource?
2. How will proposed exploration programme affect surface water resource?
3. What are the geochemical characteristics of the waste horizons?
KEY QUESTIONS
4. What are the potential benefits of a selective mine residue management & disposal strategy?
5. What are the potential benefits from a mine residue treatment strategy?
6. What are the preferred mining procedures for opencast mining operations in terms of water & contaminant balances?
7. What are the preferred mining procedures for underground mining operations in terms of water & contaminant balances?
KEY QUESTIONS
8. Are there any construction activities that could potentially pose a long-term post-closure water management risk and is prevention of these risks addressed in the EMP for the construction phase?
9. Have the post-closure risk management measures developed during the mine planning phase been properly implemented during the mine construction phase?
KEY QUESTIONS
10. Are all mine residue facilities thoroughly characterised geochemically and physically and in terms of probable post-closure water & contaminant balances?
11. Are all mine workings thoroughly characterised geochemically and physically and in terms of probable post-closure water & contaminant balances?
12. Where unacceptable post-closure contaminant loads are predicted, what water management / treatment is required and are financial provisions in place?
KEY QUESTIONS
13. Have final water management closure objectives (RWQOs) been set?
14. Have all I&APs been consulted in setting water management closure objectives?
15. Does mine have a calibrated predictive model that can predict all discharge points from mine workings in terms of location, volume and quality?
16. Does mine have a calibrated predictive model that can predict all discharge points from mine residue disposal facilities in terms of location, volume and quality?
17. Where RWQOs are not met at time of closure have appropriate post-closure water management / treatment measures been defined and are financial resources & institutional arrangements in place to ensure these are implemented?
18. Is the mine's closure and post-closure water management plan integrated into a regional post-closure water management strategy?
KEY QUESTIONS TO APPROVE CLOSURE
19. Does the risk and impact prediction assessment fully comply with all aspects of the independent review process as set out in BPG G4: Impact Prediction?
20. Does the closure water management plan consider all the relevant principles defined in Sec 2.1 of BPG G5 and does it present all the information requested in Sec 2.2 of BPG G5 and has this information been verified by the appointed reviewer?
21. Has the assessment included clear evidence, supported by the reviewer, that all prediction assessments and models have been fully calibrated and validated?
22. Does DWS have written confirmation from independent reviewer that the review was undertaken independently, objectively, scientifically and without bias and that he had access to all required information and that he deems himself competent to undertake the review?
23. Does DWS have written confirmation from the mine's Board of Directors that there has been full and complete disclosure of all relevant information that could be pertinent to the consideration of the mine closure application?
24. Does DWS have independent confirmation by suitably qualified persons that all agreed water management / treatment measures have been properly implemented and that sufficient financial provisions have been made and that suitable contractual arrangements are in place with approved third parties to ensure that all required measures will be implemented and audited for as long as has been predicted to be necessary to ensure that agreed closure objectives (RWQOs) are met?
KEY QUESTIONS
25. Confirm that no information comes to light that was known at the time of the mine closure application but that was not disclosed by the mine's Board of Directors?
26. Confirm that the implemented water management/ treatment measures continue to be implemented and that they continue to meet the defined post-closure objectives (RWQOs)?
Incorporate answers to key questions into relevant mine closure plan and IWWMP

EXPLORATION AND PROSPECTING PHASE

KEY QUESTION 1: How will the proposed drilling programme affect the integrity of the groundwater resources in the area where prospecting and exploration is intended to take place?

OBJECTIVE: To ensure that the proposed drilling programme is undertaken in a manner that ensures that no short-, medium- or long-term damage is inflicted on the groundwater resource.

WATER MANAGEMENT HIERARCHY PRINCIPLE: Pollution Prevention

QUESTIONS TO BE ANSWERED BEFORE EXPLORATION & PROSPECTING PHASE PROCEEDS

1. Has a detailed conceptual ground water model been developed for the area that may potentially be impacted upon by the proposed exploration drilling programme?
2. Has a hydrocensus been undertaken for the area to be prospected and has the collected data been used in the development of the conceptual ground water model?
3. Was the conceptual model developed by a suitably qualified person?
4. Has the conceptual model been reviewed by an independent reviewer?
5. Does the conceptual model identify data that should be collected during the exploration drilling phase to be used in refining the conceptual model?
6. Is there clear evidence that the proposed exploration drilling programme has been structured to collect this specified data?
7. Has the conceptual ground water model identified preliminary management measures that need to be implemented to ensure that the integrity of the regional ground water resources is protected during and after the exploration drilling programme?
8. Is there clear evidence that the identified preliminary management measures are adequate to protect the groundwater resource and that they are incorporated into the exploration phase environmental / water management plan?

Are all the above questions answered Yes?
- NO → CORRECT, MOTIVATE OR STOP
- YES → PROJECT PROCEEDS

QUESTIONS TO BE ANSWERED DURING SITE INSPECTIONS

9. Has the initial conceptual ground water model been updated using the data collected during the exploration drilling phase?
10. Has the updated conceptual ground water model resulted in any changes to the preliminary management measures that were specified?
11. If yes, have these revised management measures been implemented?

Are all the above questions answered Yes?
- NO → CORRECT OR MOTIVATE
- YES → PROJECT PROCEEDS

QUESTIONS TO BE ANSWERED BEFORE SITE RELINQUISHMENT

12. Has an audit been undertaken to check whether the specified management measures have been appropriately implemented?
13. If yes, has the audit confirmed that the specified management measures were appropriately implemented?

Are all the above questions answered Yes?
- NO → MINE OWNER MUST IMPLEMENT MEASURES
- YES → DEPENDING ON OUTCOME OF OTHER CRITICAL ISSUES, PROCEED TO PLANNING PHASE

EXPLORATION AND PROSPECTING PHASE

KEY QUESTION 2: How will the proposed exploration programme affect the surface water resources in the area where prospecting and exploration is intended to take place?

OBJECTIVE: To ensure that the proposed exploration programme is undertaken in a manner that ensures that no short-, medium- or long-term damage is inflicted on the surface water resource.

WATER MANAGEMENT HIERARCHY PRINCIPLE: Pollution Prevention

QUESTIONS TO BE ANSWERED BEFORE EXPLORATION & PROSPECTING PHASE PROCEEDS

1. Has a detailed hydrological and water quality assessment been undertaken for the area that may potentially be impacted upon by the proposed exploration programme?
2. Have all wetland areas been identified, defined and clearly demarcated on a site plan for the area where exploration activities will be undertaken?
3. Has all proposed infrastructure, access roads, etc been clearly shown on the site plan?
4. Is there a comprehensive site management & rehabilitation plan that ensures that there will be no lasting impacts on the surface water resource after site rehabilitation?
5. Have the above assessments and site management and rehabilitation plan been reviewed by an independent reviewer?

Are all the above questions answered Yes?
- NO → CORRECT, MOTIVATE OR STOP
- YES → PROJECT PROCEEDS

QUESTIONS TO BE ANSWERED DURING SITE INSPECTIONS

6. Has the site management plan been implemented and complied with during the exploration and prospecting phase of the project?

Are all the above questions answered Yes?
- NO → CORRECT OR MOTIVATE
- YES → PROJECT PROCEEDS

QUESTIONS TO BE ANSWERED BEFORE SITE RELINQUISHMENT

7. Has the site rehabilitation plan been implemented and complied with during the exploration and prospecting phase of the project?
8. Has an audit been undertaken to check whether the specified rehabilitation measures have been appropriately implemented?
9. If yes, has the audit confirmed that the specified management measures were appropriately implemented and that there are no long-term residual impacts on the surface water resource?

Are all the above questions answered Yes?
- NO → MINE OWNER MUST IMPLEMENT MEASURES
- YES → DEPENDING ON OUTCOME OF OTHER CRITICAL ISSUES, PROCEED TO PLANNING PHASE

EXPLORATION AND PROSPECTING PHASE

KEY QUESTION 3: What are the geochemical characteristics of the waste horizons that will be generated should the planned mine proceed and how should this mine residue be managed?

OBJECTIVE: To ensure that appropriate data is collected to enable the pollution potential of the different mine waste (residue) streams to be assessed during the mine planning phase, in order that mine residue disposal options can be investigated that minimise the long-term and post-closure risks associated with the mine residues

WATER MANAGEMENT HIERARCHY PRINCIPLE: Pollution Prevention

QUESTIONS TO BE ANSWERED BEFORE EXPLORATION & PROSPECTING PHASE PROCEEDS

1. Does the drilling programme make provision to take samples of the horizons above / between / below the extractable minerals for geochemical analyses for all drill cores?
2. Has the geochemical analytical programme for these waste horizon samples been developed by a suitably qualified geochemist in accordance with BPG G4?
3. Can a suitably qualified geochemist confirm that the developed analytical programme makes provision for both static and kinetic geochemical assessments in accordance with BPG G4 and that the timeframe for the kinetic sampling programme, with or without preservation, takes account of the mine planning schedule and allows sufficient time for the kinetic tests to be completed and the results thereof incorporated into the mine residue management programme?
4. If samples are not to be analysed immediately has an appropriate sample preservation protocol been developed and approved by a suitably qualified geochemist?
5. Has the mine provided written confirmation, signed by a person with the appropriate authorisation, that the sampling / analytical / preservation programme will be implemented?

Are all the above questions answered Yes?
- NO → CORRECT OR MOTIVATE
- YES → PROJECT PROCEEDS

QUESTIONS TO BE ANSWERED DURING SITE INSPECTIONS

6. Can it be confirmed that the drilling programme did take the agreed number of samples?
7. Can it be confirmed in writing, by a suitably qualified geochemist, that the analytical programme that should have been implemented is on track?
8. Can it be confirmed in writing, by a suitably qualified geochemist, that samples that should have been preserved have been and continue to be properly preserved?

Are all the above questions answered Yes?
- NO → MINE OWNER TO TAKE CORRECTIVE ACTIONS
- YES → DEPENDING ON OUTCOME OF OTHER CRITICAL ISSUES, PROCEED TO PLANNING PHASE

MINE PLANNING PHASE

KEY QUESTION 4: What are the potential benefits that could be obtained from implementing a selective mine residue management and mine residue disposal strategy?

OBJECTIVE: To ensure that differences, if any, in the long-term pollution potential of different mine residue streams that will be generated by the mining operations are properly established and that this knowledge is then applied to evaluate potential long-term and post-closure risks and benefits of establishing a system of selective mine residue disposal, based on quantifying the pollution potential of the residues, taking into account practical and economic constraints.

WATER MANAGEMENT HIERARCHY PRINCIPLE: Pollution Prevention

1. Has the full planned geochemical analysis and characterisation of the waste horizon samples taken from the exploration drill cores been completed under the supervision of a suitably qualified geochemist?
2. Has a suitably qualified geochemist assessed the results of the geochemical characterisation programme to determine whether residue streams will be generated that have significantly different long-term pollution potentials?

RESTART PLANNING ← NO — Are all the above questions answered Yes? — YES → PLANNING PROCEEDS

3. If the assessment referred to in Question 2 above was undertaken, did it conclude that there was a potential to generate mine residue streams with significantly different long-term pollution potentials?

CONTINUE STANDARD MINE RESIDUE DISPOSAL PLANS ← NO — Has Question 3 been answered Yes? — YES → EVALUATE SELECTIVE MINE RESIDUE DISPOSAL OPTIONS OR GO TO KEY QUESTION 5

4. Has an assessment been undertaken, by suitably qualified persons, on the potential benefits that could be obtained in terms of reduced long-term risk to the water resources, of separating mine residue streams into low and high pollution potential residue streams and then disposing of them onto separate mine residue deposits?
5. Has the option of selective (or separate) disposal of mine residue streams been evaluated from a mining, engineering and life cycle economic (including probable decommissioning and post-closure costs) perspective?

UNDERTAKE ASSESSMENTS DESCRIBED IN 4 & 5 ← NO — Have Questions 4 & 5 been answered Yes? — YES → CONTINUE TO QUESTION 6

6. Is there certainty that there are no issues with regard to the disposal and/or storage of mine residue streams that could potentially create water management problems at or after mine closure that can not be effectively and sustainably managed?

CONSIDER TERMINATING THE PROPOSED MINING PROJECT ← NO — Has Question 6 been answered Yes? — YES → CONTINUE TO QUESTION 7

7. Have both the assessments described in questions 4 and 5 above demonstrated that there is environmental and economic benefit in developing a selective mine residue disposal strategy?

ACCEPT THAT SELECTIVE MINE RESIDUE DISPOSAL IS NOT WARRANTED ← NO — Has Question 7 been answered Yes? — YES → DEVELOP A SUITABLE SELECTIVE MINE RESIDUE DISPOSAL PLAN

MINE PLANNING PHASE

KEY QUESTION 5: What are the potential benefits that could be obtained from implementing a mine residue treatment strategy to remove/reduce the pollution potential of the most reactive mine residue streams?

OBJECTIVE: To ensure that differences, if any, in the long-term pollution potential of different mine residue streams that will be generated by the mining operations are properly established and that this knowledge is then applied to determine whether or not there are any benefits to be gained, in terms of long-term and post-closure risks, from treating those mine residue streams that have the highest pollution potential in order to reduce their pollution potential, taking into account practical and economic constraints.

WATER MANAGEMENT HIERARCHY PRINCIPLE: Pollution Prevention

1. Have questions 1, 2 and 3 of the Checklist for Key Question 4 for the Mine Planning Phase been answered with a Yes?

FIRST UNDERTAKE ASSESSMENTS TO ENABLE YES ANSWER ← NO ← Are all the above questions answered Yes? → YES → PROCEED TO INVESTIGATE RESIDUE TREATMENT OPTIONS

2. Has an assessment been undertaken, by suitably qualified persons, to determine the potential benefits that could be obtained in terms of reduced long-term risk to the water resources, of treating all or a portion of the mine residue streams such that they present a lower pollution potential and then disposing of them onto separate or combined mine residue deposits?

3. Has the option of partial or total treatment and disposal of mine residue streams been evaluated from a mining, engineering and life cycle economic (including probable decommissioning and post-closure costs) perspective?

UNDERTAKE ASSESSMENTS DESCRIBED IN 2 & 3 ← NO ← Have Questions 2 & 3 been answered Yes? → YES → CONTINUE TO QUESTION 4

4. Have both the assessments described in questions 2 and 3 above demonstrated that there is environmental and economic benefit in developing a partial or total mine residue treatment and disposal strategy?

ACCEPT THAT TREATMENT OF MINE RESIDUES IS NOT WARRANTED ← NO ← Has Question 4 been answered Yes? → YES → DEVELOP A SUITABLE MINE RESIDUE TREATMENT & DISPOSAL PLAN

MINE PLANNING PHASE

KEY QUESTION 6: Based on evaluation of a most likely operational and post-closure pit water and contaminant balances, what are the preferred mining procedures for any planned opencast mining operations?

OBJECTIVE: To ensure that mines that are planning to mine using surface (opencast) mining methods, evaluate and assess alternatives with regard to their long-term and post-closure risks and benefits.

WATER MANAGEMENT HIERARCHY PRINCIPLE: Pollution Prevention

1. Is there an existing regional post-closure water management strategy in place for the area in which the intended mining operation is located?

Has Question 1 been answered Yes?
- NO → PROCEED WITH THE KNOWLEDGE THAT THERE ARE UNKNOWN RISKS FROM ADJACENT MINES
- YES → INCORPORATE REGIONAL STRATEGY INTO MINE PLANNING ACTIVITIES

2. Has a detailed conceptual groundwater model been constructed for the area that will be mined?
3. Has a preliminary groundwater model been developed for the area that will be mined that is capable of producing a provisional post-closure mine water balance?
4. Has question 1 in Key Question 4 for the Mine Planning Phase been answered yes?
5. Has the information referred to in the above 3 questions been utilised to develop a model capable of predicting the potential long term quality of water that may decant from the opencast workings after planned mine closure?
6. Has the model referred to In Question 4 above been used to evaluate the long-term potential decant positions, volumes and qualities of alternative opencast mining options?
7. Can it be demonstrated that the information generated in Question 5 was considered in evaluating and deciding on a preferred opencast mining method?
8. Is the selected opencast mining method deemed appropriate, based on a review of the information generated by questions 5 and 6 above?
9. Have appropriate financial provisions been included in the mine's closure fund to deal with projected post-closure water management impacts for the selected and preferred opencast mining method?

Have all the above questions been answered Yes?
- NO → MINE PLAN HAS NOT ADEQUATELY CONSIDERED POLLUTION PREVENTION
- YES → MINE PLAN HAS CONSIDERED POLLUTION PREVENTION ALTERNATIVES

10. Is there certainty that there are no issues with regard to the planned opencast mining operations that could potentially create water management problems at or after mine closure that can not be effectively and sustainably managed?

Has Question 10 been answered Yes?
- NO → CONSIDER TERMINATING THE PROPOSED MINING PROJECT
- YES → PROCEED WITH MINE PLANNING

MINE PLANNING PHASE

KEY QUESTION 7: Based on evaluation of a most likely operational and post-closure water and contaminant balances, what are the preferred mining procedures for any planned underground mining operations?

OBJECTIVE: To ensure that mines that are planning to mine using underground mining methods, evaluate and assess alternatives with regard to their long-term and post-closure risks and benefits.

WATER MANAGEMENT HIERARCHY PRINCIPLE: Pollution Prevention

1. Is there an existing regional post-closure water management strategy in place for the area in which the intended mining operation is located?

Has Question 1 been answered Yes?
- NO → PROCEED WITH THE KNOWLEDGE THAT THERE ARE UNKNOWN RISKS FROM ADJACENT MINES
- YES → INCORPORATE REGIONAL STRATEGY INTO MINE PLANNING ACTIVITIES

2. Has a detailed conceptual groundwater model been constructed for the area that will be mined?
3. Has a preliminary groundwater model been developed for the area that will be mined that is capable of producing a provisional post-closure mine water balance?
4. Has a preliminary ground subsidence model been developed for the area that will be mined that is capable of predicting the probable extent of subsidence that could occur during and after mining operations?
5. Have the models referred to in Questions 2&3 been used to evaluate the long term potential for different underground mining options to impact on the integrity of surface and ground water resources that may be affected by the planned mining?
6. Has question 1 in Key Question 4 for the Mine Planning Phase been answered yes?
7. Has the information referred to in the above 4 questions been utilised to develop a model capable of predicting the potential long term quality of water that may decant from the underground workings after planned mine closure?
8. Has the model referred to In Question 5 above been used to evaluate the long-term potential decant positions, volumes and qualities of alternative underground mining options?
9. Can it be demonstrated that the information generated in Questions 3 and 6 was considered in evaluating and deciding on a preferred underground mining method?
10. Is the selected underground mining method deemed appropriate, based on a review of the information generated by questions 3, 6 and 7 above?
11. Have appropriate financial provisions been included in the mine's closure fund to deal with projected post-closure water management impacts for the selected and preferred underground mining method?

Have all the above questions been answered Yes?
- NO → MINE PLAN HAS NOT ADEQUATELY CONSIDERED POLLUTION PREVENTION
- YES → MINE PLAN HAS CONSIDERED POLLUTION PREVENTION ALTERNATIVES

12. Is there certainty that there are no issues with regard to the planned underground mining operations that could potentially create water management problems at or after mine closure that can not be effectively and sustainably managed?

Has Question 12 been answered Yes?
- NO → CONSIDER TERMINATING THE PROPOSED MINING PROJECT
- YES → PROCEED WITH MINE PLANNING

MINE CONSTRUCTION PHASE

KEY QUESTION 8: Are there any construction activities that could potentially pose a long-term post-closure water management risk and is prevention of these risks addressed in the EMP for the construction phase?

OBJECTIVE: To ensure that construction activities will be undertaken in a manner that does not result in any water management impacts or risks that may persist till and after mine closure and that an environmental management plan (EMP) for the construction phase does address any such potential risks.

WATER MANAGEMENT HIERARCHY PRINCIPLE: Pollution Prevention

1. Is there an assurance that all earthworks associated with the construction of the project, including roads, road embankments, river crossings, storage and pollution control dams, footprints for office, plant or other infrastructure will only use material that has been geochemically assessed to ensure that there are no long-term water quality issues associated with the use of such material?
2. Is there an assurance that the physical location of all construction infrastructure such as site offices, access roads, river crossings, storage yards, diesel and oil storage, vehicle storage and maintenance facilities, sanitation facilities and all other construction infrastructure has been evaluated to ensure that effective site rehabilitation after construction has been completed, can be assured?
3. Is there an assurance that all wetlands have been delineated by a suitably qualified person and that all planned mine infrastructure and construction infrastructure and activities are outside the specified exclusion zones for these wetlands?

FIRST UNDERTAKE ASSESSMENTS TO ENABLE YES ANSWER ← NO ← Are all the above questions answered Yes? → YES → PROCEED TO QUESTION 4

4. Is there a suitable construction phase EMP that explicitly addresses the aspects raised in Question 1-3 above?

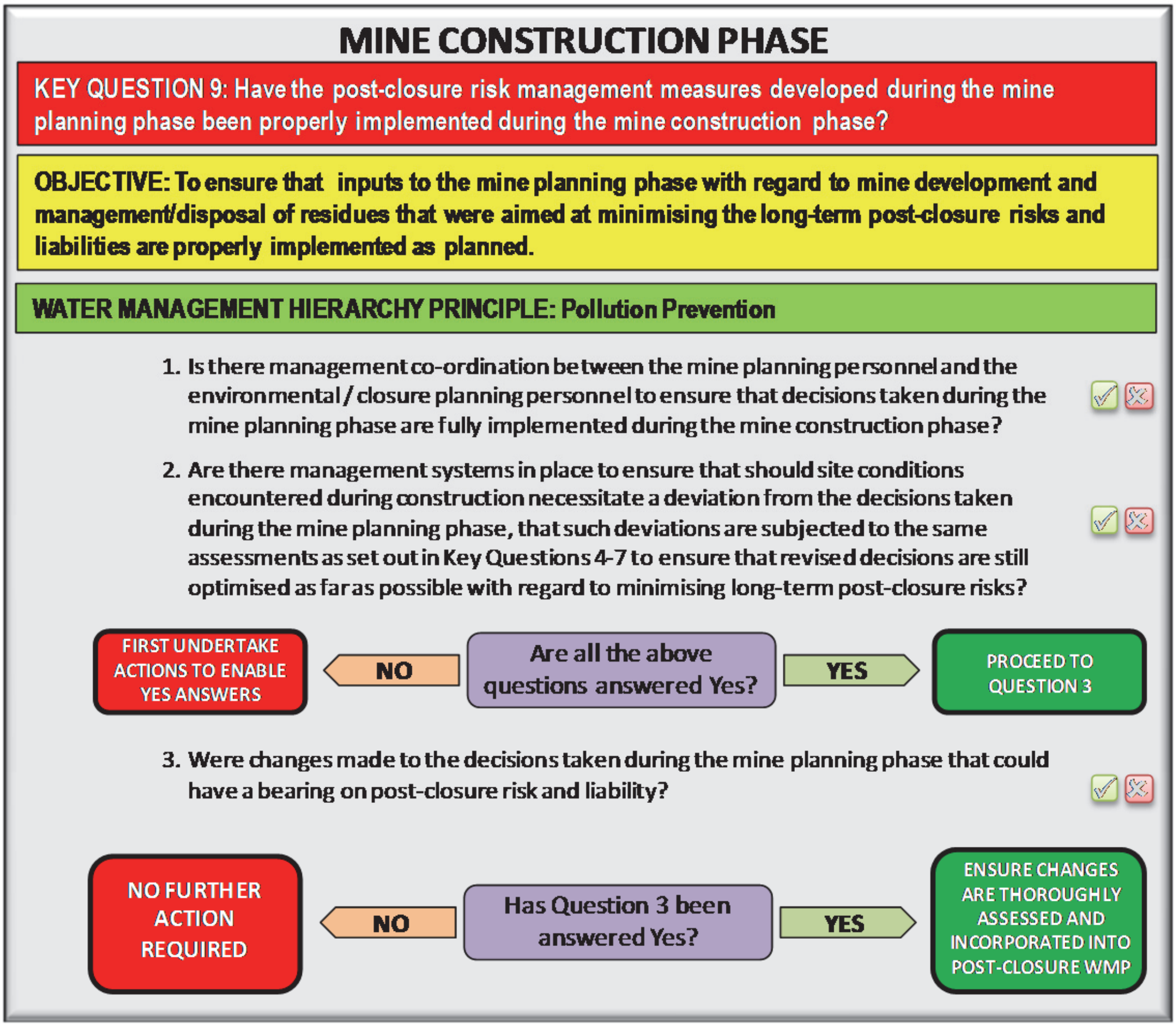
FIRST DEVELOP THE APPROPRIATE CONSTRUCTION EMP ← NO ← Is the above question answered Yes? → YES → PROCEED TO QUESTION 5

5. Is there a suitably qualified construction phase environmental officer who has responsibility for ensuring compliance with the construction phase EMP?

ENSURE THAT A SUITABLE PERSON MANAGES THE EMP ← NO ← Is the above question answered Yes? → YES → PROCEED TO QUESTION 6

6. Are there systems in place to ensure that deviations from the construction phase EMP are identified and that corrective actions are implemented to prevent recurrences and to mitigate where necessary?

INCORPORATE EMP COMPLIANCE INTO MANAGEMENT SYSTEMS ← NO ← Has Question 6 been answered Yes? → YES → ENSURE ONGOING REVIEW & UPDATE OF EMP


MINE CONSTRUCTION PHASE
KEY QUESTION 9: Have the post-closure risk management measures developed during the mine planning phase been properly implemented during the mine construction phase?
OBJECTIVE: To ensure that inputs to the mine planning phase with regard to mine development and management/disposal of residues that were aimed at minimising the long-term post-closure risks and liabilities are properly implemented as planned.
WATER MANAGEMENT HIERARCHY PRINCIPLE: Pollution Prevention
1. Is there management co-ordination between the mine planning personnel and the environmental / closure planning personnel to ensure that decisions taken during the mine planning phase are fully implemented during the mine construction phase?
2. Are there management systems in place to ensure that should site conditions encountered during construction necessitate a deviation from the decisions taken during the mine planning phase, that such deviations are subjected to the same assessments as set out in Key Questions 4-7 to ensure that revised decisions are still optimised as far as possible with regard to minimising long-term post-closure risks?
FIRST UNDERTAKE ACTIONS TO ENABLE YES ANSWERS
NO
Are all the above questions answered Yes?
YES
PROCEED TO QUESTION 3
3. Were changes made to the decisions taken during the mine planning phase that could have a bearing on post-closure risk and liability?
NO FURTHER ACTION REQUIRED
NO
Has Question 3 been answered Yes?
YES
ENSURE CHANGES ARE THOROUGHLY ASSESSED AND INCORPORATED INTO POST-CLOSURE WMP

MINE OPERATIONAL PHASE

KEY QUESTION 10: Are all mine residue facilities thoroughly characterized geochemically and physically and in terms of probable post-closure water and contaminant balances in a manner appropriate to the remaining life of mine?

OBJECTIVE: To ensure that mines continuously collect the required data and use the data to update and refine the predictions of long-term post-closure impact of mine residue facilities to the point where a high degree of confidence can be associated with the predictions. The improved predictive ability should then be used to evaluate alternative rehabilitation and closure options for these facilities from the perspective of meeting the defined post-closure water management objectives. The most appropriate options that will ensure that post-closure water management objectives are met should then be specified in detail and appropriate financial provisions should be included in the closure fund. The level of detail of the assessment and confidence in the predictions will increase as the mine approaches end of mine life.

WATER MANAGEMENT HIERARCHY PRINCIPLE: Pollution Prevention

If the length of time that the mine has already been in operation is:

- less than 2 years **or** less than 10% of the total planned mine life, then go to Section A
- greater than 2 years but less than 5 years **or** greater than 10% but less than 25% of the total planned mine life, then go to Section B
- greater than 5 years **or** greater than 25% of the total planned mine life then go to Section C

SECTION A IMPACT PREDICTIONS

(for all mine residue facilities that are planned to persist till mine closure)

1. Has a basic conceptual model been developed for each mine residue facility that is planned to persist till mine closure, in accordance with BPG G4?
2. Have a minimum of 20 samples been taken of field-weathered material from each mine residue facility that is planned to persist till mine closure and have these samples been subjected to geochemical assessment in accordance with BPG G4 (ABA, detailed mineralogy and humidity cell tests as a minimum) under the supervision of a suitably qualified geochemist?
3. Have the results of the geochemical assessment been evaluated by a suitably qualified geochemist, in accordance with BPG G4, using either equilibrium or simple kinetic geochemical models, using at least the 90th percentile worst case data from the geochemical assessments, to determine potential levels of contaminants of concern that may develop in leachate from these mine residue facilities?
4. Have the results from Question 3 been evaluated to identify those mine residue facilities where the leachate quality may potentially exceed the provisional post-closure water quality objectives?
5. For all those mine residue facilities where the leachate quality may exceed the provisional post-closure water management objectives, has a detailed plan of action been developed to subject such mine residue facilities to a SECTION B impact prediction?
6. Have all the above assessments been documented in the mine's most recent IWWMP?

LEVEL OF IMPACT PREDICTION & INFORMATION IN IWWMP IS INSUFFICIENT ← NO ← Have all the above questions been answered Yes? → YES → LEVEL OF IMPACT PREDICTION & INFORMATION IN IWWMP IS SUFFICIENT

MINE OPERATIONAL PHASE

KEY QUESTION 10 - CONTINUED

SECTION B IMPACT PREDICTIONS

(for all mine residue facilities that are planned to persist till mine closure AND that have been assessed in a SECTION A impact prediction as having the potential to generate leachates that exceed the post-closure water management objectives)

7. Has an impact prediction been undertaken for each identified (as per Question 4 in SECTION A) mine residue facility in accordance with the methodology shown in Figure 4.1 of BPG G4 and under the guidance of a suitably qualified geochemist and an independent reviewer?
8. Has a statistical review of the collected data confirmed that sufficient samples have been taken and analysed to demonstrate that there is a 90-95% confidence that the true mean value of the parameters being assessed lies within the range of values determined from the sampling?
9. Have the results from the sampling and analytical programme been incorporated into an updated and final conceptual model report that has been accepted by the independent reviewer and that has been presented to and accepted by DWS?
10. Have the uncertainties associated with the impact prediction process for the unrehabilitated mine residue disposal facilities been evaluated either by way of undertaking probabilistic modelling or, as a minimum, by undertaking appropriate sensitivity analyses to define key parameters that affect the predicted outcome?
11. If the outcome of Question 10 reveals that the leachate from any of the unrehabilitated mine residue disposal facilities will not enable the mine to meet its post-closure water management objectives, have a range of suitable rehabilitation and management measures been identified to undergo predictive review for those particular mine residue disposal facilities?
12. Have appropriate data collection and monitoring programmes been developed to enable the base case predictive model to be validated and calibrated and to enable sensible review of alternative rehabilitation and management options in the subsequent SECTION C impact predictions and have these been agreed to by the independent reviewer?
13. Have all the above assessments been documented in the mine's most recent IWWMP?

Have all the above questions been answered Yes?

NO → LEVEL OF IMPACT PREDICTION & INFORMATION IN IWWMP IS INSUFFICIENT

YES → LEVEL OF IMPACT PREDICTION & INFORMATION IN IWWMP IS SUFFICIENT

MINE OPERATIONAL PHASE

KEY QUESTION 10 - CONTINUED

SECTION C IMPACT PREDICTIONS

(for all mine residue facilities that are planned to persist till mine closure AND that have been assessed in a SECTION B impact prediction as having the potential to generate leachates that exceed the post-closure water management objectives)

14. Has an impact prediction been undertaken for each identified (as per Question 11 in SECTION B) mine residue facility in accordance with the methodology shown in Figure 4.1 of BPG G4 and under the guidance of a suitably qualified geochemist and an independent reviewer, to evaluate the beneficial effects of the identified rehabilitation and management options on the leachate from the mine residue disposal facilities?
15. Based on the outcome of the assessments undertaken to answer Question 14, has a preferred rehabilitation and/or management option been identified for each mine residue disposal facility that will enable the mine to meet its post-closure water management objectives and has the suitability of the selected options been confirmed by the independent reviewer and by DWS?
16. Have the uncertainties associated with the ability of the selected rehabilitation and/or management options to meet the post-closure water management objectives been evaluated either by way of undertaking probabilistic modelling or, as a minimum, by undertaking appropriate sensitivity analyses to define key parameters that affect the predicted outcome?
17. If the outcome of Questions 15 and 16 reveal that there is a risk that the leachate from the mine residue disposal facilities, after application of the selected rehabilitation and/or management options will not enable the mine to meet its post-closure water management objectives, have suitable measures been defined to intercept the leachate for appropriate water treatment that can be evaluated in terms of Key Question 12 for the Mine Operations Phase?
18. Have appropriate data collection and monitoring programmes been developed to enable predictive models to be regularly validated and calibrated as the mine progresses through its operational phase?
19. Is there clear evidence that the specified data is being collected and that the predictive models are being validated and calibrated at a frequency at least equivalent to every second update of the IWWMP?
20. Are the selected rehabilitation and management options for the mine residue disposal facilities being implemented concurrently with mining and in accordance with their design specifications?
21. Have appropriate financial provisions been included in the mine's closure fund to implement the specified rehabilitation and/or management measures for the mine residue facilities, to monitor their success and to maintain these measures such that they continue to perform in accordance with their specified duty?
22. Have all the above assessments been documented in the mine's most recent IWWMP?

Have all the above questions been answered Yes?

NO → LEVEL OF IMPACT PREDICTION & INFORMATION IN IWWMP IS INSUFFICIENT

YES → LEVEL OF IMPACT PREDICTION & INFORMATION IN IWWMP IS SUFFICIENT

MINE OPERATIONAL PHASE

KEY QUESTION 11: Are all mine workings thoroughly characterized geochemically and physically and in terms of probable post-closure water and contaminant balances in a manner appropriate to the remaining life of mine?

OBJECTIVE: To ensure that mines continuously collect the required data and use the data to update and refine the predictions of long-term post-closure impact of mine workings to the point where a high degree of confidence can be associated with the predictions. The improved predictive ability should then be used to evaluate alternative closure management options for the mine workings from the perspective of meeting the defined post-closure water management objectives. The most appropriate options that will ensure that post-closure water management objectives are met should then be specified in detail and appropriate financial provisions should be included in the closure fund. The level of detail of the assessment and confidence in the predictions will increase as the mine approaches end of mine life.

WATER MANAGEMENT HIERARCHY PRINCIPLE: Pollution Prevention

If the length of time that the mine has already been in operation is:

- **less than 2 years <u>or</u> less than 10% of the total planned mine life, then go to Section A**
- **greater than 2 years but less than 5 years <u>or</u> greater than 10% but less than 25% of the total planned mine life, then go to Section B**
- **greater than 5 years <u>or</u> greater than 25% of the total planned mine life then go to Section C**

SECTION A IMPACT PREDICTIONS
(for all underground and surface mine workings/voids)

1. Has a basic conceptual model been developed for each mining operation (open pit, rehabilitated pit and/or underground mine workings) in accordance with BPG G4?
2. Have a minimum of 20 samples been taken of material that is representative of the material expected to remain in the mine workings after mine closure and have these samples been subjected to geochemical assessment in accordance with BPG G4 (ABA, detailed mineralogy and humidity cell tests as a minimum) under the supervision of a suitably qualified geochemist?
3. Have basic hydrological and/or geohydrological models been employed to assess the conceptual model and provide a first-order post-closure mine water balance?
4. Have the results of the geochemical, hydrological and geohydrological assessments been evaluated by a suitably qualified person, in accordance with BPG G4, using either equilibrium or simple kinetic geochemical models, using at least the 90th percentile worst case data from the geochemical assessments, to determine potential levels of contaminants of concern that may develop in drainage from these mine workings?
5. Have the results from Question 4 been evaluated to identify those mine workings where the drainage quality may potentially exceed the provisional post-closure water quality objectives?
6. For all those mine workings where the drainage quality may exceed the provisional post-closure water management objectives, has a detailed plan of action been developed to subject such mine workings to a SECTION B impact prediction?
7. Have all the above assessments been documented in the mine's most recent IWWMP?

Have all the above questions been answered Yes?

- **NO** → LEVEL OF IMPACT PREDICTION & INFORMATION IN IWWMP IS INSUFFICIENT
- **YES** → LEVEL OF IMPACT PREDICTION & INFORMATION IN IWWMP IS SUFFICIENT

MINE OPERATIONAL PHASE

KEY QUESTION 11 - CONTINUED

SECTION B IMPACT PREDICTIONS

(for all mine workings that are predicted to decant after mine closure AND that have been assessed in a SECTION A impact prediction as having the potential to generate drainage that exceeds the post-closure water management objectives)

7. Has the potential for the mine workings to decant after mine closure been assessed within the context of a regional post-closure mine water strategy and with knowledge of the water balances of adjacent mines? ☑ ☒
8. Has an impact prediction been undertaken for each identified (as per Question 5 in SECTION A) mine workings that could decant after closure, in accordance with the methodology shown in Figure 4.1 of BPG G4 and under the guidance of a suitably qualified person and an independent reviewer? ☑ ☒
9. Has a statistical review of the collected data confirmed that sufficient samples have been taken and analysed to demonstrate that there is a 90-95% confidence that the true mean value of the parameters being assessed lies within the range of values determined from the sampling? ☑ ☒
10. Have the results from the sampling and analytical programme been incorporated into an updated and final conceptual model report that has been accepted by the independent reviewer and that has been presented to and accepted by DWS? ☑ ☒
11. Have the uncertainties associated with the impact prediction process for the mine workings been evaluated either by way of undertaking probabilistic modelling or, as a minimum, by undertaking appropriate sensitivity analyses to define key parameters that affect the predicted outcome? ☑ ☒
12. If the outcome of Question 11 reveals that the decant/drainage from any of the mine workings will not enable the mine to meet its post-closure water management objectives, have a range of suitable rehabilitation and management measures been identified to undergo predictive review for those particular mine workings? ☑ ☒
13. Have appropriate data collection and monitoring programmes been developed to enable the base case predictive model to be validated and calibrated and to enable sensible review of alternative rehabilitation and management options in the subsequent SECTION C impact predictions and have these been agreed to by the independent reviewer? ☑ ☒
14. Have all the above assessments been documented in the mine's most recent IWWMP? ☑ ☒

LEVEL OF IMPACT PREDICTION & INFORMATION IN IWWMP IS INSUFFICIENT ← NO ← Have all the above questions been answered Yes? → YES → LEVEL OF IMPACT PREDICTION & INFORMATION IN IWWMP IS SUFFICIENT

MINE OPERATIONAL PHASE

KEY QUESTION 11 - CONTINUED

SECTION C IMPACT PREDICTIONS

(for all mine workings that are predicted to decant after mine closure AND that have been assessed in a SECTION B impact prediction as having the potential to generate drainage that exceeds the post-closure water management objectives)

15. Has an impact prediction been undertaken for each identified (as per Question 12 in SECTION B) mine workings in accordance with the methodology shown in Figure 4.1 of BPG G4 and under the guidance of a suitably qualified person and an independent reviewer, to evaluate the beneficial effects of the identified rehabilitation and management options on the drainage from the mine workings?
16. Based on the outcome of the assessments undertaken to answer Question 15, has a preferred rehabilitation and/or management option been identified for each mine workings that will enable the mine to meet its post-closure water management objectives and has the suitability of the selected options been confirmed by the independent reviewer and by DWS?
17. Have the uncertainties associated with the ability of the selected rehabilitation and/or management options to meet the post-closure water management objectives been evaluated either by way of undertaking probabilistic modelling or, as a minimum, by undertaking appropriate sensitivity analyses to define key parameters that affect the predicted outcome?
18. If the outcome of Questions 16 and 17 reveal that there is a risk that the drainage from the workings, after application of the selected rehabilitation and/or management options will not enable the mine to meet its post-closure water management objectives, have suitable measures been defined to intercept the drainage for appropriate water treatment that can be evaluated in terms of Key Question 12 for the Mine Operations Phase?
19. Have appropriate data collection and monitoring programmes been developed to enable predictive models to be regularly validated and calibrated as the mine progresses through its operational phase?
20. Is there clear evidence that the specified data is being collected and that the predictive models are being validated and calibrated at a frequency at least equivalent to every second update of the IWWMP?
21. Are the selected rehabilitation and management options for the mine workings being implemented concurrently with mining and in accordance with their design specifications?
22. Have appropriate financial provisions been included in the mine's closure fund to implement the specified rehabilitation and/or management measures for the mine workings, to monitor their success and to maintain these measures such that they continue to perform in accordance with their specified duty?
23. Have all the above assessments been documented in the mine's most recent IWWMP?

Have all the above questions been answered Yes?

- NO → LEVEL OF IMPACT PREDICTION & INFORMATION IN IWWMP IS INSUFFICIENT
- YES → LEVEL OF IMPACT PREDICTION & INFORMATION IN IWWMP IS SUFFICIENT

MINE OPERATIONAL PHASE

KEY QUESTION 12: Where unacceptable post-closure contaminant loads are predicted, what water management / treatment is required and are financial provisions in place?

OBJECTIVE: To ensure that in cases where planned rehabilitation and management measures to be applied to mine workings and mine residue disposal facilities do not enable such facilities to meet post-closure water management objectives, that appropriate facilities for the collection, treatment and disposal of leachates and/or decants is specified and financially provided for.

WATER MANAGEMENT HIERARCHY PRINCIPLE: Water Treatment

1. Have the assessments undertaken as part of Key Questions 10 and/or 11, indicated that there is a risk that applied management and/or rehabilitation measures will not succeed in enabling the mine residue disposal facilities and/or mine workings leachates and/or decants from meeting the anticipated post-closure water management objectives?

Has Question 1 answered Yes?
- NO → THERE IS NO ASSESSED NEED FOR WATER TREATMENT
- YES → PROCEED TO QUESTION 2

2. Have the assessments undertaken as part of Key Questions 10 and/or 11, indicated the duration over which the leachates and/or decants will exceed the post-closure water management objectives and is there a credible prediction of the water quality and quantity for such leachates and/or decants?

Has Question 2 answered Yes?
- NO → UNDERTAKE MORE DETAILED STUDIES TO OBTAIN A YES ANSWER
- YES → PROCEED TO QUESTION 3

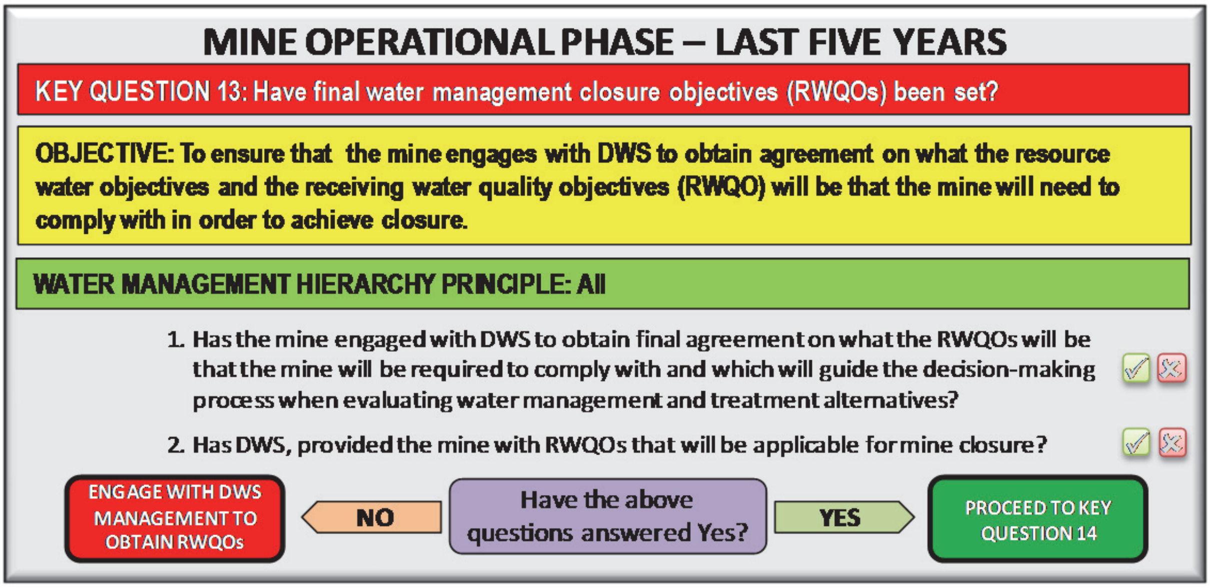
3. Have the procedures set out in Chapter 8 of BPG G5: Water Management Aspects for Mine Closure been applied to determine the extent of water treatment required?

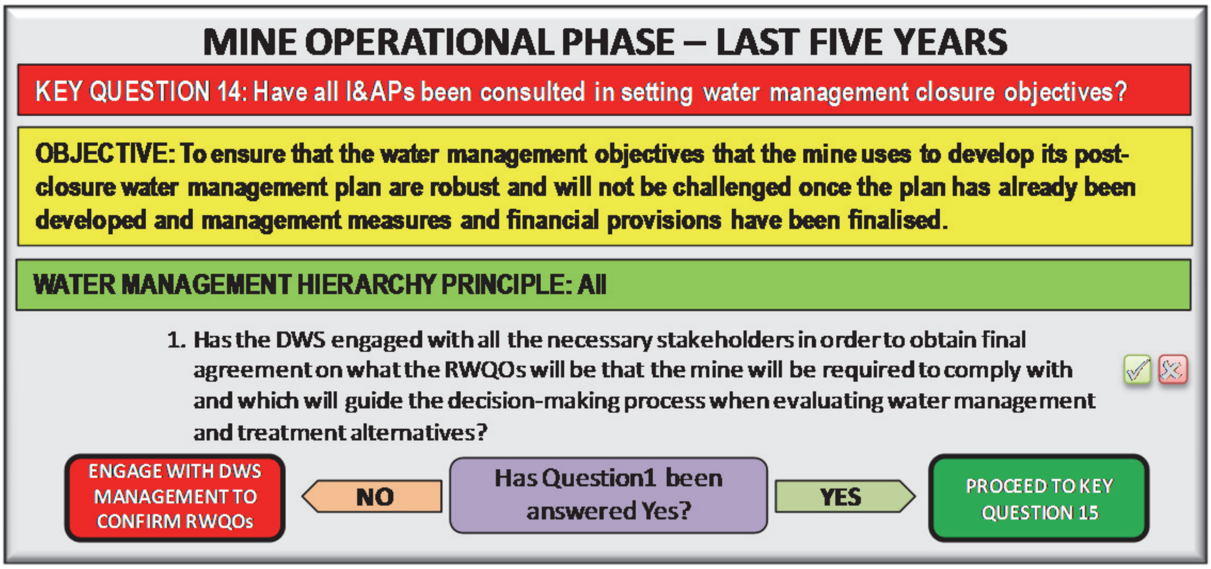
4. Have the procedures in BPG H4: Water Treatment and/or the services of a suitably qualified person been applied to specify the type of leachate and or drainage interceptions systems that will be required and the type and duty of water treatment plant that will be required in order to ensure that post-closure water management objectives are met?

Have Questions 3 and 4 answered Yes?
- NO → UNDERTAKE MORE DETAILED STUDIES TO OBTAIN A YES ANSWER
- YES → PROCEED TO QUESTION 5

5. Have financial calculations been undertaken by a suitably qualified person to determine the capital and operating costs of the required water interception and treatment systems for as long as they are predicted to be required, in accordance with Chapter 8 of BPG G5?

Has Question 5 been answered Yes?
- NO → UNDERTAKE THE NECESSARY STUDIES TO OBTAIN A YES ANSWER
- YES → INCLUDE THE RESULT OF THE QUESTION 5 STUDIES INTO THE MINE'S FINANCIAL PROVISIONS


MINE OPERATIONAL PHASE – LAST FIVE YEARS
KEY QUESTION 13: Have final water management closure objectives (RWQOs) been set?
OBJECTIVE: To ensure that the mine engages with DWS to obtain agreement on what the resource water objectives and the receiving water quality objectives (RWQO) will be that the mine will need to comply with in order to achieve closure.
WATER MANAGEMENT HIERARCHY PRINCIPLE: All
1. Has the mine engaged with DWS to obtain final agreement on what the RWQOs will be that the mine will be required to comply with and which will guide the decision-making process when evaluating water management and treatment alternatives?
2. Has DWS, provided the mine with RWQOs that will be applicable for mine closure?
ENGAGE WITH DWS MANAGEMENT TO OBTAIN RWQOs
NO
Have the above questions answered Yes?
YES
PROCEED TO KEY QUESTION 14


MINE OPERATIONAL PHASE – LAST FIVE YEARS
KEY QUESTION 14: Have all I&APs been consulted in setting water management closure objectives?
OBJECTIVE: To ensure that the water management objectives that the mine uses to develop its post-closure water management plan are robust and will not be challenged once the plan has already been developed and management measures and financial provisions have been finalised.
WATER MANAGEMENT HIERARCHY PRINCIPLE: All
1. Has the DWS engaged with all the necessary stakeholders in order to obtain final agreement on what the RWQOs will be that the mine will be required to comply with and which will guide the decision-making process when evaluating water management and treatment alternatives?
ENGAGE WITH DWS MANAGEMENT TO CONFIRM RWQOs
NO
Has Question1 been answered Yes?
YES
PROCEED TO KEY QUESTION 15

MINE OPERATIONAL PHASE – LAST FIVE YEARS

KEY QUESTION 15: Does the mine have a calibrated predictive model that can predict all discharge points from mine workings in terms of location, volume and quality?

OBJECTIVE: To ensure that the assessments described in Key Question 11 have been completed at a Section C level, that all predictions have been fully calibrated and validated and that an integrated water and contaminant balance for all the mine workings has been compiled, taking cognisance of the final post-closure water management objectives as finalised in terms of Key Questions 13 and 14.

WATER MANAGEMENT HIERARCHY PRINCIPLE: Pollution Prevention

1. Have all the mine workings (underground and/or open cast) been assessed as set out in Section C of Key Question 11?
2. Are the RWQOs that were used to guide the answers to Questions 15, 16 and 18 in Section C of Key Question 11 the same as those agreed to by way of Key Questions 13 and 14?
3. Have all the assessed mine workings and the models used therefore been fully calibrated and validated in terms of Question 20 in Section C of Key Question 11?
4. Have the financial provisions determined in Question 22 in Section C of Key Question 11 been prepared in compliance with the above questions 1, 2 and 3 of this Key Question 15?

Have the above questions answered Yes?
- NO → UNDERTAKE THE ASSESSMENTS TO OBTAIN YES ANSWERS
- YES → PROCEED TO QUESTION 5 BELOW

5. Have the outputs from the assessments of all the mine workings been combined into an integrated post-closure water and contaminant balance showing locations, qualities and timeframes of exceedance of post-closure RWQOs for all decants / discharges?

Has Question 5 answered Yes?
- NO → UNDERTAKE THE STUDIES TO OBTAIN YES ANSWER
- YES → PROCEED TO KEY QUESTION 17

MINE OPERATIONAL PHASE – LAST FIVE YEARS

KEY QUESTION 16: Does the mine have a calibrated predictive model that can predict all discharge points from mine residue disposal facilities in terms of location, volume and quality?

OBJECTIVE: To ensure that the assessments described in Key Question 10 have been completed at a Section C level, that all predictions have been fully calibrated and validated and that an integrated water and contaminant balance for all the mine workings has been compiled, taking cognisance of the final post-closure water management objectives as finalised in terms of Key Questions 13 and 14.

WATER MANAGEMENT HIERARCHY PRINCIPLE: Pollution Prevention

1. Have all the mine residue deposits (placed on surface and/or in mine workings) been assessed as set out in Section C of Key Question 10?
2. Are the RWQOs that were used to guide the answers to Questions 15, 16 and 17 in Section C of Key Question 10 the same as those agreed to by way of Key Questions 13 and 14?
3. Have all the assessed mine workings and the models used therefore been fully calibrated and validated in terms of Question 19 in Section C of Key Question 10?
4. Have the financial provisions determined in Question 21 in Section C of Key Question 10 been prepared in compliance with the above questions 1, 2 and 3 of this Key Question 15?

Have the above questions answered Yes?
- NO → UNDERTAKE THE ASSESSMENTS TO OBTAIN YES ANSWERS
- YES → PROCEED TO QUESTION 5 BELOW

5. Have the outputs from the assessments of all the mine residue deposits been combined into an integrated post-closure water and contaminant balance showing locations, qualities and timeframes of exceedance of post-closure RWQOs for all discharges?

Has Question 5 answered Yes?
- NO → UNDERTAKE THE STUDIES TO OBTAIN YES ANSWER
- YES → PROCEED TO KEY QUESTION 17

MINE OPERATIONAL PHASE – LAST FIVE YEARS

KEY QUESTION 17: Where RWQOs are not met at time of closure have appropriate post-closure water management / treatment measures been defined and are financial resources & institutional arrangements in place to ensure these are implemented?

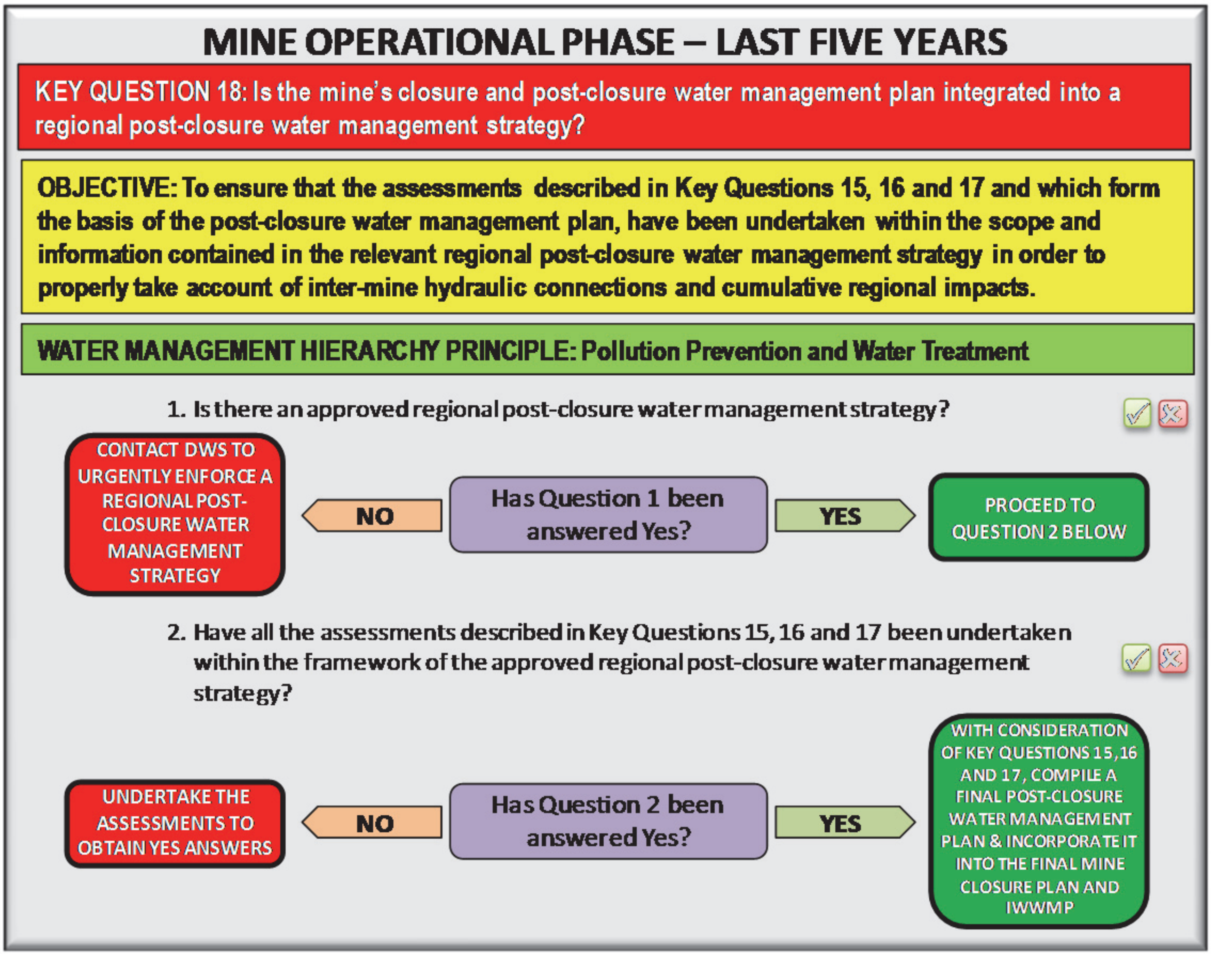
OBJECTIVE: To ensure that the assessments described in Key Question 12 have been completed on the basis of the outcome of the assessments described in Key Questions 15 and 16 and with consideration of an integrated water and contaminant balance for all the mine workings and mine residue facilities, taking cognisance of the final post-closure water management objectives as finalised in terms of Key Questions 13 and 14.

WATER MANAGEMENT HIERARCHY PRINCIPLE: Pollution Prevention and Water Treatment

1. Have all the assessments described in Key Question 12 been undertaken using the outcome of the assessments described in Key Questions 15 and 16 and taking cognisance of the final post-closure water management objectives (RWQOs) as agreed in Key Questions 13 and 14?
2. Have all the assessments described in Key Question 12 been undertaken with consideration of an integrated water and contaminant balance for all discharge points from mine workings and residue disposal facilities?
3. Have all the assessments described in Key Questions 12, 15 and 16 been undertaken within the framework of the regional post-closure water management strategy as described in Key Question 18?
4. Have the assessments in Key Questions 12, 15 and 16 been incorporated into an appropriate catchment water quality model to confirm that proposed management measures will meet the specified post-closure water management objectives, with due consideration of the effects of foreseeable worst case events on the management measures and the achievable downstream RWQOs?
5. Have the financial provisions for post-closure water management / treatment measures as described in Question 5 of Key Question 12 been updated to take account of all the above questions?

Have the above questions answered Yes?

- NO → UNDERTAKE THE ASSESSMENTS TO OBTAIN YES ANSWERS
- YES → WITH CONSIDERATION OF KEY QUESTION 18, COMPILE A FINAL POST-CLOSURE WATER MANAGEMENT PLAN & INCORPORATE IT INTO THE FINAL MINE CLOSURE PLAN AND IWWMP


MINE OPERATIONAL PHASE – LAST FIVE YEARS
KEY QUESTION 18: Is the mine's closure and post-closure water management plan integrated into a regional post-closure water management strategy?
OBJECTIVE: To ensure that the assessments described in Key Questions 15, 16 and 17 and which form the basis of the post-closure water management plan, have been undertaken within the scope and information contained in the relevant regional post-closure water management strategy in order to properly take account of inter-mine hydraulic connections and cumulative regional impacts.
WATER MANAGEMENT HIERARCHY PRINCIPLE: Pollution Prevention and Water Treatment
1. Is there an approved regional post-closure water management strategy?
CONTACT DWS TO URGENTLY ENFORCE A REGIONAL POST-CLOSURE WATER MANAGEMENT STRATEGY
NO
Has Question 1 been answered Yes?
YES
PROCEED TO QUESTION 2 BELOW
2. Have all the assessments described in Key Questions 15, 16 and 17 been undertaken within the framework of the approved regional post-closure water management strategy?
UNDERTAKE THE ASSESSMENTS TO OBTAIN YES ANSWERS
NO
Has Question 2 been answered Yes?
YES
WITH CONSIDERATION OF KEY QUESTIONS 15, 16 AND 17, COMPILE A FINAL POST-CLOSURE WATER MANAGEMENT PLAN & INCORPORATE IT INTO THE FINAL MINE CLOSURE PLAN AND IWWMP

CONSIDERATION OF POST-CLOSURE WATER MANAGEMENT PLAN

KEY QUESTION 19: Does the risk and impact prediction assessment fully comply with all aspects of the independent review process as set out in BPG G4: Impact Prediction?

OBJECTIVE: To ensure that the assessments that were undertaken in support of the post-closure water management plan were undertaken in accordance with the procedures as set out in BPG G4 and more particularly the independent review requirements as set out in Chapter 8 of BPG G4.

WATER MANAGEMENT HIERARCHY PRINCIPLE: Pollution Prevention and/or Water Treatment

1. Was the independent reviewer appointed on the basis of prior agreement being reached with DWS on which independent reviewers could be suitable and the detailed scope of appointment of the reviewers?
2. Has the reviewer declared his impartiality and lack of interest in the outcome of the assessment in writing?
3. Was the reviewer appointed at the start of the impact prediction assessment and does the impact assessment report include the written contributions and reviews of the reviewer at all points as indicated in Figure 4.1 of BPG G4?
4. Can it be confirmed that the reviewer did present his/her findings and recommendations at joint meetings held between the mining proponent, the impact assessment specialist, and where necessary, the DWS?
5. Are all review comments and documents on record and in the public domain?
6. Has the reviewer declared that he/she was able to undertake their review without pressure or interference from any of the parties involved in or with an interest in the outcome of the assessment (this includes the mine, its specialists, DWS and public stakeholders)?
7. Has the reviewer incorporated his/her review findings into appropriate sections of the impact prediction / assessment report as set out in Chapter 9 of BPG G4?

Have all the above questions answered Yes?

- NO → REJECT THE SUBMITTED POST-CLOSURE WATER MANAGEMENT PLAN
- YES → PROCEED TO EVALUATE THE POST-CLOSURE WATER MANAGEMENT PLAN

CONSIDERATION OF POST-CLOSURE WATER MANAGEMENT PLAN

KEY QUESTION 20: Does the post-closure water management plan consider all the relevant principles defined in Section 2.1 of BPG G5 and does it present all the information requested in Section 2.2 of BPG G5 and has this information been verified by the independent reviewer?

OBJECTIVE: To ensure that the assessments that were undertaken in support of the post-closure water management plan were undertaken in accordance with the principles and procedures as set out in BPG G5 and that this has been verified by the independent reviewer.

WATER MANAGEMENT HIERARCHY PRINCIPLE: Pollution Prevention and/or Water Treatment

1. Does the submitted post-closure water management plan include a checklist that confirms that all the principles set out in Section 2.1 of BPG G5 have been considered and complied with, unless it is motivated why such compliance is not required?
2. Is the checklist relating to Section 2.1 of BPG G5 complete with respect to the following principles: legal compliance and best practice; risk-based approach; sustainability; consideration of regional context; consideration of social aspects; communication and public participation; consideration of timeframe; continual improvement; concurrent rehabilitation and reduction of desertification?
3. Does the submitted post-closure water management plan include a checklist that confirms that all the principles and information requirements set out in Section 2.2 of BPG G5 have been considered and complied with, unless it is motivated why such compliance is not required?

Have all the above questions answered Yes?

- NO → REJECT THE SUBMITTED POST-CLOSURE WATER MANAGEMENT PLAN
- YES → PROCEED TO EVALUATE THE POST-CLOSURE WATER MANAGEMENT PLAN

CONSIDERATION OF POST-CLOSURE WATER MANAGEMENT PLAN

KEY QUESTION 21: Has the assessment included clear evidence, supported by the reviewer, that all prediction assessments and models have been fully calibrated and validated?

OBJECTIVE: To ensure that the assessments that were undertaken in support of the post-closure water management plan are credible and that this has been verified by the independent reviewer.

WATER MANAGEMENT HIERARCHY PRINCIPLE: Pollution Prevention and/or Water Treatment

1. Does the submitted post-closure water management plan include details and results of a monitoring programme that was specifically designed to collect data to be used in the calibration and validation of prediction models?
2. Does the submitted post-closure water management plan include the results of the calibration and validation exercise to confirm the accuracy and reliability of the predictions of future impact?
3. Does the submitted post-closure water management plan include a statement on the level of uncertainty associated with the impact prediction and what confidence can be placed in the predictions by considering the contributing elements of uncertainty as set out in Chapter 8 and Section A6 of Annexure A of the WRC Report K5/2127?

Have all the above questions answered Yes?

- NO → REJECT THE SUBMITTED POST-CLOSURE WATER MANAGEMENT PLAN
- YES → PROCEED TO EVALUATE THE POST-CLOSURE WATER MANAGEMENT PLAN

CONSIDERATION OF POST-CLOSURE WATER MANAGEMENT PLAN

KEY QUESTION 22: Does DWS have written confirmation from the independent reviewer that the review was undertaken independently, objectively, scientifically and without bias and that he had access to all required information and that he deems himself competent to undertake the review?

OBJECTIVE: To ensure that the independent review process was undertaken by a competent and truly independent person in order to enhance the credibility of the impact prediction exercise and the resultant post-closure water management plan.

WATER MANAGEMENT HIERARCHY PRINCIPLE: Pollution Prevention and/or Water Treatment

1. Is the required written declaration by the independent reviewer that his review was undertaken independently, objectively scientifically and without bias and that he had access to all required information and that he deems himself competent to undertake the review?

Has question 1 above been answered Yes?

- NO → REJECT THE SUBMITTED POST-CLOSURE WATER MANAGEMENT PLAN
- YES → PROCEED TO EVALUATE THE POST-CLOSURE WATER MANAGEMENT PLAN

CONSIDERATION OF POST-CLOSURE WATER MANAGEMENT PLAN

KEY QUESTION 23: Does DWS have written confirmation from the mine's Board of Directors that there has been full and complete disclosure of all relevant information that could be pertinent to the consideration of the mine closure application?

OBJECTIVE: To ensure that DWS has access to all the relevant information that it requires to make a correct and informed decision to approve or reject the submitted post-closure water management plan.

WATER MANAGEMENT HIERARCHY PRINCIPLE: Pollution Prevention and/or Water Treatment

1. Is the required written declaration by the mine's Board of Directors, or a duly authorised person that all information that may be pertinent to or that may influence the decision by DWS to approve or reject the post-closure water management plan, has been fully disclosed within the post-closure water management plan?

Has question 1 above been answered Yes?

- NO → REJECT THE SUBMITTED POST-CLOSURE WATER MANAGEMENT PLAN
- YES → PROCEED TO EVALUATE THE POST-CLOSURE WATER MANAGEMENT PLAN

CONSIDERATION OF POST-CLOSURE WATER MANAGEMENT PLAN

KEY QUESTION 24: Does DWS have independent confirmation by suitably qualified persons that all agreed water management / treatment measures have been properly implemented and that sufficient financial provisions have been made and that suitable contractual arrangements are in place with approved third parties to ensure that all required measures will be implemented and audited for as long as has been predicted to be necessary to ensure that agreed closure objectives (RWQOs) are met?

OBJECTIVE: To ensure that the agreed water management and treatment measures that will be required to continue after approval of the post-closure water management plan are properly implemented and operational and that adequate financial resources are available to ensure that such treatment plants will be able to continue operating for as long as has been predicted to be necessary.

WATER MANAGEMENT HIERARCHY PRINCIPLE: Water Treatment

1. Has the required statement by suitably qualified persons been made regarding the implementation of the agreed water treatment measures, the availability of adequate funds and the establishment of suitable institutional and contractual arrangements to ensure that the treatment plants will be capable of operating for as long as has been predicted to be necessary?

Has Question 1 above been answered Yes?

- NO → REJECT THE SUBMITTED POST-CLOSURE WATER MANAGEMENT PLAN
- YES → PROCEED TO EVALUATE THE POST-CLOSURE WATER MANAGEMENT PLAN

POST-CLOSURE MANAGEMENT

KEY QUESTION 25: Confirm that no information comes to light that was known at the time of the mine closure application but that was not disclosed by the mine's Board of Directors?

OBJECTIVE: To allow for a forensic audit to ensure that the full and correct information was available to the DWS when it considered the post-closure water management plan in the event of an unforeseen adverse post-closure impact arising from the mine that DWS is required to bear the liability for.

WATER MANAGEMENT HIERARCHY PRINCIPLE: Pollution Prevention and/or Water Treatment

1. In the event that an unforeseen, unpredicted and adverse impact arises from a mine where DWS has previously approved the post-closure water management plan, has a forensic audit been undertaken by suitably qualified persons to confirm that the statement made by the mine's Board of Directors in compliance with Key Question 23 was correct and truthful?

Has Question 1 above been answered Yes?

- NO → APPLY THE RELEVANT PROVISIONS OF THE NWA TO HOLD THE MINE ACCOUNTABLE FOR MANAGING THE ADVERSE IMPACT
- YES → DWS ACCEPTS THE RESPONSIBILITY OF MANAGING THE UNFORESEEN IMPACT

POST-CLOSURE MANAGEMENT

KEY QUESTION 26: Confirm that the implemented water management / treatment measures continue to be implemented and that they continue to meet the defined post-closure objectives (RWQOs)?

OBJECTIVE: To allow for the undertaking of regular assessments to confirm that the implemented water management/treatment measures stipulated in the post-closure water management plan and confirmed to be in place in terms of Key Question 24, continue to operate as specified.

WATER MANAGEMENT HIERARCHY PRINCIPLE: Pollution Prevention and/or Water Treatment

1. Are the institutional, contractual and financial arrangements that were put in place and confirmed as such in terms of Key Question 24 continuing to operate in accordance with design specifications for the time period stipulated in the post-closure water management plan?
2. Do implemented downstream monitoring programmes confirm that the post-closure water management objectives (RWQOs) are being met by the combination of applied water management and water treatment measures?
3. Are the answers to questions 1 and 2 above being provided to the DWS by independent auditors that were financially provided for in terms of the funding arrangements confirmed as part of Key Question 24 for the time period stipulated in the post-closure water management plan?

Are the above questions answered Yes?

- NO: APPLY THE RELEVANT PROVISIONS OF THE NWA TO HOLD THE MINE ACCOUNTABLE FOR MANAGING THE ADVERSE IMPACT
- YES: COMMITTMENTS MADE IN THE POST CLOSURE WATER MANAGEMENT PLAN ARE BEING COMPLIED WITH