GROUNDWATER CLEAN-UP :ASSESSING MINING IMPACTS AND REHABILITATION/MANAGEMENT ALTERNATIVES

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ABSTRACT

Contaminated seepage from mine water or waste impoundments is a common problem which has to potential to degrade groundwater resources. Rehabilitation and/or management strategies for addressing the problem could encompass a wide range of approaches, from no action necessary, through monitored natural attenuation, pump and treat systems, in-situ bioremediation etc. Such active methods may be expensive, long term, and may result in unforeseen side effects to the environment, unless appropriately characterized.

Knowledge of the exposure pathways and relationship between the seepage and the water resources, is therefore required in order to assess the impact of the seepage and characterize the possible risk posed to water users in the area. A conceptual model "check-list" combined with risk characterization of alternative management strategies can provide a useful basis for understanding the possible impacts and engineering limitations for various different remedial measures under consideration.

The author has modified the impact assessment methodology used for the formulation of Environmental Impact Assessments (EIA) in order to formulate a Comparative Risk Analyses methodology to provide a qualitative assessment of the possible impacts, if any, from mine water or waste impoundments on the water resource and guide the selection of management options.

1. INTRODUCTION

Contaminated seepage from mine water or waste impoundments is a common problem for many mines in South Africa. Rehabilitation and/or management strategies to address the problem could encompass a wide range of approaches. This could include, for example, no action if the risk is determined to be low and acceptable through to active intervention from monitored natural attenuation, pump and treat systems and/or in-situ bioremediation. Whether or not remediation is warranted depends on the magnitude of the direct or indirect risk to human health, the environment and the extent that risk reduction can be achieved by removal or containment of the contamination, (Wenning *et.al*., 2005; ITRC, 2007).

In general, the risk assessment is based on a simplistic and conservative determination of the probable baseline risk, followed by determination of the cleanup technologies to address an unacceptable risk, but the efficacy of the remedial method may be assumed or given only cursory attention, (Wenning *et.al*., 2005). In practice, remediation or source containment is a dynamic process which may require the use of multiple management or treatment approaches which could ultimately be expensive and in the long term could result in unforeseen side effects to the environment and/or limited effectiveness.

The author proposes that a ranking system of environmental risks and environmental benefits be utilized, in conjunction with a cost/benefit analyses for considering the various remediation options available.

Risk assessments that form the basis for remedial decisions are designed to provide a conservative approach and this may result in an overestimation of the environmental risk. Whilst this bias follows the precautionary principal and may be appropriate in some cases, it can in some instances result in the selection of an overly onerous management approach. Whilst conservative risk assumptions should always be used in the preliminary assessment process, the final decision should be based on realistic estimates of risk provided by site-specific data (Bridges, *et al.*, 2006**)** as suggested by the USEPA Tiered Risk Approach. The balancing of benefits (or risks) and costs can, in certain circumstances, result in the best remedy strategy being not intrusive but instead involving the implementation of pollution-prevention measures and/or point and nonpoint source controls to allow natural recovery processes such as biodegradation and chemical degradation to result in a reduction in risk to the water resource (Wenning *et.al*., 2005, USEPA, 2004).

Knowledge of the source of the seepage, its quality and the exposure pathways and relationship between the seepage and the receiving water resources, namely the surface and ground water, is required in order to assess the impact of the seepage on the water resources and characterize the possible risk posed to water users in the area. A conceptual model "check-list" combined with a comparative risk characterization of the proposed management strategies can provide a useful basis for understanding the possible impacts and engineering limitations for the various different remedial measures proposed, in association with consideration of overlying site specific, legislative and corporate governance considerations.

The author has modified the impact assessment methodology used for the formulation of Environmental Impact assessments in order to formulate a Comparative Risk Analyses methodology. The Comparative Risk Analyses (CRA) provides a qualitative assessment of the possible impacts, if any, from mine water or waste impoundments on the water resource and is used to optimize the way forward and hence manage the impact, if any, to the water resource. This process forms part of a consideration and evaluation process and is not intended as a categorical standard.

2. PROBLEM STATEMENT

Strategize rehabilitation and/or management options for the seepage of contaminated water from a mine tailings disposal system.

3. THE CONCEPTUAL MODEL TICK LIST

A conceptual model "check-list" combined with a comparative risk characterization of the proposed management strategies can provide a useful basis for understanding the possible impacts and engineering limitations for various different remedial measures proposed. The conceptual model is not prescriptive and should be modified on a site by site basis. The conceptual model list does, however, suggest criteria required for assessing the sources of contamination. The screening criteria were developed on the basis of the RBCA model requirements (RBCA Toolkit, 1998), site experience, and reference to local and international experience and guidance (Carey, *et al*., 2002, ASTM, 2005; USEPA, 1999, USEPA 2004). A conceptual site model is presented in Table 1.

Table 1. Tabulated Conceptual Site Model

ITEM	**DESCRIPTION/ VALUE (Include Assumptions, limitations and comment on data)**
Nature of Source	
Material Nature of source	Type of waste
Source extent	Volume and footprint area of the source. Topography
Material composition	Geochemical, Acid Generating Potential , Neutralisation Potential, toxicity, pH, leachate characterization ie TCLP/SAAR etc.
Material composition	Physical/migration/dispersal characteristics, permeability
Release history	Relevant site history, time period. Records of accidents / spills, Regulatory issues
Design considerations which potentially reduce leachate from the source	
"Liner" material composition	Type of the liner, underlying compacted soils, clay, HDPE etc
Vertical permeability	Vertical permeability through the liner
"Cap" material composition / description	Includes a type of the capping (if any), contoured surface, surface water cut-off, vegetated cap, clay, etc
Infiltration Rate	Infiltration rate through the cap
Source control measures	e.g. Groundwater abstraction
Geology and soils	
Lithology	e.g. Granite and granitoids
Stratigraphy	e.g. Lebowa Granites, Bushveld Igneous complex
Structures	Structures and discontinuities/ fracture size and spacing
Soil type	e.g. Clay or gravels and silty clay residual of dolomitic chert breccias for example
Soil Properties	Permeability/ moisture / fraction of organic carbon / porosity/ grain size/ density/ clay content etc
Soils Quality	Concentrations of natural soils, concentrations of hazardous components of the soil
Unsaturated Zone thickness	Horizontal and Vertical thickness of unsaturated zone
Affected Zone	Vertical and horizontal extent of the contamination
Hydrogeology	
Depth of water table	Include comment on mounding if observed around source as well as seasonality
Water strike	Depth, blow yield, lithology etc of water strikes

ITEM	DESCRIPTION/ VALUE (Include Assumptions, limitations and comment on data)
Aquifer Description	Description of the Aquifer Zone e.g. unconfined shallow aquifer
Aquifer Classification	Aquifer classification e,g, Minor Aquifer, (Parsons, 1995)
Aquifer Properties	Lateral and vertical variation in aquifer properties, Aquifer thickness and mixing depth
Aquifer vulnerability	Including historical, current and future aquifer management
Flow mechanism	Intergranular or fractured for example. Influence of geological structures. Single or multi-layered aquifer and significance of aquitards. Artificial influences
Fate and mobility comment	i.e. factors influencing future movement / extrapolation of future movement
Recharge	Natural recharge
Hydraulic properties	Hydraulic gradient, porosity, vertical and horizontal conductivities etc.
Flow:	Direction of flow relative to targets. Also identify preferential flow paths, confining units, impediments to contaminant flow, “sinks” Estimated flow rate
Aquifer Status	Natural versus Present Status
Use	Include groundwater abstractions and discharge to springs and streams.
Affected Zone	Note any abstraction, distance to abstraction wells, status, horizontal and vertical extent of plumes / presence of DNAPL’s etc.
Biological and Chemical Environment	e.g. aerobic or anaerobic, presence of microbial population, pH, temperature etc.
Quality	Background (ambient), Other applicable quality standards
Hydrology	
Description	Hydrology including catchment
Surface/ Groundwater interactions	e.g. Groundwater contribution of base flow to streams
Climate	Rainfall, potential and actual evaporation
Flow rates (seasonality)	If is groundwater interactions, provide relative flow rates in streams and estimate loads if possible
Quality	Background (ambient), Other applicable quality standards or objectives
Biological	Bio-monitoring/ Aquatic ecosystems
Vulnerability	Include sensitive systems
Use	Including abstractions and discharges
Contaminant behavior, fate and movement in the environment and plume extent	
Chemicals Identified / present	Leachate analyses, Concentrations of hazardous constituents etc.
Chemical fate and mobility	Chemical reactions/competition between contaminants, influence of biochemical environment on contaminant processes, significance of natural attenuation, bio-accumulation etc
Contaminant type and properties	Form (dissolved, DNAPL etc), phase (solid, sorbed, residual, free phase, dissolved phase, vapour phase)
Contaminant properties	Solubility, density, biodegradability, toxicity, sorption coefficients,
Contaminant distribution	Distribution and variability in time and space / degradation over time etc
Biological	Aerobic/anaerobic; pH, temperature, EC, redox, microbiology etc.
Affected media / Receptor exposure point concentrations	soil/ groundwater / surface water
Processes affecting contamination /migration	e.g. dispersion, dilution, mixing, natural attenuation etc.
Secondary Source media	e.g. soil, water, surface water

ITEM	DESCRIPTION/ VALUE (Include Assumptions, limitations and comment on data)
Geometry of Plume	Horizontal and Vertical extent of the plume
Description of plume	Shrinking, stable, expanding, seasonal etc
Daughter products	Presence of breakdown or daughter products
Other sources of potential contamination	e.g. Sewage treatment plant also contributing to nitrate contamination as well as explosives residues in mine water effluent dam.
Pathways and Receptors	
Transport Mechanism	e.g. Groundwater, Air, Surface water etc.
Exposure Route	Groundwater: Potable use
POD, POC	Description of monitoring points present / Points of Demonstration/Compliance
Points of exposure & compliance	Describe monitoring point positions used to model or observe the plume and compliance and/or receptor locations as well as the distance to these from the source
Receptors	Provide detail on receptors, population, type of use, exposure (dermal, ingestion, inhalation) and distance from source
Current status	Include current status of receptor quality
Population	Demographic profile (age, sensitive groups, etc)
Land Use	Current use and proposed future use.
Other Hazards	i.e. Stability/ sinkholes / etc
Regulatory guidelines	Include detail or reference to other Regulatory guidelines which may apply / Clean up standards, reserve determinations etc.
Site screening levels	Define Preliminary screening levels / Clean up goals or ACLs
Data level	e.g. Tier 1, Tier 2 etc

4. THE COMPARATIVE RISK ANALYSES (CRA) METHODOLOGY

The Comparative Risk Analyses methodology utilizes a generic impact assessment methodology to provide a systematic and structured approach for undertaking environmental impact assessments following the regulations outlined by Schedule R 385 (2006) section 32 (2), sub-section K of the National Environmental Management Act, 1998 (Act No. 107 of 1998) and building on the ranking system outlined by Hacking 1998. The methodology provides a common method for assessing the significance of risks/impacts which will enable authorities, stakeholders and clients to understand the process and rationale upon which the risks/impacts have been based.

Comparative Risk/Impact Assessment Methodology

Stage 1: Identification of environmental activities, aspects and impacts based on the conceptual site model

The first stage of CRA is the identification of environmental activities, aspects and impacts. This is supported by the conceptual site model (CSM) as described above as well as the identification of receptors and resources. This allows for an understanding of the impact pathway and an assessment of the sensitivity to change.

The definitions used in the impact assessment are given below:

- An activity is a distinct process or task undertaken by an organization for which a responsibility can be assigned. Activities also include facilities or pieces of infrastructure that are possessed by an organization.
- An environmental aspect is an ‘element of an organizations activities, products and services which can interact with the environment’. The interaction of an aspect with the environment may result in an impact.
- Environmental risks/impacts are the consequences of these aspects on environmental resources or receptors of particular value or sensitivity, for example, disturbance from noise, health effects due to poorer air quality, and health effects from leachate contaminating water resources.

- Receptors can comprise, but are not limited to, people or human-made systems, such as local residents, communities and social infrastructure, as well as components of the biophysical environment such as aquifers, flora and paleontology. In the case where the impact is on human health or well being, this should be stated. Similarly, where the receptor is not anthropogenic, then it should, where possible, be stipulated what the receptor is.
- Resources include components of the biophysical environment.
- Frequency of activity refers to how often the proposed activity will take place.
- Frequency of impact refers to the frequency with which a stressor (aspect) will impact on the receptor.
- Severity refers to the degree of change to the receptor status in terms of the reversibility of the impact; sensitivity of receptor to stressor; duration of impact (increasing or decreasing with time); controversy potential and precedent setting; threat to environmental and health standards.
- Spatial scope refers to the geographical scale of the impact.
- Duration refers to the length of time over which the stressor will cause a change in the resource or receptor.

Stage 2: Assigning significance

In the impact assessment, the significance of the impact is assessed by rating each variable numerically according to defined criteria as outlined below. The significance of the impact is then assessed by rating each variable numerically according to defined criteria as outlined below. The purpose of the rating is to develop a clear understanding of influences and processes associated with each impact. The significance rating can also be used for prioritization of remedial action by categorizing the potential contaminant risk to human health and/or the (USEPA, 2005 and Waste Act, 2006) as requiring:

- immediate remedial action,
- remedial action within a certain period, as not presenting an immediate risk or
- representing no risk to human health or the environment.

The severity, spatial scope and duration of the impact together comprise the consequence of the impact and when summed can obtain a maximum value of 15. The frequency of the activity and the frequency of the impact together comprise the likelihood of the impact occurring and can obtain a maximum value of 10. The values for likelihood and consequence of the impact are then read off a significance rating matrix, and are used to determine whether mitigation is necessary. (Taking cognizance that although some impacts/risks are low, mitigation will still be required).

The model outcome of the impacts is then assessed in terms of impact certainty and consideration of available information. The Precautionary Principle is applied in line with USEPA Tiered Risk Approach, USEPA,2004. In instances of uncertainty or lack of information by increasing assigned ratings or adjusting final model outcomes. In certain instances where a variable or outcome requires rational adjustment due to model limitations, the model outcomes are adjusted.

Stage 3: The Comparative Risk Assessment

The comparative risk assessment (CRA) utilizes the above method for assigning significance in terms of the remedial options identified to address a possible impact. The CRA provides a visual tool for assessing these criteria whilst taking cognizance of the duration and spatial scale of each aspect of a potential impact and the best practical environmental option as defined by the National Waste Act (2008) as " the option that provides the most benefit or causes the least damage to the environment as a whole, at a cost acceptable to society, in the long term as well as in the short term".

Inherent in the CRA is consideration of the rehabilitation options in terms of the technical feasibility with regard to the following:

- the amenability of treatment (geotechnical),
- that possible byproducts from the treatment process do not present an unacceptable risk to the environment
- the capture/treatment of the plume
- the treatment time
- the successful achievement of remedial objectives
- long term effectiveness
- effect of the treatment method on the water resources
- Cost effectiveness
- Access
- Prioritization of action to protect the water resource
- Regulatory constraints
- The possible hazards associated with transport or handling of the materials and/or remedial options,
- The impact or potential impact of the waste on health and the environment
- Environmentally sensitive nature of a natural resource or the amount of natural resource consumed in the manufacturing or production

Table 2. Criteria for assessing significance of impacts

SEVERITY OF IMPACT	RATING
Insignificant / non-harmful	1
Small / potentially harmful	2
Significant / slightly harmful	3
Great / harmful	4
Disastrous / extremely harmful	5
SPATIAL SCOPE OF IMPACT	**RATING**
Activity specific	1
Mine specific (within the mine boundary)	2
Local area (within 5 km of the mine boundary)	3
Regional (Greater area)	4
National	5
DURATION OF IMPACT	**RATING**
One day to one month	1
One month to one year	2
One year to ten years	3
Life of operation	4
Post closure / permanent	5

CONSEQUENCE

FREQUENCY OF ACTIVITY / DURATION OF	RATING
Annually or less / low	1
6 monthly / temporary	2
Monthly / infrequent	3
Weekly / life of operation / regularly / likely	4
Daily / permanent / high	5
FREQUENCY OF IMPACT	**RATING**
Almost never / almost impossible	1
Very seldom / highly unlikely	2
Infrequent / unlikely / seldom	3
Often / regularly / likely / possible	4
Daily / highly likely / definitely	5

LIKELIHOOD

Table 3. Significance Rating Matrix

	CONSEQUENCE (Severity + Spatial Scope + Duration)														
LIKELIHOOD (Frequency of activity + Frequency of impact)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45
	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60
	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90
	7	14	21	28	35	42	49	56	63	70	77	84	91	98	105
	8	16	24	32	40	48	56	64	72	80	88	96	104	112	120
	9	18	27	36	45	54	63	72	81	90	99	108	117	126	135
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150

Table 4. Negative mitigation ratings

Colour Code	Significance Rating	Value	Negative Impact Management Recommendation
	Very high	126-150	Improve current management
	High	101-125	Improve current management
	Medium-high	76-100	Improve current management
	Low-medium	51-75	Maintain current management
	Low	26-50	Maintain current management
	Very low	1-25	Maintain current management

5. UTILISING THE COMPARATIVE RISK ANALYSES METHODOLOGY

To illustrate the approach the following remedial options were considered in respect of a hypothetical water impoundment where the nitrate residues from explosives used in the mine are determined to be present in seepage from the system to underlying groundwater resources.

Table 5. Identification of environmental activities, aspects and impacts based on the conceptual site model

Activity	Storage of nitrate contaminated water arising from explosive residues and mine dewatering
Aspect	Leachate of water to the groundwater
Conceptual Site Model Status	Tier 1 – (Generic site data, high level of precaution applies)
Pathways	Groundwater
Receptors	Sole source aquifer, however, aquifer is low yielding and of poor quality (Class 3) due to elevated nitrate concentrations from anthropogenic sources, (DWAF, 1998). Non-perennial stream which flows only seasonally after rainfall, however, intermittent flow is observed in localized areas of the stream where base flow seepage is observed and this water is used by communities for domestic use, stock watering and irrigation of subsistence crops. The ambient water quality is also of poor quality (Class 3) due to the naturally elevated nitrate concentrations, (DWAF, 1998; Barnard, 2000). It is assumed that there is insufficient water to support an aquatic ecosystem in the river.
Environmental Risk/Impacts	The ambient nitrate concentrations in the surface water are around 20 mg/l as N but concentrations in the groundwater are highly variable (12 – 80mg/l as N). This water therefore classifies as Class 3 (Poor Quality) for domestic use, (DWAF, 1998). Use of this water is contra-indicated for infants under a year old due to the risk of methanomaglominea especially if malnourished or suffering from an iron or vitamin C deficiency, (Hesseling *et al*., 1991, DWAF, 1996, DWAF, 1998, Shrimali & Singh, 2001, IRIS, 1991). The impact to livestock and crops is negligible at these concentrations, (DWAF, 1996; IRIS, 1991). It is assumed that the seepage is having a measurable impact (quality and quantity) on the surface water and on the groundwater zone over a short stretch of the river. The quality results in elevated, 50 mg/l as N, concentrations over the short stretch of the river during the dry season but is diluted during to below the ambient quality during rainfall periods. As a result of the seepage, water is accessible to communities from the short stretch of river all year round.
Natural Mitigation	The ground water plume is localised. The surface and groundwater comprises naturally elevated nitrate due to the use of fertilizers and human and animal waste.

The various remedial options considered could include but are not restricted to monitored natural attenuation approach – i.e. allow the current status quo to continue with monitoring to ensure that the risk posed to the environment remains within acceptable limits, removal of the source or source control, management of the water resource through collection of seepage through a scavenger wells.

Table 6. Comparative Risk Methodology - Rehabilitation options

Option	Methodology	Pros	Cons	Consequence			Likelihood			Significance / Decision
"Monitored Natural Attenuation"	Routine monitoring to demonstrate that there is a managed impact on the water resources.	Inexpensive. No engineering required. Seepage into the river provides an additional source of water to the community (irrigation and stock watering only)	Contravenes Regulations 704, Section 7 a, (DWAF,1999) Contamination will continue to leach to the resources and quality will deteriorate further over time. Community discussions are required. Use of boreholes will continue to draw plume towards users. DWAF may not agree to supply of ambient water to communities as this water is naturally high in nitrate and would require treatment. More and more communities may need to be supplied as the plume extends down the valley.	Spatial Scope Duration Severity	3 5 3	11	Frequency of Activity Frequency of impact	3 4	7	77: MEDIUM-HIGH Additional site work is required to confirm potential impact to receptors. Given the available information, this options is considered to be: UNACCEPTABLE at the present time.
Reduce or Remove the source	Either replace with lined impoundment to minimize leachate to the environment Fill in impoundment and contour surface to minimise infiltration	Source reduction will limit future seepage from the dam.	Relatively expensive. Source of water no longer available to the community. Contamination may continue to leach to the groundwater from residual contaminated soils. The residual soil footprint may be unsuitable for alternative re-use.	Spatial Scope Duration Severity	2 4 3	8	Frequency of Activity Frequency of impact	3 3	6	48: LOW Depending on the site assessment, this could be a possible option if studies indicate that the area will improve following the removal of the source and that the impact to off-site users is acceptable
Groundwater abstraction	Install scavenger wells to abstract water. Provide alternative water to the community	The seepage to the stream will be reduced and the plume contained to some extent depending on the placement of the scavenger wells.	The hydrogeology must be assessed to determine technical suitability. The water will have to be re-cycled or re-used or treated. It may not be possible limit the seepage for the full extent of the plume. Base flow and storage within the alluvium of the stream will also be abstracted. Abstraction will require licensing under the NWA, 1998 Section 21 (a) and d).	Spatial Scope Duration Severity Duration Severity	2 4 1 5 3	7	Frequency of Activity Frequency of impact Frequency of impact	2 2 4	4	42: LOW As above

6. CONCLUSIONS

The Comparative Risk Analyses methodology is suggested as a qualitative, assessment tool to rank possible impacts and risks associated with remedial options for addressing groundwater contamination by active management or remediation. The use of the significance matrix, although inherently subjective, could, if used together with a comprehensive conceptual site model, provide a consistent approach in assessing the remedial options proposed.

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