Eskom	**Standard**	

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Compiled by	**Functional Responsibility**	**Authorised by**
Z Mkhize	**F Havenga**	**K Pather**
Senior Environmental Advisor	**Eskom Environmental Manager**	**General Manager** **Risk and Sustainability Division**
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Content

1. Introduction

The objective of this document is to provide a standard on how to minimise and manage the potential impact of Eskom operations on groundwater systems. The groundwater governance standard is a document which provides requirements that are mandatory for the business to implement to ensure compliance with the National Water Act, groundwater related legislation, licenses and regulations.

Section 24 of the Constitution provides that everyone has the right to a healthy environment, and the right to have the environment protected from pollution and ecological degradation, which promotes conservation and secures ecologically sustainable development.

Section 28 duty of care under the National Environmental Management Act (NEMA) requires every person who causes, has caused or may cause significant pollution or degradation of the environment to take reasonable measures to prevent such pollution or degradation from occurring, continuing or recurring, or, in so far as such harm to the environmental is authorised by law or cannot reasonably be avoided or stopped, to minimise and rectify such pollution and degradation of the environment. "Reasonable measures" include measures to: investigate, assess and evaluate the impact on the environment; cease, modify or control any act causing pollution or degradation and remedying the effects of pollution or degradation.

Therefore, whether a site has a water use license or not it is imperative that operations and projects that may have an impact on groundwater are known, the extent of the risk is understood and managed accordingly.

1.1 Overview of the Groundwater Governance Guidelines

A Generic Groundwater Management Framework (in the form of a flow diagram) guides the users through the process of developing a sound groundwater monitoring programme (see Figure 1). An explanation of the various steps in the framework is presented in Section 2. Detailed technical guidance is provided on the following groundwater management elements:

- Groundwater Site Characterisation (GWG01);
- Geophysical Survey Guideline (GWG02);
- Borehole Drilling Construction and Design (GWG03);
- Aquifer Testing (GWG04);
- Groundwater Monitoring (GWG05a);
- Groundwater Sampling (GWG05b);
- Aquifer Vulnerability Assessment (GWG06);
- Hydrocensus (GWG07);
- Conceptual Site Model (GWG08);
- Numerical/Analytical/Risk-based Groundwater Modelling (GWG09);
- Risk Assessment (GWG10);
- Pollution Source Management (GWG11); and
- Groundwater Remediation (GWG12).

Eskom sites must use the guidance provided in the document to enhance their understanding of groundwater risks associated with their sites and develop a site-specific groundwater monitoring plan corresponding to that risk.

2. Supporting clauses

2.1 Scope

Technical guidance is provided for implementing a two-phased groundwater protection programme:

- The first phase consists of evaluations to determine the risk of groundwater pollution posed by systems, structures, components, or work practices at Eskom sites. This evaluation process enables sites to prioritise appropriate mitigation actions to reduce this risk.

- The second phase of the programme guides implementing a comprehensive groundwater monitoring programme (if it is warranted).

The guidelines inform the sites of the risk of groundwater pollution with detailed recommendations for developing a site conceptual model, installing monitoring wells and analysing, and interpreting and storage of data/information. If a more detailed understanding of the site hydrogeology is required, the guidelines describe several tools and methods for consideration.

2.1.1 Purpose

The purpose of this standard is to guide Eskom sites for responsible and effective groundwater resource management within the context of the relevant regulatory requirements. The groundwater governance standard is an overarching document that seeks to define the essential management and technical elements required to implement sound groundwater management practices.

2.1.2 Applicability

This document shall apply throughout Eskom Holdings SOC Limited, subsidiaries, and entities in which Eskom has a controlling interest or influence.

2.2 Normative/Informative references

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs.

2.2.1 Normative

[1] ISO 14001 Environmental Management Systems

[2] Eskom SHEQ Policy (32-727)

[3] Eskom Holdings Environmental Management Strategy (240-82410629)

[4] Eskom Water Management Policy (32-1163)

2.2.2 Informative

[5] EPRI, 2008. Groundwater Protection Guidelines for Nuclear Power Plants: Public Edition. Palo Alto, CA: 1016099

[6] National Water Act 36 of 1998

[7] National Environmental Management: Waste Act 59 of 2008

[8] Department of Water Affairs and Forestry, 2008. Policy and Strategy for Groundwater Quality Management in South Africa. First Edition

[9] Department of Water Affairs and Forestry, 1998. Minimum Requirements for Water Monitoring at Waste Management Facilities, Second Edition

2.3 Definitions

Active remediation: Human intervention to remediate contamination such as pump and treatment of groundwater.
Aquifer: A geological formation with structures or textures that hold water or permit appreciable water movement through them. Source: National Water Act 36 of 1998.
Aquifer classification: Classification based on geology and/or primary/secondary porosity and the aquifer's importance in yield and water quality.
Aquifer test: A test to determine hydrological properties of the aquifer involving the withdrawal of measured quantities of water from or the addition of water to a well and the measurement of resulting changes in the head of the aquifer, both during and after the period of discharge or additions.
Aquifer vulnerability: Tendency or likelihood that contamination will reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer.
Borehole: Includes a well, excavation, or any other artificially constructed or improved underground cavity that can be used to intercept, collect, or store water in or remove water from an aquifer, for observing and collecting data and information on water in an aquifer, or for recharging an aquifer. Source: National Water Act 36 of 1998.
Compliance monitoring: Monitoring is done in compliance with permit conditions.
Conceptual site model: A descriptive representation of a groundwater system that incorporates an interpretation of the geological and hydrological conditions. It consolidates the current understanding of the key processes of the groundwater system, including the influence of stresses, details the gaps in the existing knowledge base, and assists in understanding possible future changes.

Confining layer: A body of material of low hydraulic conductivity that is stratigraphically adjacent to one or more aquifers. It may lie above or below the aquifer.
Contamination: Substances that make water impure and unfit for consumption or an intended use and can cause harm to human health or the environment. Contaminants can occur naturally or be caused by humans.
Contamination source: All wastes or products stored on a temporary or permanent basis that could affect surface or groundwater quality by leaching into or coming in contact with water.
Data interpretation: The analysis of data to obtain information concerning the groundwater system, which in turn can be used to manage/remediate the system.
Data management: The effective use of data while ensuring its integrity and providing a centralised repository for storage.
Dose-response models: Mathematical expressions fitted to scientific data that characterise the relationship between dose and response. Mathematical models consist of three basic components: 1) assumptions used to derive the model, 2) a functional form for the model, and 3) parameters that are components of the functional form.
Groundwater: Water found in the subsurface in the saturated zone below the water table.
Groundwater flow: The movement of water through openings in sediment and rock that occurs in the zone of saturation in the direction of the hydraulic gradient.
Groundwater modelling: Numerical representation of a groundwater flow system that attempts to mimic the natural processes in nature. It is a simplified version of a natural system, compiled with geological, hydrogeological, hydrological, and meteorological data, which utilises a governing equation to incorporate all this data to simulate the hydraulic properties of the groundwater system.
Groundwater remediation: The interim or permanent elimination through mitigation or reduction of contaminants that pose human health consequences or threats to the environment.
Groundwater risk: An understanding of the generation of the groundwater hazard, the probability that the hazard will occur and the consequences if it should occur, that is, understanding of the complete cause-and-effect cycle.
Hydrogeology: The study of the interrelationships of geologic materials and processes with water, especially groundwater.
Impact assessment: A formal process used to predict the environmental consequences (positive or negative) of a plan, policy, programme, or project before the implementation decision. It proposes measures to adjust effects to acceptable levels or investigate new technological solutions.
Monitoring: The regular or routine collection of groundwater data (for example, water levels, water quality, and water use) to provide a record of the aquifer response over time.
Monitoring network: A network that contains monitoring positions that can be used to assess the groundwater status in certain areas.
Pathway: A route or means by which a receptor can be exposed to, or affected by, a contaminant.
Plume: An underground pattern of contaminant concentrations in groundwater created by the movement of groundwater beneath a contaminant source. Contaminants mostly spread laterally in the direction of groundwater movement. The source site has the highest concentration, and the concentration decreases away from the source.
Point source pollution: A single identifiable source of pollution.
Pollution source management: Prevention or minimising pollution through applying appropriate assessment techniques, the application of appropriate design, and the ongoing and effective management and re-evaluation of the installed pollution-prevention measures.

Recharge borehole: A borehole specifically designed to be pumped into an aquifer to recharge the groundwater reservoir.	
Risk assessment: The process or method of determining if an activity (human or natural) will harm human health or the environment. Therefore, risk assessment is a decision-making tool for prioritising actions, reducing expenditure, and setting management targets for environmental protection.	

For other technical terms used in **Section 3** of this document, please refer to the following website for a detailed explanation: http://www.dwaf.gov.za/Groundwater/GroundwaterDictionary.

2.4 Abbreviations

Abbreviation	Explanation
BU	business unit
CSM	conceptual site model
DWS	Department of Water and Sanitation
DEA	Department of Environmental Affairs
DFFE	Department of Forestry, Fishery and the Environment
GMF	Groundwater Management Framework
GGG	Groundwater Governance Guideline
ISO	International Organisation for Standardization
NWA	National Water Act
NWRS 2	National Water Resource Strategy 2

2.5 Roles and responsibilities

- The site managers are accountable to ensure that this standard is adhered to on the individual sites.
- The environmental managers at or for Eskom sites shall be responsible for the implementation of this standard and for ensuring that the requirements are met.
- The water portfolio holder within the Risk and Sustainability Division is the custodian of this standard and shall be responsible for periodic review and updating in consultation with the applicable Eskom Divisions and subsidiaries.

2.6 Process for monitoring

Groundwater reviews will be conducted through level 1 and 2 assurance plans on a sample of sites and components of the standard to ensure compliance with the standard and other groundwater-related regulatory requirements.

2.7 Related/Supporting documents

None.

3. Groundwater Governance Standard

Figure 1 presents a groundwater management framework in the form of a flow diagram. The ~~flow~~ diagram details the key elements to be considered in developing a sound groundwater management system. Table 1 provides a descriptive narrative of the groundwater management framework. Reference is made in the framework to the applicable groundwater management guidelines. Details of the guidelines for each of the key groundwater management aspects are provided in Sections 3.1 to 3.13.

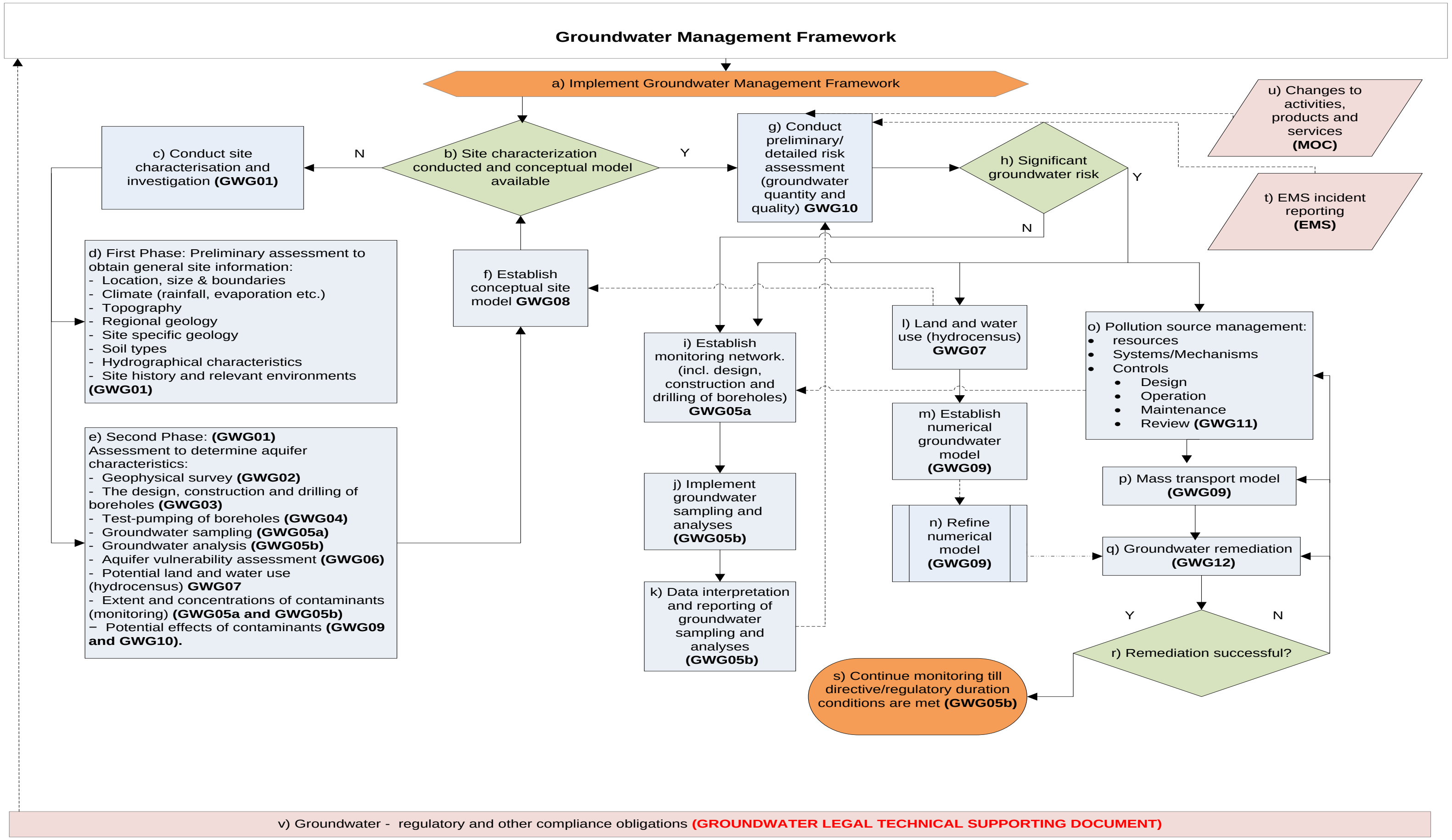


Figure 1: Groundwater Management Framework Flow Diagram

Table 1: Simplified descriptive narrative of the groundwater management framework

GMF flow diagram reference	Task/Decision/ Input	Guideline reference	Description
a) Implement a groundwater management framework	Task		The developed Groundwater Management Framework (GMF) flow diagram defines the essential management activities and technical elements required to implement sound groundwater management practices.
b) Site characterisation conducted and conceptual model available	Decision	• Groundwater Site Characterisation Guideline (GWG01). • Conceptual Site Model Guideline (GWG08).	Determine whether a site characterisation and subsequent conceptual model has been completed. If yes (and the quality of the site characterisation and conceptual model is adequate), continue to g). If no, continue to c).
c) Conduct site characterisation and investigation	Task	• Groundwater Site Characterisation Guideline (GWG01).	All hydrogeological studies require an initial conceptual model that captures the understanding of the hydrological system. Existing knowledge is used to develop a conceptual understanding of the groundwater system. The design of subsequent information gathering is based on the initial conceptual model, and information gathered during further investigation is used to refine the conceptual model. Both phases d) and e) should be completed where the need for groundwater monitoring has been established by regulatory obligations, water use licence (WUL), etc.
d) First phase: Preliminary assessment	Task	• Groundwater Site Characterisation Guideline (GWG01). • Conceptual Site Model Guideline (GWG08).	The preliminary assessment is required to obtain general site information: • Site location, size, and boundaries; • Climate (rainfall, evaporation, etc.); • Topography; • Regional geology; • Site-specific geology; • Soil types; • Hydrographical characteristics; • Current, previous, and potential land and water use for the site and nearby areas; and • Site history (previous owners, activities, associated contaminants, etc.).

GMF flow diagram reference	Task/Decision/ Input	Guideline reference	Description
			All relevant, existing information is identified, and key texts should be reviewed. Central to the hydrogeological study is identifying boreholes in the area and all users and uses that could be impacted. The National Groundwater Archive, GRIP, and WARMS of Department of Water and Sanitation (DWS) are good starting points to identify boreholes, but databases may not be up to date or may contain incorrect information.
e) Second phase: Assessment to define the spatial extent and risk of groundwater impact to human health, etc.	Task	• Groundwater Site Characterisation Guideline (GWG01). • Geophysical Survey Guideline (GWG02). • Borehole Drilling Construction and Design Guideline (GWG03). • Aquifer Testing Guideline (GWG04). • Groundwater Monitoring Guideline (GWG05a). • Groundwater Sampling Guideline (GWG05b). • Aquifer Vulnerability Assessment (GWG06). • Hydrocensus Guideline (GWG07).	Field studies are used to characterise the subsurface environment. The conceptual model of the study area will help identify issues that require improved understanding, while the conceptual understanding of the mechanism by which impact occurs will help to prioritise issues to be clarified. Activities include: • Geophysical survey; • Design, construction, and drilling of boreholes; • Aquifer testing; • Groundwater sampling, and analysis; • Aquifer vulnerability assessment; • Hydrocensus; • Extent and concentrations of contaminants (monitoring); and • The potential effect of contaminants.
f) Establish conceptual site model	Task	• Conceptual Site Model Guideline (GWG08).	A conceptual (hydrogeological) site model (CSM) is a descriptive representation of a groundwater system that incorporates an interpretation of the geological and hydrological conditions. It consolidates the current understanding of the key processes of the groundwater system, including the influence of stresses, details the gaps in the existing knowledge base, and assists in understanding possible future changes.

GMF flow diagram reference	**Task/Decision/ Input**	**Guideline reference**	**Description**
			Developing an appropriate conceptual model is required to ensure that the groundwater evaluation/assessment achieves its objectives. The conceptual model development process may need to include people with a range of skills (hydrology, hydrogeology, climate, soil, etc.) and represents a key point in the site assessment process. The level of complexity of the conceptual model should be appropriate to both the objectives of the site, its characteristics, and available data. In the early phase of groundwater assessment, when basic data on these items is usually scarce, it may only be possible to produce a rough concept of the real system. Later on, the level of complexity that can be depicted will increase as more data become available. Besides playing an important role in the preliminary analysis of the groundwater system, the model is the basis for designing a groundwater monitoring programme. Data collected for the conceptual model, either existing or new, should be analysed for indications of potential impacts on receptors. The development of a conceptual model should be one of the first actions of the site characterisation, even if this first attempt is very simplified.
g) Conduct preliminary/detailed risk assessment (groundwater quantity and quality)	Task	• Risk Assessment Guideline (GWG10).	Risk assessment is the process or method of determining if an activity (human or natural) will harm human health, agricultural activities or the environment. Therefore, risk assessment is a decision-making tool for prioritising actions, reducing expenditure, and setting management targets for environmental protection. In its simplest form, risk assessment involves (sometimes qualitative or subjective) decisions on: • The probability of an adverse effect occurring as a result of an activity; and • The severity of the consequences if an adverse effect does occur. This combines both the likelihood that an event will take place (e.g. a spill of some toxic chemical in a recharge area and the

GMF flow diagram reference	Task/Decision/ Input	Guideline reference	Description
			chemical dissolving in the groundwater) and the likelihood that it will cause harm if it does take place (e.g. people who drink the water become ill). Groundwater risk-based approaches must take into account: • The source(s) of risk; • The groundwater pathway connecting the source to the receptor; and • The nature of the receptor(s). An initial screening-level assessment should be undertaken to determine the critical receptor(s) for a particular source term on which impact with be the most severe. A fully integrated quantitative risk assessment should use the 'source-pathway-receptor' model and involves the following components: • Assessing of the source terms and properties of the chemical substance (solubility, infiltration potential, toxicity, etc.); • Identifying and confirming the beneficial uses in the vicinity of the site through a hydrocensus and review of expected land use; • Determining groundwater flow direction and the potential exposure of the receptors to the chemical substances (e.g. the site may be located hydraulically down-gradient of a sensitive receiver and an assessment has demonstrated that impacted groundwater will migrate towards the receiver); and • Assessing the impact on water quality in the receiving environment compared to DWS water quality criteria. Eskom requires that a quantitative risk assessment be performed in the following circumstances: • Where ecosystem protection is the principal beneficial use and harm to water resource/ecosystem may occur;

GMF flow diagram reference	Task/Decision/ Input	Guideline reference	Description
			and • The beneficial uses of the groundwater are for a potable water supply, and harm to (the) water users may occur.
h) Significant groundwater risk	Decision	• Risk Assessment Guideline (GWG10).	If significant groundwater risk exists (yes), continue to i), l), and o). All three activities should be performed. If no significant groundwater risk exists, only perform i). It is, however, important to note that, if activity k) (data interpretation and reporting) indicates high levels of contamination or risk, which was not detected/anticipated during phase g) (preliminary/detailed risk assessment), phase g) may have to be repeated and the need for groundwater remediation, activity q), may still have to be initiated immediately in high-risk scenarios.
i) Establish a monitoring network (including design, construction, and drilling of boreholes)	Task	• Groundwater Monitoring Guideline (GWG05a). • Groundwater Sampling Guideline (GWG05b). • Borehole Drilling Construction and Design Guideline (GWG03).	It is important to prepare a good site-specific monitoring plan. The conceptual model and risk assessment should be used to structure the network design based on a geophysical survey. A groundwater monitoring network should contain monitoring positions that can assess the groundwater status in certain areas. Boreholes should be grouped/classified according to the source-pathway-receptor indication. Groundwater monitoring is the meaningful measurement of variables and can be done through the following: • As a minimum, a once-off test during initial impact assessments; • Routine tests as part of compliance with licence conditions; or • Ongoing groundwater investigations to quantify the impact on the groundwater resource or sensitive receptors. A groundwater monitoring network should contain monitoring positions that can assess the groundwater status in certain areas. A monitoring point should represent the response of a part of the regional

GMF flow diagram reference	Task/Decision/ Input	Guideline reference	Description
			groundwater system or the system as a whole. Examples of such stresses are the drawdown of the water table caused by pumping or contamination of the groundwater system by contamination sources, such as ash dumps or coal stockyards. Monitoring networks can be designed to operate on local, regional, and national scales. A source-specific monitoring network is intended for a single waste management facility, whereas regional monitoring relates to a combination of waste management facilities, such as those usually present at power stations.
j) Implement groundwater sampling and analyses	Task	• Groundwater Sampling Guideline (GWG05b).	It is important to prepare a good site-specific sampling plan. The plan will describe where, what, why, how and when Eskom requires sampling and who will be doing it. This should be based on WUL conditions and contaminants of concern. Water samples must be analysed by a recognised analytical laboratory that uses approved analytical procedures. Groundwater quality is characterised by many parameters, including physical, chemical, and biological types. The interest in these parameters differs with the objectives of the analysis and, therefore, the sampling and monitoring procedures will also differ. These objectives may be of a general type, for instance, “general groundwater characterisation” related to the actual situation and the potential for use, or they may be more specific, such as conducting studies of groundwater quality under the influence of contamination or remedial measures. The complexity of groundwater quality problems usually increases with the intensity of groundwater development, and so does the need for more specific data collection procedures.

GMF flow diagram reference	Task/Decision/ Input	Guideline reference	Description
k) Data interpretation and reporting of groundwater sampling and analyses	Task	• Groundwater Monitoring Guideline (GWG05a). • Groundwater Sampling Guideline (GWG05b).	Data should be interpreted in accordance with the background water quality, WUL and other licences/authorisation conditions, receptor-specific quality criteria (e.g. drinking water), and end land use water Resource Quality Objectives (RQO), where relevant and appropriate. Conclusions should be drawn based on the relevant legal obligations applicable and the risk to Eskom.
l) Land and water use (hydrocensus)	Task	• Hydrocensus Guideline (GWG07).	A hydrocensus is essentially a site familiarisation involving collecting important groundwater data from the study area and surrounding environments to an Eskom facility, such as a power station. It comprises a census of key boreholes, springs, and any other groundwater-related information. The objective is to identify the potential (pollution) risk and depletion risk to receptors – particularly groundwater users such as communities and farmers. The extent (intensity and area covered) of the hydrocensus will depend upon the level of the study (national, local, or site-specific) and the particular requirements of the study, but it must provide wide coverage of information far enough outside Eskom's operations to allow an overview of the aquifer system(s) to be captured at the necessary level of detail. The information obtained, such as quality and static water levels, assist in defining the groundwater system regionally.
m) Establish and refine a numerical groundwater model	Task	• Numerical/ Analytical/Risk-based Groundwater Modelling Guideline (GWG09).	A groundwater model is a numerical representation of a groundwater flow system that attempts to mimic the processes in nature. It is a simplified version of a natural system, compiled with geological, hydrogeological, hydrological, and meteorological data, which utilises a governing equation to incorporate all this data to simulate the hydraulic properties of the groundwater system. For some assessments, particularly at the site-specific level, preparing a numerical, analytical or risk-based model of the groundwater system may be desirable or

GMF flow diagram reference	Task/Decision/ Input	Guideline reference	Description
			necessary. Where a model is prepared, predictions of the long-term behaviour of the groundwater system under the planned development can be made, and simulations of certain aspects being investigated, such as migration of pollution plumes with time, can be undertaken. Once the model has been finalised, this can be used as input for risk-based decision-making.
n) Refine numerical groundwater model	Task	• Numerical/ Analytical/Risk-based Groundwater Modelling Guideline (GWG09).	Update and refine the model with time-series information to improve its accuracy.
o) Pollution source management	Task	• Pollution Source Management Guideline (GWG11).	The core of integrated water management at Eskom operations should be, in the first instance, to seek to implement pollution-prevention measures optimally. If these measures do not address all the water management issues, the operation should secondly develop and implement appropriate water reuse and reclamation strategies. These strategies may include a greater or lesser degree of water treatment to render the water suitable for reuse. If there is still a residual water management problem, the operation could evaluate and negotiate options with regulators for the discharge of such water to the water resource.
p) Mass transport model	Task	• Numerical/ Analytical/Risk-based Groundwater Modelling Guideline (GWG09).	Reactive transport modelling in porous media refers to creating computer models integrating chemical reactions with the transport of fluids through the earth's crust. Such models predict the distribution in space and time of the chemical reactions along a flow path.
q) Groundwater remediation	Task	• Groundwater Remediation Guideline (GWG12).	If pollution source management has failed to prevent or negate the effects of significant risks to human health and the ecosystem through a risk assessment, the remediation process can be embarked upon in consultation with regulators. If remediation is not effective, the pollution source management aspects might still be ineffective, and this should be revisited and alternative remediation options considered. If remediation is successful, continue with monitoring following the remediation plan or in accordance with the remediation directive requirements.

GMF flow diagram reference	Task/Decision/ Input	Guideline reference	Description
r) Remediation successful?	Decision	• Groundwater Remediation Guideline (GWG12).	If the groundwater remediation is successful, continue to activity s). If not, re-assess adequacy of activities o), p), and q).
s) Continue monitoring till directive/ regulatory duration conditions are met	Task	• Groundwater Monitoring Guideline (GWG05a). • Groundwater Sampling Guideline (GWG05b). • Groundwater Remediation Guideline (GWG12).	Ensure compliance to regulatory obligations, e.g. directives and approved remediation plans concerning the duration and other monitoring specifications.
t) EMS incident reporting	Input	• ISO 14001.	Ensure that all environmental incidents (especially spillage and external complaints from water users) are brought to the attention of the geohydrologist/consultant. It may trigger an update requirement to activity g).
u) Changes to activities, products, and services	Input	• Management of change (MOC).	Ensure that any changes in activities, products, and services are brought to the attention of the geohydrologist/consultant as it might trigger an update of activity g).
v) Regulatory and other requirements/ obligations	Input	• Technical Legal Supporting Document.	Ensure that the latest regulatory obligations about groundwater are considered in the implementation of the GMF.

3.1 Groundwater Site Characterisation Guideline (GWG01)

Introduction

The backbone of any groundwater management system is a groundwater site characterisation. Before any groundwater problem can be identified or assessed, a site characterisation of the area under question is required. The outcome of the site characterisation will assist in planning and prioritising the appropriate groundwater investigations required and the budget that must be allocated.

Purpose

The purpose of this part of the guideline is to ensure that there are clearly defined process controls in place to assist Eskom personnel unfamiliar with hydrogeology to evaluate a basic groundwater site characterisation process.

Site characterisation process

A groundwater site characterisation must consider ecological, hydrological, geohydrological, social, climatic, and economic factors. It should be noted that the application of this methodology will vary because of the scale and/or spatial intensity of the operation.

SACNASP-registered groundwater professionals should do a preliminary assessment to assist Eskom in evaluating the potential groundwater impact of the site (for example, Megawatt Park vs power station). If a potential for impact is found in the preliminary phase, a definition of the objectives and scope of elements to be detailed in the groundwater impact phase should be considered, given the groundwater situation and budgetary constraints of Eskom. A site characterisation should include, but not be limited to, the following elements:

A: Selecting the appropriate approach

The issues that are typically associated with hydrogeological investigations are detailed below. Although diverse issues are listed, the basic approach to understanding the associated hydrogeological implications would be similar. Key elements of an approach to hydrogeological inputs are presented in Table 2 below. Not all of the steps listed will be required in all instances, especially where the significance and likelihood of impact on the groundwater environment are small or where there is a good understanding of the groundwater system. In addition, please note that this is not a linear approach, as some steps may overlap.

Table 2: Key elements of an integrated approach to a groundwater site characterisation process

Phase	Guideline	Description
Initial/Conceptual planning	• Groundwater Site Characterisation (GWG01): Preliminary assessment of the presence or absence of groundwater impact. • Aquifer Vulnerability Assessment (GWG06). • Conceptual Site Model Guideline (GWG08).	All hydrogeological studies require an initial conceptual model that captures the understanding of the hydrological system. Existing knowledge is used to develop a conceptual understanding of the groundwater system. The design of subsequent information gathering is based on the initial conceptual model, and information gathered during further investigation is used to refine the conceptual model.
Reconnaissance and information review	• Groundwater Site Characterisation (GWG01): Preliminary assessment of the presence or absence of	All relevant, existing information is identified and key texts reviewed. Central to the hydrogeological study is identifying boreholes in the area and all users and uses that could be impacted. The National Groundwater Archive, GRIP, and

Phase	Guideline	Description
	groundwater impact. • Aquifer Vulnerability Assessment (GWG06). • Hydrocensus Guideline (GWG07). • Conceptual Site Model Guideline (GWG08.)	WARMS of DWS provide a good starting point to identify boreholes but are insufficient. Databases may not be up to date or may contain incorrect information. A hydrocensus is also an appropriate way to collect information on groundwater occurrence, quality, and use in an area.
Field studies	• Groundwater Site Characterisation Guideline (GWG01): Assessment to define the spatial extent and risk of groundwater impact on human health or the environment. • Geophysical Survey Guideline (GWG02). • Borehole Drilling Construction and Design Guideline (GWG03). • Aquifer Testing Guideline (GWG04). • Groundwater Monitoring Guideline (GWG05a). • Hydrocensus Guideline (GWG07).	Field studies are used to characterise the subsurface environment. The conceptual model of the study area will help identify issues that require improved understanding, while the conceptual understanding of the mechanism by which impact occurs will help to prioritise issues to be clarified. Approaches include water quality testing, water level and spring flow measurement, borehole drilling, aquifer tests, and geophysics.
Analysis	• Conceptual Site Model Guideline (GWG08). • Numerical/Analytical/Risk-based Groundwater Modelling Guideline (GWG09).	The information gathered during the field study phase will be analysed, and the results will refine the initial conceptual model. The validity of the analysis results may be tested through numerical flow or transport modelling. Results of the data gathering and hydrocensus or monitoring will serve to calibrate these models.
Refined model	• Numerical/Analytical/Risk-based Groundwater Modelling Guideline (GWG09). • Risk Assessment Guideline (GWG10).	Based on the information gathered during the previous steps, a refined model of the system (and its linkages) is generated. This may take the form of a calibrated numerical model. This updated model is then used to assess the potential impacts of groundwater associated with the proposed operation.

Phase	Guideline	Description
Risk assessment	• Numerical/Analytical/Risk-based Groundwater Modelling Guideline (GWG09). • Risk Assessment Guideline (GWG10).	Ecosystem protection is the principal beneficial use, and harm to water resource/ecosystem may occur. The beneficial uses of the groundwater are for a potable water supply, and harm to a water user may occur.
Pollution source management	• Pollution Source Management Guideline (GWG11).	The core of integrated water management at Eskom operations should be, in the first instance, to seek to implement pollution-prevention measures optimally. If these measures do not address all the water management issues, the operation should develop and implement appropriate water reuse and reclamation strategies. These strategies may include a greater or lesser degree of water treatment to render the water suitable for reuse. If there is still a residual water management problem, then the operation could evaluate and negotiate options with regulators for the discharge of such water to the water resource.
Remediation	• Groundwater Remediation Guideline (GWG12).	If pollution source management has failed to prevent or negate the effects of significant risks to human health and the ecosystem through a risk assessment, the remediation process can be embarked upon in consultation with regulators.

B: First phase: Preliminary assessment of the presence or absence of groundwater impact

The preliminary assessment can usually be done via a detailed desktop study. The desktop study would entail collating, scrutinising, and evaluating available and relevant meteorological, geographical, geological, hydrogeological, and groundwater quality data. Once the desktop study has been undertaken, the level of input required for further assessment and/or the planning phases can be determined based on the potential impact. Three broad categories of groundwater-related impacts are recognised:

- Where effluent or chemicals with the potential to change groundwater quality are handled as part of the operation or discharged into the environment because of the project;
- Where the volume of groundwater in storage or entering groundwater storage is changed; and
- Where the groundwater flow regime is changed.

Should none of the above be relevant, it may be concluded that groundwater impacts are not applicable, and no further groundwater work is required.

For example, for a development that falls in the first of these categories, where the concern is around the impact on groundwater quality, the focus of the input (and hence the initial conceptual model) would be on understanding groundwater recharge volume and pathways, the chemical character of the effluent or chemicals, and on geochemical processes that could alter the chemical character of the infiltrating pollutant. If the concern is that the groundwater resource may be exhausted by over-abstraction (included under the second of the category classes), the focus of the input would be on understanding groundwater recharge, storage volume, and the volume and timing of groundwater abstraction and discharge. Similarly, where the project may lower the water table because of an excavation (the third of the category classes), such as an open-pit mine, the input would need to focus on understanding the groundwater flow regime.

The steps involved in the preliminary assessment for groundwater impacts are discussed separately under the headings below.

B1: Detailed site description

A detailed site description is required, which must include:

- Details of the current land owner and occupiers of the land;
- The site co-ordinates, irrespective of the site of the facility;
- The farm, plot, and/or site numbers;
- The current site plan with a scale bar showing northerly direction, local water drainage, and other locally significant features, such as receptors on site and immediately off site. The plan must also show the historical location of structures that may have affected the distribution of contamination (coal stockyards, underground mining areas, ash dumps, etc.);
- Location and size of the site and its boundaries with other areas or the ocean;
- Identification of protected wetlands, such as RAMSAR sites;
- The climate of the area, including rainfall, temperature, and evaporation;
- General classification of the aquifers underlying the site, using the DWA Aquifer Classification Map of South Africa;
- General aquifer vulnerability of the aquifers underlying the site, using the DWA Aquifer Vulnerability Map of South Africa;
- Topography, the division into mountainous, hilly or plain zones, using 1:50 000 topographical maps. These topographical characteristics are often related to the geology of the area;
- Groundwater-surface water interaction and hydrographical characteristics; and
- Determination of contamination potential based on on-site activities and waste facilities.

B2: Site history

The site history is required, which must include:

- The description of the past and present activity that led to contamination or dewatering;
- The type of contaminant or known dewatering areas/decanting areas;
- The nature and extent of contamination or dewatering (including resources known to be contaminated);
- Details of the previous polluter(s) or land user(s);
- A description of the current conditions of the site; and

- Known flooding or decanting areas.

B3: Relevant studies

Any relevant studies were conducted, including the contents and results of those studies. The following studies should be evaluated:

- Environmental audits, EIAs, IWWMPs, WULs, and EMPRs;
- Contamination studies and risk assessments;
- Geohydrological studies, including sampling reports;
- Geophysical profiles of exploration and/or monitoring boreholes previously drilled in the area;
- Geological reports;
- Geotechnical reports;
- Hydrological studies, including sampling reports;
- Wetland studies;
- Engineering reports and designs;
- Waste storage and handling procedures; and
- Environmental incident reports.

B4: The description of the environment

The description of the environment that may be or has been affected, which must include:

- The local topography and geology, including soil types;
- The drainage patterns, surface cover, vegetation;
- Details of any relevant sensitive environments;
- A determination of groundwater quality and direction as well as the sensitivity of aquifers and the depth to the water table;
- Current and future and use;
- The quality of and proximity to surface water;
- The proximity to drinking water supplies; and
- Meteorological data, including annual rainfall.

B5: Formal authorisation(s), notice(s), order(s), and/or directives

Formal instructions (WUL, etc.) are issued by regulatory organisations, such as DWS or DEA.

B6: Initial conceptual model

The initial conceptual model must be based on the review of available data detailed above and must physically describe the Eskom operation in terms of those aspects that would have a bearing on the impact prediction. It must also describe the pathways along which the impact will propagate and then describe the procedure applied to determine who/what the critical receptor is.

The type of study being undertaken should determine the complexity of the initial conceptual model, for example, a simplified conceptual model for a screening-level study and a more detailed conceptual model for a closure application. The initial conceptual model must also ensure that the necessary information/questions are defined to support the tools to be used to answer the stipulated requirements of further investigations.

See Eskom, 2014. Conceptual Site Model Guideline (GWG08).

B7: Identify areas for additional work

Using the results from the above, undertake a gap analysis to identify areas of insufficient information to define the spatial extent and risk of groundwater impact on human health, the environment, or any structures and property.

C: Second phase: Assessment to define the spatial extent and risk of groundwater impact on human health or the environment

As mentioned earlier, if the elements discussed in the preliminary assessment are significant in terms of groundwater impact, a more detailed assessment will be required, using the methods/tools listed below. The complexity of further work should be determined by the initial screening-level assessment and inherent groundwater impacts. Three broad categories of groundwater-related impacts are recognised:

- Where effluent or chemicals with the potential to change groundwater quality are handled as part of the operation or discharged into the environment because of the project;
- Where the volume of groundwater in storage or entering groundwater storage is changed; and
- Where the groundwater flow regime is changed.

If the above is relevant, it can be concluded that groundwater impacts are applicable, and no further groundwater work is required. However, Eskom must consider the potential significant direct, indirect, and cumulative impacts of a proposed or existing activity. This requires the following:

- The conceptualisation of possible cause-effect pathways resulting from the proposed or existing operation;
- An understanding of current and plans, projects and activities in the same area;
- An awareness of other threats or trends that could affect the groundwater resources in the area in which the development is proposed;
- An understanding of the likely resilience and status of the affected resource; and
- An understanding of broader strategic goals or targets for the area affected by the proposed project.

The level of detail in which these should be considered will be influenced by the nature of the proposed project and issues raised through the scoping process. Where potentially significant cumulative effects are likely and cannot be addressed, Eskom, through a consultant, should alert decision-maker(s) to these effects and make explicit recommendations as to ways of addressing them (for example, through a strategic environmental assessment or systems-based approach).

Groundwater is particularly susceptible to the cumulative effect of numerous small impacts. Eskom must give this due regard and thoroughly consider it in a designated section of the assessment report. Where RQOs exist, the impact of the proposed development on these should be discussed in the context of its contribution to the cumulative effect.

C1: Description of the key elements to a groundwater site characterisation process

The following paragraphs discuss key elements of an approach to hydrogeological input.

Geophysical survey

A geophysical survey aims to map preferential flow paths and detect basic intrusions like dolerite dykes and sills, which are normally associated with groundwater occurrence and contaminant pathways.

See Eskom, 2014. Geophysical Survey Guideline (GWG02).

The design, construction, and drilling of boreholes

Drilling boreholes aim to allow investigation of the following:

- Obtain information regarding the geological units with depth;
- Obtain information regarding the geological units responsible for the geophysical anomalies;
- The possible presence of preferential flow paths (fractured and/or weathered zones) along which contaminants may migrate;
- The hydraulic properties of the aquifer systems utilising aquifer tests;
- The current and future groundwater quality through monitoring;
- The current and future water level measurements through monitoring; and
- The presence and extent of possible contaminant plumes emanating from the site.

See Eskom, 2014. Borehole Drilling Construction and Design Guideline (GWG03).

Aquifer testing of water boreholes

The aim of aquifer testing or aquifer tests is to find reliable hydrogeological values for the geological formations through which groundwater is moving.

See Eskom, 2014.Aquifer Testing Guideline (GWG04).

Groundwater sampling and analyses

Sampling must include the nature of samples collected, the sampling procedures followed, including field sampling quality assurance and quality control requirements. The analyses undertaken, methodologies used, and laboratory quality assurance/quality control procedures, including laboratory certificates and appropriate accreditation listed, must also be included.

See Eskom, 2014. Groundwater Monitoring and Sampling Guidelines (GWG05a and GWG05b), and Eskom, 2014. Hydrocensus Guideline (GWG07).

Aquifer vulnerability assessment

This is an assessment of the tendency for or likelihood of contamination reaching a specified position in the groundwater system underlying the site after introduction at some location above the uppermost aquifer.

See Eskom, 2014. Aquifer Vulnerability Assessment Guideline (GWG06).

Potential land and water use

This refers to the current, previous, and potential land and water use for the site and nearby areas.

See Eskom, 2014. Hydrocensus Guideline (GWG07).

Refinement of the CSM

The CSM is a descriptive representation of a groundwater system that incorporates an interpretation of the geological and hydrological conditions. It should consolidate the current understanding of the key processes of the groundwater system, including the influence of stresses. It details the gaps in the existing knowledge base and assists in the understanding of possible future changes.

See Eskom, 2014. Conceptual Site Model Guideline (GWG08).

Extent and concentrations of contaminants

This specifies the actual extent and concentrations of contaminants in all appropriate environmental media on site, based on verified test data.

See Eskom, 2014. Groundwater Monitoring and Sampling Guidelines (GWG05b and GWG05b), and Eskom, 2014. Hydrocensus Guideline (GWG07).

Potential effects of contaminants

This refers to any potential effects of contaminants on human health and the environment.

See Eskom, 2014. Risk Assessment Guideline (GWG10) and Eskom, 2014. Numerical/Analytical/ Risk-based Groundwater Modelling Guideline (GWG09).

D: Output of the site characterisation process

D1: Preliminary assessment report of the presence or absence of groundwater impact

This report must comply with the following minimum requirements:

- Detailed site description;
- Details of the site history;
- Details of the desktop study and supporting information;
- Description of the environment;
- Details of formal authorisation(s), notice(s), order(s), and/or directives;

- Initial CSM;
- Identification of areas requiring further work;
- Confirmation of knowledge gaps; and
- Preparation of a work plan for an impact prediction or risk assessment, if required.

D2: Assessment report to define the spatial extent and risk of groundwater impact on human health or the environment

This assessment report must comply with the following minimum requirements:

- Details of potential land and water use through aquifer classification and hydrocensus information;
- Detailed CSM with supporting information, such as geophysical survey, aquifer testing, and borehole logs;
- Aquifer vulnerability assessment;
- Extent and concentrations of contaminants, based on monitoring or sampling data;
- Risk assessment through dose-response and numerical models;
- Prediction of potential impacts;
- Interpreting impact assessment criteria;
- Establishing thresholds of significance;
- Describing the distribution of impacts – beneficiaries and losers;
- Identifying key uncertainties, assumptions, and risks;
- Defining confidence levels and constraints to input;
- Recommend management actions, such as monitoring network design, liner designs, and interception trenches;
- Identifying the best practicable environmental option; and
- Communicating the findings of the specialist input.

As a general guide, the site characterisation process should:

- Consider the full project cycle;
- Answer the “to what” and “to whom” questions of probable impacts, that is, what are the likely consequences of impacts, how severe would they be, and who would be affected by these impacts;
- Predict, assess, and evaluate potentially significant direct, indirect, and cumulative impacts, both with and without management actions. The evaluation of significance should be linked to thresholds of significance;
- Assess and evaluate impacts for the different alternatives and for different environmental and operating scenarios, where appropriate;
- Consider not only impacts on the affected site but also impacts beyond the site boundaries; and
- Assess and evaluate any opportunities and constraints posed by the receiving environment/ operating context on the proposed development.

3.2 Geophysical Survey Guideline (GWG02)

Introduction

As most of Eskom's operations are situated on fractured rock formations, such as the Karoo rock formations, this guideline mainly focuses on geophysics using electromagnetic (EM) and magnetic (Mag) methods to map preferential flow paths as these are the most commonly applied methods employed on these formations. However, as magnetic methods can only be applied in areas with no power lines, metals and infrastructure and cannot delineate contamination, the Resistivity Method using the Lund Imaging System will also be discussed.

While the magnetic method is used to detect basic intrusions like dolerite dykes and sills, which are normally associated with groundwater occurrence, the EM method detects changes in electrical conductance of the subsurface. As water is normally a conducting substance in the rock, the method is sensitive to the presence of groundwater. Combining the two methods lends itself to identifying and mapping potential groundwater preferred flow paths.

Resistivity measurements are carried out by recording the electric potential (voltage) from a current input into the ground, thus collecting information on the conductive ability of the subsurface.

Please note that geophysical textbooks should be consulted for more detailed information on EM, Mag and resistivity methods.[1]

Purpose

The purpose of this guideline is to ensure that there are clearly defined process controls in place to evaluate a geophysical survey. The guideline is to be applied at all Eskom operations that require the mapping of preferential pathways of potential for groundwater contamination or where boreholes are required to be drilled for abstraction or monitoring.[2]

Geophysical survey procedure

A: Survey objectives and principles

The procedure is to ensure that geophysical surveys are performed so that repeatable results can be obtained.

[1] Parasin, D.S. (1997) Principles of Applied Geophysics, fifth ed., ISBN 0 412 64080 5, Chapman and Hall London

[2] Eskom, 2014. Site Characterisation Guideline

B: Preparation

The preparation for the survey is discussed in the following paragraphs.

B1: Legal considerations

Before incurring the expense of a geophysical survey, an Eskom site representative shall ensure that all legal requirements regarding the survey on the property are reviewed and complied with. This shall include both surface rights, for example, as defined by local bylaws and the property title deed, and subsurface rights, for example, as it relates to the intended exploitation of the groundwater resource in terms of the requirements of the National Water Act 36 of 1998.

B2: Environmental considerations

The Eskom site representative shall ensure that the appropriate level of consideration is given to the effect that the geophysics, and the potential borehole drilled at the selected site, will have on the environment and vice versa. Factors to be considered in this regard relate to the potential occurrence of exclusion zones, such as wetlands.

B3: Physical considerations

An Eskom site representative should study the property plans to identify exclusion areas in which the drilling and operation of a borehole may not be possible. In the absence of property plans, exclusion areas will need to be identified based on visual observations and knowledge that can be sourced locally. Such areas may include, but are not limited to, the following:

- Sensitive ecosystems, such as wetlands;
- Areas offering restricted access for the drilling machine and equipment;
- Areas providing restricted clearance for raising the mast of the drilling machine;
- Areas defining existing and proposed routes for surface and subsurface services, for example, power cables and pipelines;
- Areas supporting foundations and other underground structures; and
- Areas providing restrictions on the installation, operation, and maintenance of pumping equipment.

B4: Planning

Planning for a geophysical survey is essential to avoid wasting time in the field. The following shall be completed before embarking on a geophysical survey:

- Understand the scope and objectives of the assessment and the purpose of the borehole(s);
- The owner of the property or designated responsible officer where the survey is to be carried out shall be notified in advance of the intended survey date(s) and time;
- Study of existing and available geological, geophysical or groundwater literature (or all of these), data, and information relevant to the area or region in which the property is located. This activity can provide information regarding the general occurrence and quality of groundwater;

- Study of relevant existing and available maps, aerial photographs, and other remotely sensed information for the area or region in which the property is located. This activity can assist in identifying appropriate drilling targets as well as surrounding circumstances potentially influencing the precision of the survey (high-voltage power transmission,[3] pipelines, historic buried concrete structures, etc.);
- Identify or select the general area within the aquifer where boreholes are required. Interpret the black and white stereo pair air photography and satellite imagery in and surrounding the area of interest to identify structural features (for example, dykes, faults, fracture zones), weathering, and other features (for example, karst) of importance to groundwater occurrence;
- Survey of existing boreholes in the area or region in which the property is located. This activity can provide information about typical borehole depths and drilling success rates, the depth of water levels, and the general quality of groundwater in the area (see Annexure A);
- A scaled map and preferably GPS co-ordinates showing the positions of the proposed traverses should be supplied to Eskom by the consultant conducting the survey;
- The instruments must be checked before leaving for the site; and
- The following equipment is essential for conducting a geophysical survey and must be packed before leaving for the site:

Electromagnetic and Magnetic

- Spare batteries;
- Sunscreen, hat, insect repellent;
- Water bottles;
- Danger tape to mark stations in the field;
- GPS;
- Field data sheets;
- Waterproof field notebook;
- More than one waterproof marking pen;
- Protective clothing to adhere to site requirements (if any);
- Wooden stakes or “droppers” and a hammer to mark drilling positions, if required; and
- Tool and spare kit.

Lund

- Battery;
- Electrode selector and connecting cables;
- Lund spread cables and a suitable number of cable joints and cable jumpers;
- A suitable quantity of electrodes; and
- Tool and spare kit.

B5: General

- In areas of dense vegetation where a clear pathway is not visible, the GPS may be used to pre-mark traverses with environmentally friendly tape at intervals of 50 m or 100 m to ensure a straight bearing;

[3] If applicable, arrangements shall be made to contact the relevant owner in order to discuss intermitted operation during the time of the electromagnetic survey.

- GPS co-ordinates (decimal degrees, WGS84) must be taken at the start and endpoint of each traverse as well as at intervals of 100 m along the traverse;
- Accurately note any changes in surface geology, topography, soil colour/type, vegetation;
- Accurately note the presence of any above-ground or underground servitudes, pipelines, cables, fences, roads, or prominent landmarks along traverses;
- Take note of significant changes (anomalies) in measurements recorded along traverses. Where deemed necessary, take GPS co-ordinates at these anomalies. Avoid starting or ending a traverse where a significant change in readings occurs. Ensure that there are at least 50 m of readings before and after a position where an anomaly occurred;
- Once the survey is completed, perform a battery test and make a note if batteries need replacement; and
- Ensure that all equipment is packed away and leave the site as found.

C: Electromagnetic and Magnetic survey procedure

How to conduct the EM and Mag survey is discussed in the following paragraphs.

C1: Electromagnetic survey

- Set up the instrument using the 10 m, 20 m, or 40 m coil spacing according to the depth of investigation;
- Take both horizontal dipoles as well as vertical dipole measurements at station intervals of 10 m, aiming in a generally straight direction as indicated on the map;
- Avoid having to cross any metal or electrical objects as far as possible. If this is not possible, attempt to cross underneath power lines or over fences in a perpendicular direction instead of diagonally. If traverses have to be conducted parallel to fences, pipelines, or power lines, attempt to keep a constant distance of at least 50 m away. In the case of high-voltage power lines, it may be necessary to move several hundreds of metres away to obtain stable and accurate readings; and
- Where data anomalies occur, it is advisable to cover those areas with coil separations of both 20 m and 40 m to ensure optimal interpretation of the anomalies.

C2: Magnetic survey

- Avoid having to cross any metal or electrical objects as far as possible. If this is not possible, attempt to cross underneath power lines or over fences in a perpendicular direction instead of diagonally. If traverses have to be conducted parallel to fences, pipelines, or power lines, attempt to keep a constant distance of at least 20 m away. In the case of high-voltage power lines, it may be necessary to move several hundreds of metres away to obtain stable and accurate readings; and
- Where data anomalies occur, it is advisable to cover those areas with 2,5 m station spacing to ensure optimal interpretation of the anomalies.

C3: Borehole pegging

The consultant shall employ the information collected within the agreed scope of the site suitability assessment to identify and mark a borehole site. This position shall be identified to an Eskom representative.

D: Lund imaging system procedure

The following filed procedure assumes that the standard ABEM Lund equipment with four cables with 21 electrode take-outs is used.

D1: Layout

At the first measurement station, start laying out and connecting three cables only and connect the instrument between the first two cables. All cables should be rolled out in the direction of the profile. It is a good rule to have the profiles always running south-north or west-east to avoid confusion when the results are presented. Decide on the number of electrodes.

D2: Connect cables and insert electrodes

Decide which electrode configuration to use. Link together the inner and outer electrode cables with a cable joint. Take care to connect it in the right direction. The groove on the cable joints should point towards the instrument in the layout centre. Connect the electrodes to the odd-numbered take-outs on all active electrode cables. If the ground is soft and moist, the electrodes can be pushed into the ground and connected, otherwise hammering and wetting can be applied. Check the contact surfaces between the electrode, cable jumpers, and electrodes for dirt and oxide, which can ruin the data quality, and clean if needed.

D3: Measurement

Select suitable protocol files. Interconnect the instrument at the second measurement station and all the following stations as long as all four cables are connected while the line is extended. There must be no overlapping of electrode take-out at the cable intersections. While measuring occurs, electrode cables can be rolled out, and electrodes can be connected to the next investigation line.

Reporting

A written report shall present the salient results and findings of the survey, including graphs and data. This activity will also provide a written record of the service(s) rendered by the consultant for purposes of future reference. The report should include at least the following items:

- Description of the method employed and why;
- The scope and objectives of the assessment and the purpose of the survey;
- The methods employed and spacing used for the traverses, as well as coil/electrode spacing used for the survey;

- Scaled map and preferably GPS co-ordinates showing the traverses;
- The considerations that led to the selection of the traverses;
- Description of the local geology (weathering zone, highly conductive zone, etc.);
- Tables of the field data and notes describing potential interference of the data;
- Interpretation of data to identify structural features (for example, dykes, faults, fracture zones), weathering, and other features (for example, karst) of importance to groundwater occurrence;
- Image graphs and representations;
- Inferred structure details, such as:
    - Type
    - Orientation
    - Extent
    - Depth
    - Conductive zones
- Siting of boreholes on graphs, scaled maps, and GPS co-ordinates in tables and reasoning behind the borehole position; and
- Assumptions and limitations.

3.3 Borehole Drilling Construction and Design Guideline (GWG03)

Introduction

When dealing with groundwater problems, borehole drilling is required to obtain detailed knowledge of the following site-specific groundwater characteristics, among others:

- The geological units responsible for the geophysical anomalies;
- The possible presence of preferential flow paths (fractured and/or weathered zones) along which contaminants may migrate;
- The hydraulic properties of the aquifer systems using hydraulic tests;
- Information on water levels, fluctuations, and flow directions;
- The current groundwater quality in the vicinity of the site; and
- The presence and extent of possible contaminant plumes emanating from the site.

Furthermore, boreholes can also be used as part of monitoring networks or for abstraction purposes.

Purpose

The purpose of this guideline is to ensure that there are clearly defined controls in place to evaluate the design, construction and drilling of a percussion borehole. The guideline is to be applied at all Eskom operations that require information on aquifer characteristics for impact assessments or where boreholes are required for monitoring purposes.[4]

[4] Eskom, 2014. Site Characterisation Guideline

Design, construction, and drilling procedure

The preparation, planning, construction, and drilling procedure is discussed under the headings below.

A: Preparation

The preparation for drilling is discussed in the following paragraphs.

A1: Legal considerations

Before embarking on the drilling exercise, an Eskom site representative shall ensure that all legal requirements regarding drilling on the property are reviewed and complied with. This shall include both surface rights, for example, as defined by local bylaws and the property title deed, and subsurface rights, for example, those related to the intended exploitation of the groundwater resource in terms of the requirements of the National Water Act 36 of 1998.

A2: Environmental considerations

The Eskom site representative shall ensure that the appropriate level of consideration is given to the effect that the drilling will have on the environment. Factors to be considered in this regard relate to the potential occurrence of exclusion zones, such as wetland areas.

B: Planning

Planning for the design, construction, and drilling exercise is essential to avoid wasting time in the field. The following shall be completed before embarking on drilling:

- Determine whether the purpose of the boreholes will be for monitoring or abstraction;
- Review all available documents and information about the groundwater system;
- The consultant or Eskom should ensure that the drilling contractor is competent and thoroughly prepared for the drilling;
- All necessary Eskom site-specific health and safety procedures should be completed before embarking on drilling;
- The owner of the site to be drilled, or another responsible person, should be contacted in advance to inform him/her of the planned drilling;
- The consultant or Eskom shall supply the drilling supervisor with all the relevant site information, with special emphasis on the expected locations of the boreholes to be drilled and the underground services;
- The drilling supervisor should consult with the consultant or Eskom as to whether or not samples have to be taken from the boreholes and as to whether the boreholes are for sampling or monitoring purposes;

- Should sampling be required, the quantity and types of samples should be decided upon and detailed to the drilling supervisor;
- At least the following essential equipment and criteria are required for drilling:
  - The drill rig must be in working order and a suitable and safe condition;
  - A hand drill or breaker – if required – to break through concrete pavement before drilling;
  - A generator and/or extension cord to supply power to the drill or breaker;
  - Enough of the relevant field forms, that is, borehole clearance review form, drill log sheet, borehole construction sheet, soil sampling form and chain of custody (COC), must be available to describe the soil profile during drilling and if sampling is required; and
  - Waterproof field notebook and stationery.
- If equipping of the borehole is expected for monitoring and/or remediation purposes, the drilling contractor must be informed that the following should be taken to the site for borehole construction:
  - The approximate solid casing according to the construction specifications determined by the project manager;
  - The approximate perforated casing according to the construction specifications determined by the project manager;
  - Top and bottom end-caps to cover the casing ends;
  - A manhole to protect the borehole;
  - Inert washed silica gravel (3-6 mm) for the filter pack between the perforated casing and the borehole sides;
  - Bentonite to form a sanitary seal from surface level down to at least 0,5 mbgl;
  - Building aggregate and cement to construct manhole;
  - Marker pole;
  - Sampling bottles for specific groundwater samples;
  - Sampling bags to collect drilling logs at one-metre intervals; and
  - Camera.

B1: General

The contractor shall supply a drilling rig and equipment required for the type of drilling operation to be undertaken. The contractor shall maintain the drilling rig in efficient working order at all times. The drilling rig and ancillary equipment shall not leak fuel, oil, or any fluid, nor negatively affect the environment surrounding the drill site. Site safety should be considered, such as overhead power cables, optic fibre cables, underground tanks, etc., before any drilling commences.

C: Field procedure

When on site, the drilling supervisor should firstly introduce him/herself to the site manager or responsible person. Thereafter, a short site walkover must be done to get acquainted with the site and to clarify the proposed drilling localities. These localities must be indicated on a site map, using WGS84 GPS co-ordinates in decimal degrees.

Once all the HSSE requirements for the site have been met, drilling can commence by carrying out the following actions:

C1: Before drilling

- Ensure that hand clearance is done to at least 1,5 m below surface, or as required by Eskom;
- Inform the drill operator how deep the boreholes are to be drilled and at what intervals samples are to be set out (normally one per metre); and
- Determine chip/cut sample placement area and sequence.

C2: During drilling

- Make certain that the samples taken are not contaminated by the soil from other portions of the borehole;
- Note the depths at which samples are set out and describe the soil profile;
- Record the penetration rates per metre;
- Record the depth when/if water was struck or seepage occurred. Estimate blow yields where applicable;
- Take samples for chemical analysis if and as stipulated by the consultant;
- Log the borehole geologically and geohydrologically;
- It is important to take photographs of the borehole chips laid out on the ground surface. The photo direction should always be done as if reading a book; and
- Take field notes regarding standing time, pressure loss, problems encountered, etc.

Borehole logging

Borehole logging should be done according to the paragraphs described below.

Hole and casing diameters

The borehole diameter(s) should be noted, as well as the internal diameter and depth at which the casing of that specification has been installed.

Chip size/Cutting size range

The average size of fragments retrieved should be noted. The size will be influenced by the hardness of the rock and the type of drilling bit used. Generally, the finer the chip size, the harder the formation.

Water rest levels

Several water levels may be recognised in a borehole. These may include the permanent water table, which shows little seasonal variation in elevation, and the perched water table, which lies above the permanent water table and is usually subject to great seasonal variation. Perched water tables may develop on low-permeability strata during the rainy season and may disappear during the dry season.

Water rest levels should be read at least 24 hours after completing the borehole and should be checked. It is recommended that permanent casings be installed in several boreholes on a site for long-term monitoring. In addition to noting the water rest levels in the borehole, it is important to record where water was first encountered.

Penetration time

The penetration time should be recorded in minutes and seconds taken to penetrate each metre drilled. This time excludes flushing, cleaning, and other delays. These figures are to be recorded in the appropriate column. The detail required to execute certain projects may necessitate noting this time over distances of less than one metre.

Depth

The depth below ground level of the contacts between strata is recorded in this column. The final depth of the borehole is reported as a depth in metres below ground level.

Borehole screen depths and design

This is the size and type of casing and borehole screen used in the as-built construction of the borehole. If the as-built construction of the borehole entails more than one size or type of casing (or both) and borehole screen, then the depth interval (reported as a depth in metres below ground level) over which each size and type occurs in the borehole shall be recorded.

Blow yield

The final blow yield of the borehole must be determined. This determination shall be made after the borehole has reached its final depth. To obtain as accurate a measurement as possible, the method of determination shall be appropriate to the magnitude of the yield.

NOTE: If the blow yield is determined during drilling, then it is possible to establish the individual blow yield of each successive water occurrence (fractures). This will be the difference between the latest and previous measured values.

Legend

Use relevant symbols to describe the geology, casing, screens, etc.

Description

The major portion of the sample should be described first. For soil, the descriptors colour, soil texture, and origin are used. For rock, the descriptors colour, weathering, and rock type are used.

The subordinate portions of the sample are described using the aforementioned descriptors, incorporating the following qualifications:

- Traces – the subordinate amount is less than 10% of the total sample;
- Minor – the subordinate amount is between 10% and 30% of the total sample;
- Abundant – the subordinate amount is between 30% and 50% of the total sample; and
- Equal amounts – the major fractions occur in equal amounts.

The moisture condition is generally not described, as a number of factors may influence the final value, the addition of water during the drilling process, samples left exposed before being sealed, desiccation during the air-flushing process, etc. In the description of the sample, unambiguous distinctions should be made between fact and interpretation. Interpretations will usually contain words such as “possibly”, “probably”, and “interpreted as”, automatically clarifying the assessment being made.

Soil component

Colour

To obtain a standardised basis for judging the colour and to take cognisance of changes in colour with changes in moisture content, it is recommended that the soil be described as wet. (A small portion of the soil is taken in the palm, and sufficient water is added to create a paste.) Owing to the difficult and subjective nature of assigning colour descriptions, it is recommended that a colour chart be used. The Mansell colour chart or the Borland colour disc is recommended.

Soil type

The soil type is described based on grain size. The following descriptions are relevant:

- Gravel:
  - Gravel consists of fragments of rock between 200 mm and 2.0 mm in size. The shape of the gravel particles should also be described as this assists the interpretation of origin: well-rounded, rounded, subrounded, subangular, or angular.
- Sand:
  - Sand consists of discrete particles between 2.0 mm and 0.06 mm in size. The particles are visible to the naked eye, except for the finer sizes.
- Silt:
  - Silt consists of discrete particles smaller than 0.06 mm and larger than 0.002 mm in size. Generally, silt particles are barely felt when rubbed with water on the palm.
- Clays:
  - Clays consist of particles smaller than 0.002 mm in size. In general, the particles are flaky and have a soapy or greasy feel when rubbed on the palm with water. There is no sensation of grittiness. Most natural soils are a combination of one or more of the above textures, and, in describing such a soil, adjectives are used to denote the lesser constituent, for example, a silty clay is clay with some silt.

Origin

Where possible, the origin of the soil should be given, e.g. alluvium, residual dolomite, etc.

Contamination

With increasing depth and in uncased boreholes, the risk of contamination increases. It may be necessary to adjust descriptions in accordance with sudden changes in penetration times.

Rock component

The finest component should be washed out before describing the coarse component.

Colour

To ensure that surfaces are representative of the colour of the rock material, only recently broken surfaces should be examined for the description. Surfaces altered by contaminants or surface abrasion should be avoided. Colour descriptions should be kept as simple as possible corresponding with those on an acceptable colour chart, such as the Munsell colour chart or Borland colour disc. Where a rock chip displays a secondary colour, this may be added to the predominant rock colour as an adjective, for example, yellowish brown. Where significant, the colour could further be amplified by using the following descriptions for further distinction: very light, light, medium, dark, very dark.

Weathering

The state of weathering of the rock should be described in broad categories.

Rock name

The rock should be described lithologically and stratigraphically, for example, Lebowa Suite granite.

C3: After drilling

Permanent casing

If a permanent casing is installed in the borehole, the annulus between the borehole wall and the casing should be grouted, a concrete collar cast at the surface around the casing to secure and seal the head of the borehole, and a suitable lockable cap secured.

Backfilling of borehole

If not required for monitoring, the borehole should be backfilled with suitable spoil material. Suitable additional fill material must be used to ensure that the entire volume of the borehole is adequately backfilled. The addition of cement to the backfill material is strongly recommended.

Sealing of borehole

The upper 5 m of the borehole should be backfilled with concrete, and a concrete slab 1 m square should be cast over the backfilled borehole. This slab will prevent water ingress and the possible development of a sinkhole in karst terrain.

Marking and labelling

Boreholes drilled in the field must be marked with a marker pole at least 1 m high. The marker poles must be black and yellow, according to Eskom's specific needs. The marker pole must be secured to the ground with concrete. All boreholes should be clearly labelled with the following information, either printed on a platelet or written on the borehole cap:

- Number of the borehole;
- Depth drilled;
- Screen depth;
- Water strike depth;
- Blow yield;
- Date of drilling; and
- Drilling contractor.

Acceptance documents

After completing the borehole, the competent person shall produce acceptance documents and the drilling log for Eskom's signature. These documents shall include, among other things, the completed drilling log and details of any development work done.

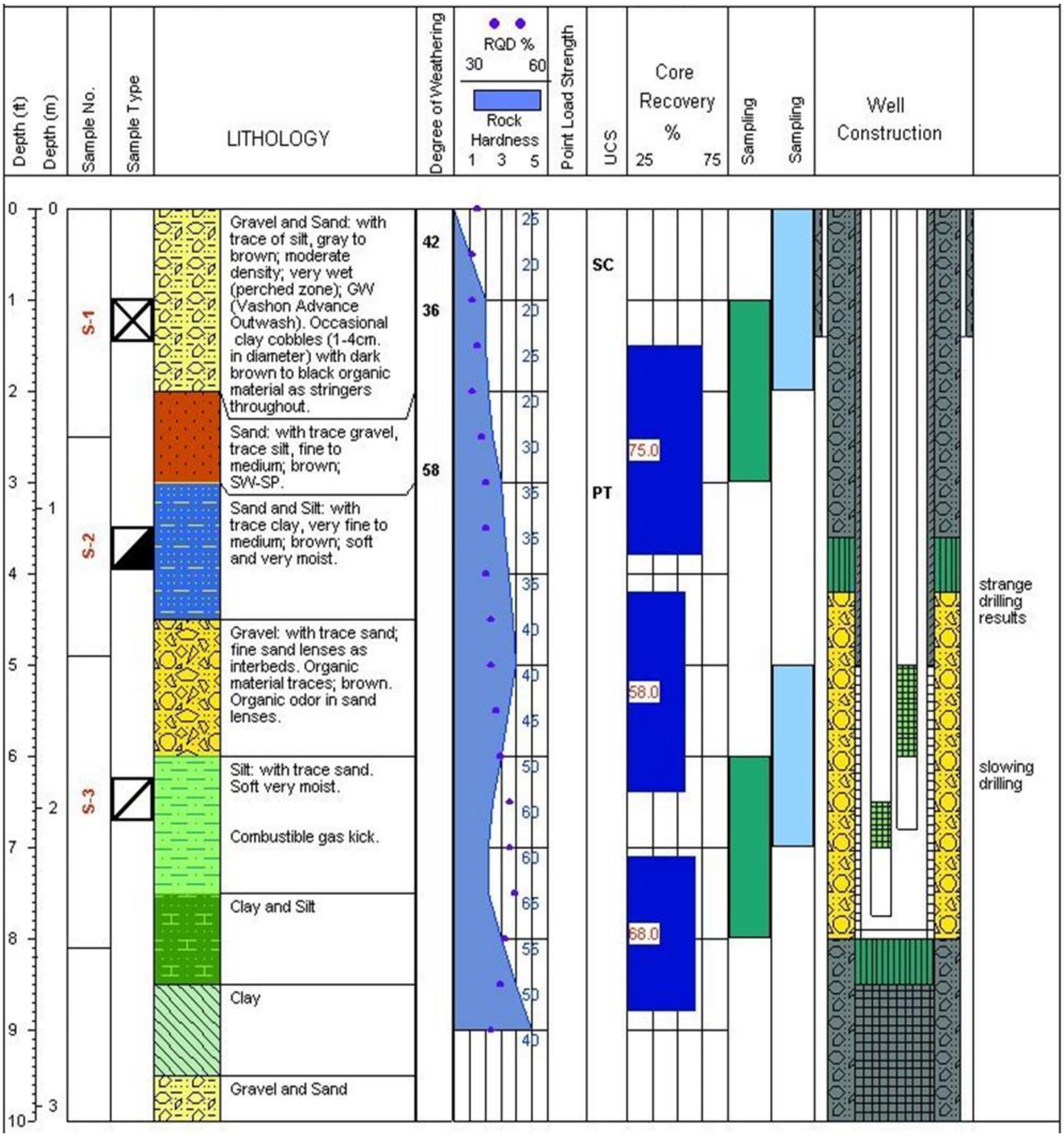
D: Reporting

When the drilling has been completed, a report should be written about the design and construction of the drilled boreholes. The report should include at least the following items:

- The considerations that led to the selection of the drilling positions;
- A map showing the location of the drilled boreholes as well as a description of the geology encountered;
- Lithological cross section if more than one borehole is drilled;
- The borehole logs, depicting the following information:
    - Hole and casing diameters;
    - Slotted and solid casing;
    - Chip size range;
    - Water strikes;
    - Water rest levels;
    - Penetration time;
    - Depth;
    - Borehole screen depths and design;
    - Blow yield;
    - Legend;
    - Geological description of each borehole drilled; and
    - Construction description of each borehole drilled.
- Tables of the field notes;

- A hydrogeological description describing features of importance to the groundwater resources (for example, cavities, fissures, fractures, water strike depths, blow yield);
- Photos of completed boreholes;
- Drilling record; and
- Intended use or purpose of the borehole.

Example of properly constructed borehole log



3.4 Aquifer Testing Guideline (GWG04)

Introduction

When working on groundwater flow problems, Eskom has to find reliable values for the hydraulic characteristics of the geological formations through which the groundwater is moving. Aquifer testing has proved to be one of the most effective ways of obtaining such values.

Purpose

The purpose of this guideline is to ensure that there are clearly defined process controls in place to evaluate an aquifer testing exercise. The guideline must be applied at all Eskom operations situated on fractured rock aquifers that require information on aquifer characteristics or where boreholes are required for water supply.[5]

General considerations

A: Aquifer test objectives

Aquifer test objectives should be defined as specifically as possible to avoid ambiguity in test design. The objectives affect many other aspects of an aquifer test, including the analysis methods used, schedule required, number of tests used and their properties, etc. The extent to which test objectives can be defined and the degree to which those objectives are accommodated in design, deployment and analysis directly affect the likelihood of success. Results that can be obtained from the aquifer test are the following:

- Groundwater resource evaluation, the aquifer parameters, that is, the ability of the aquifer to store and transmit groundwater;
- Flow directions and rates of contaminants within the aquifer;
- Existence of barriers or recharge boundaries;
- Spacing of production boreholes in the production borehole field;
- Borehole construction performance or borehole efficiency;
- Design of the production system, that is, the pump size and the reticulation system; and
- Information regarding the borehole’s sustainable yield.

B: Preparation

The preparation for aquifer testing is discussed in the following paragraphs.

[5] Eskom, 2014. Site Characterisation Guideline

B1: Legal considerations

Before embarking on the expense of an aquifer test, an Eskom site representative shall ensure that all legal requirements regarding the aquifer test on the property are reviewed and complied with. This shall include both surface rights, for example, as defined by local bylaws and the property title deed, and subsurface rights, for example,, relating to the intended exploitation of the groundwater resource in terms of the requirements of the National Water Act 36 of 1998.

B2: Environmental considerations

The Eskom site representative shall ensure that the appropriate consideration is given to the effect of the aquifer test on the environment, especially the potential discharge of contaminated water next to surface water resources or wetlands.

B3: Planning

Planning for the aquifer test is essential to avoid wasting time in the field. The following shall be completed before embarking on an aquifer test exercise:

- First, determine the purpose of the test. Different procedures are followed for the estimation of aquifer parameters and an estimation of the sustainable yield of a borehole;
- Notify the owner of the boreholes or the designated responsible officer in advance of the intended testing date(s) and time;
- Obtain a map showing the positions of the boreholes from the consultant; and
- Ensure beforehand that the borehole(s) to be tested are not blocked and are accessible for conducting the test. This could be done by physical inspection or contacting the owner or responsible person.

C: Slug test procedure

Slug tests are performed by “rapidly” changing water levels in a borehole. The rapid change is induced by adding or removing small quantities of water, air, or an object displacing groundwater. The time required to restore the water to its original level is used to calculate the permeability. Slug tests are typically performed in areas where access or budget is limited or where the extraction or addition of water potentially affects the surrounding area. Slug tests are appropriate where the aquifer will not yield enough water to conduct an aquifer test, or the introduction of water could change or affect the water quality. A major factor in conducting a slug test is ensuring that the water level during the test reflects the aquifer characteristics and is not unduly affected by the borehole construction.

Where the water is shallow and clean water is readily available, water injection or bailing is often the easiest method. The displacement or injection method may be desirable at locations where the water level is deep and rapid injection or removal of water is difficult. A number of slug test methods exist. The choice depends on the hydrologic and geologic conditions, borehole size, and construction.

C1: Selecting the slug test

The method of inducing a rise or fall in the water surface depends on the purpose of the test and conditions at the site. Where the water level is shallow and clean water is readily available, water injection or bailing is often the easiest method. One limitation of the test accuracy is the initial water flowing down the inside wall of the borehole. Dropping a slug to cause a rapid rise by displacing water in the borehole is preferable at remote sites where water may not be readily available. The displacement or air injection method may also be desirable at locations where the water level is deep. Rapid injection or removal of water may require collection and treatment or at borehole sites used for water chemistry studies.

C2: Field implementation

Before introducing the slug, the borehole sidewall, screen, or filter pack needs to be clear of any obstructions that will impede the movement of water from the riser to the surrounding materials. The borehole diameter and length need to be measured as accurately as possible, and the water level must be stabilised and recorded as accurately as possible. The water level measurements must begin immediately following the introduction of the slug or displacement.

Where the water level changes slowly, measurements may be made by using a water level indicator. For most tests, water levels should be recorded by a pressure transducer and automatic data logger.

C3: Test interpretation

The FC_EXCEL software is the simplest method of analysis. The FC software incorporates the method of determining the hydraulic conductivity of an aquifer developed by Bouwer and Rice (1976). Originally developed for unconfined aquifers, it has been found that it can also be used in confined aquifers, provided the top of the borehole is some distance below the bottom of the upper confining layer.

D: Tracer test procedure

In its simplest form, tracer testing can be defined as injecting one or more tracers, usually chemical compounds, into the subsurface to estimate its flow and storage properties. A tracer test is an indirect method for characterising aquifer properties. As stated above, tracer tests are used to characterise subsurface media. Tracers are usually chemical or radioactive compounds that flow in a fluid phase without altering the transport properties of the phase.

The advantage of tracer testing over other, direct means of characterisation is that the volume sampled can be designed to be at the appropriate scale of interest.

D1: General

Certain tracer requirements are site-independent. That is, the tracers must exhibit these properties to be considered a viable candidate. The tracer must be non-toxic, be detectable at low concentrations, be both available and affordable, and have low background concentrations in situ. Background concentrations may be because of the natural occurrence or the compounds' historical use. Because tracer compounds exhibit a wide range of behaviour (for example, reversible adsorption, diffusion from dead-end pores), one cannot simply conclude the tracer can be used if it has not been used recently. Elevated background concentrations are detrimental to the tracer's use.

D2: Tracer selection and testing

Having determined that a tracer test is a suitable method for obtaining answers to the questions at hand, candidate tracer compounds must then be screened for use. Tracer property requirements are detailed as follows:

- Non-toxic;
- Available and affordable;
- Good solubility for injection, low detection limits;
- Low natural background concentrations;
- Negligible effect on transport properties (density, viscosity, pH, etc.);
- Stable or well-characterised degradation;
- Thermal or radioactive decay acceptable;
- Photodegradation is unacceptable;
- Biodegradation is acceptable if appropriate for test goals (reactive tracer tests);
- Well-behaved partitioning over all concentrations;
- For conservative tracers, no partitioning;
- For partitioning tracers, constant, reversible partitioning;
- Adsorption is usually unacceptable unless appropriate for test goals;
- Site-specific properties (from column tests with site soil, water, contaminants);
- Equilibrium partitioning at field rates (that is, not rate-limited partitioning); and
- No ion exclusion or adsorption.

D3: Field implementation

Deploying a tracer test essentially requires following the test design steps discussed above, with a single additional concern. The borehole drilling technique, borehole design, and completion materials can impact the tracer tests. All aspects of borehole drilling and construction should be reviewed for a possible adverse impact on tracer tests, whether one is evaluating the suitability of an existing borehole or designing a new borehole for use in a tracer test. Using an existing borehole that is inappropriately drilled or completed for the test is false economy and may lead to incorrect test interpretation. The steps required to implement a tracer test in the field are discussed below.

- Consideration of tracer/borehole interaction;
- Review of borehole drilling, construction, completion, and materials;
- Review of borehole development;
- Establishing the expected flow field;
- Introduction of tracer;
- Sampling and analysing the required boreholes;
- Noting the results:
    - Lapsed period; and

- Concentration fluctuations.
- Noting the field observations:
    - Site conditions during the test;
    - Operations during the test; and
    - Deviations from the test plan.

D4: Test interpretation

A host of analysis methods are available. These can be generally categorised as qualitative, quantitative, and numerical methods, as described below.

Qualitative

Qualitative methods are usually yes/no analyses: either the tracer was recorded at a certain time or not. Under certain conditions, this analysis is the appropriate level of detail. However, it can be misleading if tracer properties are not adequately measured.

Quantitative

Quantitative methods for tracer test analysis rely on steady-state flow conditions and require calculating the tracer's mean residence time in the subsurface. Since this calculation is used throughout this section, it is reviewed below.

The mean residence time of a tracer, t, is also known as the first temporal moment of the tracer. It is the time-weighted average of a tracer history and is easily calculated from the tracer history itself. Defining C as the dimensionless concentration of the tracer and is as the time over which the tracer was injected (sometimes referred to as "slug size"), we can define the mean residence time as:

$$\bar{t} = \frac{\int_0^\infty Ctdt}{\int_0^\infty Cdt} - \frac{t_s}{2}$$

The integrals given above can be calculated in various ways. If the data is smooth, a curve can be fitted to the data and integrated analytically. Usually, however, the integration is approximated numerically in a spreadsheet.

Numerical methods

The use of numerical models has become a standard method of interpreting tracer tests. Known as history matching, for obvious reasons, the purpose is to simulate the test (injection and extraction operations, tracer details, boundary conditions, etc.) and match the tracer histories at each borehole by modifying the porous medium properties. A successful history match implies that the properties in the model are correct. Of course, successful is a subjective term, and the problem itself is mathematically ill posed. Nevertheless, it is a useful and insightful exercise under many conditions. A key point in interpreting numerical results is the importance of understanding the assumptions and limitations associated with the model itself.

History matching is done either manually or with inverse models. A manual history match is where the analyst runs a forward model (for example, fate and transport model), compares simulated results with tracer histories, and manually changes input parameters to the model. Inverse modelling does the same, but the parameter estimates are updated automatically in response to the calculated sensitivity of simulated response to changes in the parameter. Both methods require a large number of forwarding model runs. One advantage of automatic history matching programmes is that they provide statistics that describe the level of confidence one might have in the parameters estimated, including parameter uncertainty and sensitivity and error propagation. These statistics are useful in determining the extent to which tracer test objectives are met.

E: Packer test procedure

Packer testing is a technique in which one or more inflatable bladders, or packers, are used to isolate different regions of a borehole for hydraulic testing or water sampling. Packer tests are carried out to assess the variability of a borehole as it intersects various hydrogeological units. Open borehole water levels, slug tests, tracer tests, and pumping tests can give misleading results in such environments. Therefore, packer testing is often utilised to help understand the detailed hydrogeological properties of the various horizons. This knowledge can often be essential to the proper design of the CSM.

E1: Types of tests

Packer tests measure the rate of flow and/or pressure build-up/decay in the test interval over some time. The upper range of hydraulic conductivity that can be measured using packer systems will be limited by the hydraulics of the injection system (rate and pressure output limit of the pump, supply line [friction losses], water availability, etc.). Therefore, before starting the testing programme, it is important to determine the expected testing range of the zones of interest before finalising equipment.

Injection (Lujeon) tests

Injection testing methods, otherwise known as Lujeon tests, are carried out in drill holes with static water levels below ground level. Water is injected at specific pressure “steps”, and the resulting pressure is recorded when the flow has reached a quasi-steady-state condition.

The steps are used to “ramp” up and down through the expected pressure range. The reaction of the system to the increasing and recovery injection can produce useful information on the rock and fracture behaviour, as well as packer and injection performance.

Discharge tests

Discharge tests are carried out in boreholes with flowing artesian conditions. In these boreholes, the natural formation pressure response is monitored after the equilibrated shut-in is allowed to decay with respect to time. The data are plotted logarithmically and analysed using standard Jacob straight-line techniques.

Shut-in recovery tests

Shut-in recovery tests are usually run immediately following a discharge test. The shut-in pressure build-up over time is monitored and plotted against log10(t/t′), where it is the time elapsed since the start of the discharge test, and t′ is the time since the recovery test was started.

E2: Injection test interpretation

Data for each pressure step should be plotted on a flow rate vs pressure graph. The shape of the plot, especially with regard to the decreasing pressure curve match, is used to assess the test results. The data from the injection test can be used to determine the effective transmissivity (T) using the Thiem equation.

E3: Discharge test interpretation

The apparent transmissivity of the packer-isolated interval can be estimated from the time and discharge data using a modified Jacob-Lohman (straight-line) equation.

E4: Shut-in recovery test interpretation

The pressure readings are plotted against log10(t/t′), the log10 ratio of the time since the discharge test started (t) over the time since the recovery test has started (t′). The apparent transmissivity of the test interval can be estimated using the Cooper-Jacob method.

F: Pump testing procedure

A pumping test is conducted to evaluate an aquifer by "stimulating" the aquifer through constant pumping and observing the aquifer's "response" (drawdown) in the borehole or observation boreholes. Pump testing is the most common tool that hydrogeologists use to characterise a system of aquifers, aquitards, and flow system boundaries.

F1: Sizing the correct pump

Before beginning to install the pump, it is important to choose the correct pump size. This is done through the following procedures:

- If the blow yield is known, use this as a guide and install a pump of at least this capacity; and
- If no information is available, use a slug test to estimate the yield using the equation Q (L/h) = 117155 t - 0.824, where t (seconds) is the time to 90% recovery.

F2: Installation of the pump unit

- Upon arrival, manoeuvre the pump test unit so that it is directly above the borehole;
- Pitch the tripod stand;
- Record the borehole number, time, date, and any other relevant observations in the field notebook;
- Remove the borehole cover carefully, inspect the borehole, and record abnormalities observed and remove the cap of the borehole if present;
- Measure and record the collar height of the borehole;
- From the top of the collar, measure the following:
  - Depth of the borehole to ensure that the borehole has not collapsed and/or that no foreign objects have been dropped into the hole;
  - Depth of the static groundwater level to an accuracy of 1 mm; and
  - Note that all depth measurements are made from the top of the collar.
- Install the pump to approximately 2 m above the bottom of the borehole or, if the fracture depth is known, then just above; and
- Secure the pump outlet at least 50 m or more away from the borehole to prevent recharge of the borehole from above ground.

F3: Calibration test

Regardless of the purpose of the test, a calibration test needs to be done to determine information on the abstraction of the borehole and blow yields. Once the pump is installed and the generator is started, a four-step calibration test must be done.

- For 15 minutes, pump at a rate of no more than one-third of the blow yield:
  - Note the pumping rate; and
  - Continuously measure the depth of the water table and note the time elapsed in minutes.
- For the next 15 minutes, pump at two-thirds of the blow yield rate:
  - Note the pumping rate; and
  - Continuously measure the depth of the water table and note the time elapsed in minutes.
- For the next 15 minutes, pump at the blow yield rate:
  - Note the pumping rate; and
  - Continuously measure the depth of the water table and note the time elapsed in minutes.
- For the next 15 minutes, pump at the maximum rate possible for the pump:
  - Note the pumping rate; and
  - Continuously measure the depth of the water table and note the time elapsed in minutes.
- Switch off the pump and measure the recovery of the borehole with the dip meter at the same time intervals as for pumping;
- It can be assumed that enough data has been gathered when the depth of the water in the borehole has recovered to 95% or twice the time of the pump test; and
- Plot the data from the calibration test in a graph of time vs depth to water level.

F4: Step test

A step test is a requirement if the sustainable yield of a borehole needs to be determined. The purpose of this test is to determine the borehole efficiency under stress.

With the pump installed as above, perform the following actions:

- Measure the static water level;
- Switch on the pump at the lowest rate determined from the calibration test;
- Measure the rate of drawdown of the water level at the prescribed schedule as listed in the field data sheets;
- Measure the discharge rate from the pump at the beginning of the test. Thereafter, measure it at 7, 15, and 60 minutes, then measure the discharge rate whenever water level measurements are taken;

- Measure and record the actual pumping rate during each step of the test;
- Continue for a recommended period of 60 minutes;
- Once 60 minutes has elapsed, increase the pumping rate to the next rate determined from the calibration test;
- Repeat the procedures above for at least three steps; and
- Once the test is complete, immediately measure the water level recovery rate until the depth of the water in the borehole has recovered to 95%.

F5: Constant discharge test

If the objective of the test is to estimate aquifer parameters, a constant rate test must be conducted. From the step test, acquire the locations of main water strikes and fractures, and choose a pumping rate that will not allow the dewatering of these water-yielding structures.

If the objective of the test is to estimate sustainable yield, use the results from the step test to acquire the locations of main water strikes and fractures. Choose a pumping rate that will just allow the dewatering of these water-yielding structures.

With the chosen pumping rate, execute the following actions:

- Measure the static water level;
- Start the pump and measure the drawdown of the water level;
- Record the water levels over at least eight hours (a longer period may be necessary depending on the interpretability of the drawdown curves);
- Measure the water levels at logarithmic time intervals;
- Measure the discharge rate from the pump at the beginning of the test. Thereafter, measure it at 7, 15, 60, 120, and 180 minutes, then measure the discharge rate whenever water level measurements are taken;
- Once the prescribed time has elapsed, stop the pump and immediately measure the recovery. Recovery must be measured at the same time intervals as during pumping; and
- Collect a water sample from the borehole to submit to a laboratory for analysis for macro determinants, as a minimum: pH, Total Dissolved Solids (TDS), electrical conductivity (EC), Ca, Mg, Na, K, HCO_3, SO_4, Cl, NO_3, F, Fe, Mn.

F6: Recovery test

The results gained from the recovery test are used to determine the aquifer parameters and to determine how rapidly the water level recovers. The recovery test is done after a step-drawdown test or a constant discharge test (or both), as required by the consultant. Ensure that the discharge pipeline from the test pump is fitted with a non-return valve and that the water in the discharge pipeline does not return to the borehole since this would result in incorrect observations.

At the end of the pumping test (constant discharge test or step-drawdown test [or both]), switch off the pump and immediately start collecting residual drawdown readings at the intervals as during pumping:

- The water level recovers to less than 5% of the total drawdown during the constant discharge test;
- At least three readings taken in succession are identical; or
- A time equal to the total time taken for the constant discharge test has elapsed.

F7: Observation boreholes

Specific yield (in unconfined aquifers) and storage capacity (in confined aquifers) can only be calculated from water levels or time data obtained from observation boreholes. The direction and distance of observation boreholes from the pumping borehole are site-specific and must be determined by the project geohydrologist.

However, if no project specifications exist, bear the following in mind:

- If there is a borehole close to the borehole to be tested, water level observations collected from the adjacent observation borehole while the test borehole is being test-pumped will provide valuable information;
- If the observation borehole is used for pumping purposes, switch off its pump at least a day before aquifer testing the test borehole and do not allow it to be restarted until after the water level recovery test has been completed; and
- Measure the distance, in metres, between the two boreholes and record the information.

F8: Aquifer testing interpretation

Calculating hydraulic characteristics would be relatively easy if the aquifer system (that is, aquifer plus borehole) were precisely known. This is generally not the case, so interpreting an aquifer test is primarily a matter of identifying an unknown system. System identification relies on models, the characteristics of which are assumed to represent the characteristics of the real aquifer system.

Theoretical models comprise the type of aquifer and initial and boundary conditions. In an aquifer test, the type of aquifer and the inner and outer boundary conditions dominate at different times during the test. They affect the drawdown behaviour of the system in their ways. Therefore, to identify an aquifer system, one must compare its drawdown behaviour with that of the various theoretical models. The model that compares best with the real system is then selected to calculate the hydraulic characteristics.

System identification includes the construction of diagnostic plots and specialised plots. Diagnostic plots are log-log plots of the drawdown versus the time since the test started. Specialised plots are semi-log plots of drawdown versus time or drawdown versus distance to the borehole. They are specific to a given flow regime. A diagnostic plot allows the dominating flow regimes to be identified. These yield straight lines on specialised plots. The characteristic shapes of the curves can help in selecting the appropriate model. In a number of cases, a semi-log plot of drawdown versus time has more diagnostic value than a log-log plot.

We, therefore, recommend that both types of graphs be constructed. The choice of a theoretical model is a crucial step in interpreting pumping tests. If the wrong model is chosen, the hydraulic characteristics calculated for the real aquifer will not be correct. A troublesome fact is that theoretical solutions to flow problems are usually not unique. Some models, developed for different aquifer systems, yield similar responses to given stress exerted on them. This makes system identification and model selection a difficult affair. One can reduce the number of alternatives by conducting more fieldwork, but that could make the total costs of the test prohibitive.

G: Reporting

When the evaluation of the aquifer test data has been completed through the correct and applicable theoretical model or analysis, a report should be written about the results. The report should include at least the following items:

- A map showing the location of the test site, the borehole, and the piezometers and recharge and barrier boundaries, if any;
- A lithological cross section of the test site, based on the data obtained from the boreholes and showing the depth of the borehole screen and the number, depth, and distances of the observation boreholes;
- Tables of the field measurements made of the discharge/displacement and the water levels in the borehole and the piezometers;
- Hydrographs, illustrating the corrections applied to the observed data, if applicable;
- Time-drawdown/Displacement/Recovery curves and distance-drawdown curves;
- The considerations that led to the selection of the theoretical model used for the analysis;
- The calculations and interpretation in an abbreviated form, including the values obtained for the aquifer characteristics and a discussion of their accuracy, such as:
    - Water levels;
    - Boundary conditions;
    - Transmissivity values;
    - Sustainable yield;
    - Long-term dewatering extent (cone of depression);
    - Storage capacity (confined aquifers); and
    - Specific yield (unconfined aquifers);
- Borehole water quality results compared to DWS standards; and
- Recommendations for further investigations, if applicable.

H: Aquifer test data templates

SLUG / BAIL TESTS

Project Details											
Site Name:				Client:				Project Number:			
Site Details											
Site Address:				Date:				Test By:			
Borehole Details											
Hole Number:		Hole Number:		Hole Number:		Hole Number:		Hole Number:		Hole Number:	
Depth of hole:		Depth of hole:		Depth of hole:		Depth of hole:		Depth of hole:		Depth of hole:	
Time:		Time:		Time:		Time:		Time:		Time:	
Free Phase:		Free Phase:		Free Phase:		Free Phase:		Free Phase:		Free Phase:	
S. W. L. :		S. W. L. :		S. W. L. :		S. W. L. :		S. W. L. :		S. W. L. :	
Casing height:		Casing height:		Casing height:		Casing height:		Casing height:		Casing height:	
Auto Level (Dumpy):		Auto Level (Dumpy):		Auto Level (Dumpy):		Auto Level (Dumpy):		Auto Level (Dumpy):		Auto Level (Dumpy):	
Hole dia. (mm):		Hole dia. (mm):		Hole dia. (mm):		Hole dia. (mm):		Hole dia. (mm):		Hole dia. (mm):	
Time (s)	Depth (m)	Time (s)	Depth (m)	Time (s)	Depth (m)	Time (s)	Depth (m)	Time (s)	Depth (m)	Time (s)	Depth (m)

STEP TESTS

Project Details

Name:

Site

Site Details

Site Coordinates: **Date:** **Test By:**

Hole Details

Hole Number:

Depth of hole:

Time:

S. W. L. :

Casing height:

Hole dia. (mm):

Drawdown - Step

Time (s)	Depth (m)	Yield (l/s)

Recovery

Time (s)	Depth (m)

3.5 Groundwater Monitoring Guideline (GWG05a)

Introduction

Groundwater monitoring is the meaningful measurement of variables and can be done through the following:

- A once-off test during initial impact assessments;
- Routine tests as part of compliance with permit conditions; or
- Ongoing groundwater investigations to quantify the impact.

Groundwater monitoring should be done within a designed monitoring network consisting of positions that can assess the groundwater status in certain areas. A monitoring point should represent the response of a groundwater system or the system as a whole to the stresses upon it. Examples of such stresses are the drawdown of the water table caused by pumping or contamination of the groundwater system by contamination sources, such as ash dumps or coal stockyards.

A site-specific monitoring network is intended for a single waste management facility, whereas regional monitoring relates to a combination of waste management facilities, such as those usually present at power stations.

Purpose

The purpose of this guideline is to ensure that there are clearly defined process controls in place for Eskom personnel to evaluate groundwater monitoring requirements and networks. The intended use of the guideline is for Eskom personnel to evaluate monitoring requirements and networks as well as to guide consulting scientists on conducting groundwater monitoring. The guideline must be applied at all Eskom operations that require groundwater monitoring.

Designing a site-specific monitoring network

A monitoring network involves monitoring point-specific (site-specific) sources, which could affect groundwater by over-abstraction or polluting activities (that is, quality and quantity monitoring of groundwater). Generally, the user will do this level of monitoring as a condition attached to the licence or water authorisation.

A: Monitoring objectives

When developing a monitoring network, it is important that the purpose of monitoring be well defined and communicated to the stakeholders who need to support the monitoring efforts. It is critical that monitoring needs are established at the outset and that all participants in groundwater monitoring, from the monitoring system designer to the sampling technicians and data capturers, understand the monitoring needs. No data should be collected simply for the sake of populating databases. Monitoring can be an expensive exercise and can only be valuable if the information generated is useful for purposes such as:

- The protection of an aquifer from damage. Over pumping causes long-term depletion of groundwater and can damage the aquifer. Water quality can decline because of over pumping;
- Quality monitoring will determine if the aquifer is being contaminated from sources, such as ash dumps, coal stockyards, etc.;
- Understanding aquifer flow dynamics (that is, recharge quantification, natural flow patterns, and residence times of groundwater);
- The protection of the quality and quantity of water required satisfying the basic human need component of the groundwater reserve;
- Monitoring can also be used to estimate flooding/stage curves, time to decant and decant rates;
- The protection of groundwater dependant ecosystems as part of the ecological reserve;
- Quantifying the effectiveness of contamination prevention measures;
- Quantifying the effectiveness of remediation measures; and
- Acting as an early warning system to avoid unnecessary future remediation.

The information can be used for various purposes, for example, being incorporated in water-balance calculations or models used to prepare graphic presentations that communicate useful information to DWS or affected parties, producing practical resource operational tools for risk management or as justification for management decisions.

Groundwater monitoring data should be used to support decisions for taking actions that might lead to the improvement of resource protection and management. Information collected through groundwater monitoring programmes may also be useful in refining resource classification, delineating future protection zones, or updating RQOs.

B: Iterative approach

Monitoring system design is not a once-off activity. It requires regular updating and refinement to ensure that the data collection procedures are valid and provide valuable information to meet the monitoring objectives. The data collection and capture to information systems must be followed by a phase of data analysis and interpretation. During this assessment phase, data gaps should be identified and the successes and shortcomings highlighted for feedback into the next cycle of monitoring system design.

C: Monitoring procedure

The assessment and monitoring process comprises a series of linked steps discussed below.

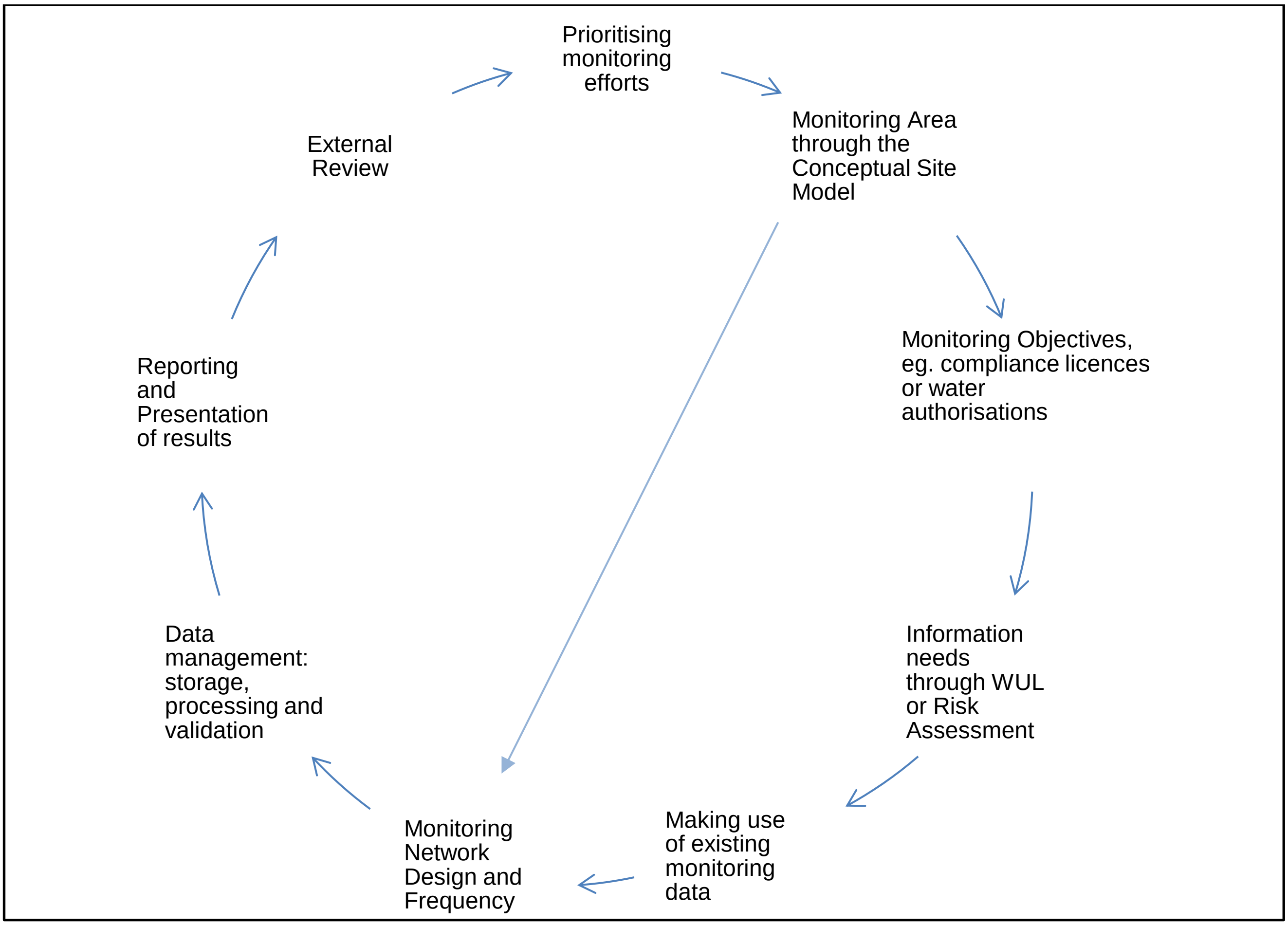


Figure 2: Monitoring procedure cycle

C1: Prioritising monitoring efforts

One way of setting monitoring priorities is by using a risk assessment. Therefore, the monitoring will be to quantify the risk through quantification of the groundwater hazard, the probability that the hazard will occur, and the consequence of the groundwater hazard.

C2: Definition of the monitoring area

The first and most critical component of a monitoring network is developing a suitable, detailed CSM to address groundwater concerns. The CSM is arguably the most important step in the monitoring process as it defines the questions that need to be answered by monitoring, the design of the sampling programme, the tools and techniques to be applied in the prediction, and the various assumptions and data values that will be used in the monitoring programmes. As a general principle, the area to be monitored should be defined on hydrological or hydrogeological criteria, which should be defined in turn by the CSM.

C3: Set monitoring objectives

Decide on monitoring objectives, that is, compliance with licensing or water authorisation conditions for quality and quantity of water.

C4: Defining information needs

An early step in the preliminary stages of planning and implementation of a monitoring programme is to define the information needed as a basis for managing the quantity and quality of groundwater. This means deciding who (from a broad range of potential stakeholders) wishes or requires to be informed about groundwater, what types of information they need and for what purposes. In general, the WUL or risk assessment will define the information needs for Eskom.

C5: Making use of existing data

The strategy for designing a monitoring and assessment programme should consider existing information. At an early stage, inventories should bring together available information but is often distributed between different agencies and institutions or their various departments.

Inventories should cover the major aspects relevant to the identification and analysis of issues. These include, for example, water uses and water needs, groundwater levels, groundwater quality, land uses, and non-point contamination sources from land use, such as fertilisers and pesticides. Water quality surveys are intended to give a first insight into the functioning of the aquatic ecosystem and the occurrence of contamination and its impacts on groundwater systems. The availability of existing groundwater levels and quality records should also be considered when designing the monitoring network and selecting sites as maintaining long-term series is likely to be an important monitoring objective.

C6: Contamination network design

The conceptual model and risk assessment should be used to structure the network design based on a geophysical survey. A groundwater monitoring network should contain monitoring positions, which can assess the groundwater status in certain areas. Boreholes can be grouped/classified according to the purposes discussed below. Figure 6 illustrates an ideal constructed monitoring network around a single source term.

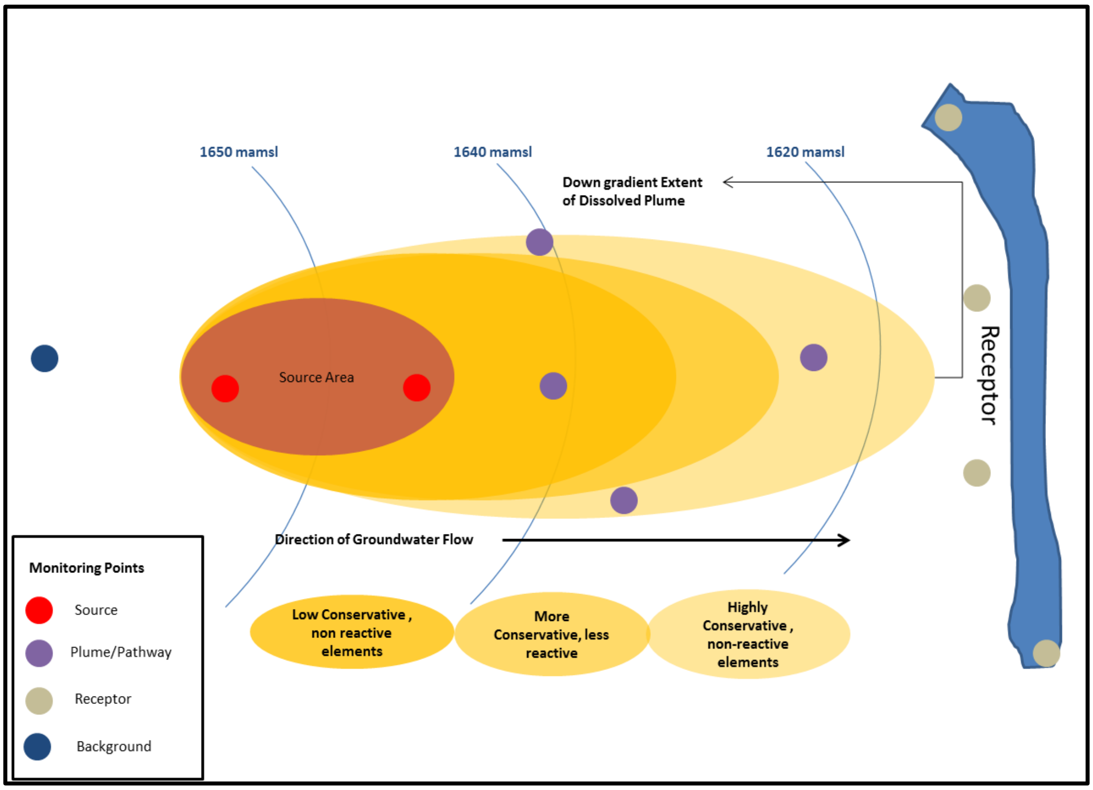


Figure 3: Plan view of an example of a monitoring network (not to scale)

Source monitoring

Monitoring boreholes should be placed close to or in the source of contamination to evaluate the impact thereof on the groundwater chemistry. Typical placement around sources should be as follows:

- Coal stockpiles (2-3 boreholes);
- Ash disposal facilities (2-3 boreholes); and
- Dirty water systems (2-3 boreholes).

Plume monitoring

Monitoring boreholes are placed in the primary groundwater plume's migration path to evaluate the migration rates and chemical changes along the pathway.

- Coal stockpiles (2-3 boreholes in the primary plume's migration path);
- Ash disposal facilities ((2-3 boreholes in the primary plume's migration path); and
- Dirty water systems ((2-3 boreholes in the primary plume's migration path).

Impact monitoring

Monitoring possible impacts of contaminated groundwater on sensitive ecosystems or other receptors is essential. These monitoring points are also installed as early warning systems for contamination breakthrough at areas of concern.

- Designated boreholes between the plume and critical receptors;
- Streams and wetlands (upstream down, midstream, and downstream of the source); and
- Privately owned boreholes identified by the hydrocensus and conceptual model.

Background monitoring

Background groundwater quality is essential to evaluate the impact of a specific action/contamination source on the groundwater chemistry.

- Boreholes upstream of any contamination plumes and within the quaternary catchment unaffected by anthropogenic activities (effects of human activity).

C7: System response monitoring network

Groundwater levels: The response of water levels to abstraction is monitored. Static water levels are also used to determine the flow direction and hydraulic gradient within an aquifer. Where possible, all of the water levels of the abovementioned borehole need to be recorded during each monitoring event.

C8: Monitoring borehole design

The main objective of placing a monitoring borehole is to intersect groundwater moving away and evaluate the concentration of fluctuation from a contamination source as defined by the conceptual model and risk assessment.

Porous flow aquifers

In porous flow aquifers, monitoring boreholes should be located on either side of the waste facility in the direction of the groundwater gradient. If very little is known about the groundwater gradient, at least one monitoring borehole should also be placed at the lowest topographical point. In cases where the aquifer consists of weathered granite or other igneous rock, geophysical methods should be used to determine the size, shape, and orientation of the aquifer.

Fracture flow aquifers

Fractures and other lineaments, such as dolerite dykes, may be identified by using aerial photos, satellite images, and airborne magnetics followed by a ground geophysics survey. These are specialised techniques and should preferably be applied by a geohydrologist.

Borehole construction and design

The local geology dictates the borehole construction, while the design will be based on the use of the borehole and monitoring requirements. A competent hydrogeologist should monitor borehole design and construction.

<u>Borehole type</u>

Boreholes must be drilled employing a drilling technique that will not introduce contamination into the aquifer. Air-percussion drilling, without the addition of chemicals, is recommended. This allows the collection of rock chips and measurement of water yield while drilling. In instances of difficult drilling, degradable chemicals may be introduced. Upon completion of drilling, the hole and the inside of the casing should be flushed.

<u>Borehole diameter</u>

Monitoring boreholes must be of a diameter that will allow easy access to the aquifer for water sampling and lowering other test instruments. For newly drilled monitoring holes, a diameter of 110 to 165 mm is suggested.

<u>Borehole depth</u>

A monitoring hole must be such that the section of the groundwater most likely to be polluted first is suitably penetrated to ensure the most realistic monitoring results. This implies that monitoring holes will at least extend through the weathered zone, the aquifer below, and 5 m into the non-water-yielding formation deeper down. The latter is intended to act as a sump where material that falls down the borehole will accumulate without affecting the performance of the monitoring system.

Groundwater depth commonly ranges from 5 to 10 m below the surface in high rainfall areas (Mpumalanga) to more than 50 m below the surface in dry areas (Namaqualand). Weathering can be recognised by the brownish discoloration of the rock. Commonly, weathering extends to 5 to 15 m below the surface. A depth of 40 to 60 m for boreholes monitoring groundwater quality should therefore be sufficient, except in special instances.

<u>Casing, screens, and filters</u>

As surface water contamination sources, such as ash dumps, usually create a perched aquifer surrounding the dump, it is important to construct the source boreholes in such a way that the shallow weathered aquifers, as well as the deeper fractured aquifer, are measured separately. The materials used for casing, screens, and filters in contact with water must be compatible with and resistant to chemical attack by the water being monitored.

- Casing, screens, and filters must allow easy access for monitoring purposes and may in no way block the flow of water through the borehole.
- The top of a casing in a monitoring borehole should rise from 30 to 40 cm above the general ground surface to ensure that surface run-off does not flow into the borehole during flood conditions.
- The casing should preferably be of slotted PVC or a polymer suitable for the particular application, protected by a short steel casing at the surface.

- Where monitoring boreholes are to be installed in loose material such as sand, gravel, deposited waste, or rock spoil, the collapse of the boreholes may have to be prevented by means of properly designed borehole screens.
- A security cap must be fitted to prevent accidental or wilful interference with a monitoring borehole. Caps fitted with bolts or secured by other mechanical means may have an advantage over locks that can be broken and vandalised.
- The borehole number should be engraved onto the cap and casing or stamped onto a suitable rustproof tag set into the concrete block.
- The bottom of the casing should extend only a couple of metres into the solid rock. If the groundwater level is shallow and is likely to rise within the casing, the casing must be slotted to ensure lateral groundwater flow. A minimum slot density of 1% is required.
- A concrete block around the top of the casing, to protect the casing and borehole, as well as to prevent surface contamination from flowing down the side of the casing, is essential. The required minimum dimensions for the concrete block are 750 mm x 750 mm x 150 mm.

Borehole protection

Monitoring boreholes must be adequately protected to prevent accidental damage to the boreholes. Destruction of a monitoring facility results in a break in the data sequence. Securing monitoring boreholes should therefore be a high priority. It is recommended that monitoring boreholes be secured by fencing. Sufficient markings should be posted to prevent accidental damage to the boreholes.

C9: Springs, boreholes, dams, pans, streams, and rivers

Water sources around the Eskom site, within a radius as suggested by the risk assessment, must be sampled and preserved for chemical analysis. Flow from springs and in streams must be estimated. If contamination occurs because of waste management, then continuous recording of flow and water quality should be done.

C10: Monitoring parameters

Water samples must be analysed by a recognised analytical laboratory that uses approved analytical procedures. When permits have been issued, permit conditions will specify analyses and constituents to be tested for. The range of elements that may be found by analysing a waste environment is very extensive. For this document, the required analysis is grouped under two headings:

- Comprehensive analysis; and
- Indicator analysis.

Comprehensive analysis

For all new sites and first-time monitoring at existing sites, a comprehensive analysis is required. Accurate background levels must be established at the outset for as wide a range of constituents as possible. This will usually include a complete macro-analysis and an analysis for the trace elements, such as chromium and mercury at power stations and selected isotopes at nuclear facilities.

The comprehensive analysis should be repeated on the closure of the operation and during the operational period at least every 3 to 5 years or as guided by the risk posed.

Indicator analysis

Indicator analysis may be performed once comprehensive analyses have been completed. This process may continue until undesirable trends are uncovered. This will keep analytical costs to a minimum but still provide enough information upon which further action can be initiated, if necessary. Depending on the type of waste handled, so-called "contamination indicators" for Eskom may be identified. Examples are the following:

- General and special variables for discharge of Eskom effluent into public streams, such as pH, EC, TDS, SO_4, Fe, Al, Mn, COD;
- The so-called sewage variables, such as pH, TDS, COD, NH_4, NO_3, PO_4, *E. coli;*
- Hazardous waste disposal variables, such as pH, TDS, COD, VOC, THM, Cr^{6+};
- General waste disposal variables, such as COD, Cl, NO_3, NH_4;
- Mine contamination variables, such as pH, EC, TDS, SO4, Fe, Al, Mn;
- Ash disposal facilities, such as pH, Na, K, Cl, Mg, EC, TDS, SO_4, Fe, Al, Mn (Class I: Eu, Hf, La, Mn, Rb, Se, Sm, Th, Zr and Me, Class II: B, Se, I, As, Cd, Ga, Ge, Pb, Sb, Sn, Te, Ti, Zn, Ba, Be, Bi, Co, Cr, Cs, Cu, Mo, Ni, and Sr, Class III: Hg, Br and Cl);
- Coal stockyard contamination variables, such as pH, EC, TDS, SO_4, Fe, Al, Mn;
- Coal-fired power station contamination variables, such as pH, EC, TDS, SO_4, Fe, Al, Mn;
- Nuclear power station contamination variables, such as specified isotopes, pH, EC, TDS; and
- Hydrocarbon contamination variables, such as Gasoline Range Organics, Diesel Range Organics, Polycyclic Aromatic Compounds, Polychlorinated Biphenyl for Transformer areas.

C11: Monitoring frequency

This step addresses the "when to monitor" question. Once the location of the monitoring points and the parameters to be measured have been defined, it will be necessary to define the frequency of the measurements. The frequency of measurement depends on whether continuous or intermittent (grab sampling) data are required. The following factors will usually influence this decision:

- Importance of the monitoring point, for example, is it a regulatory compliance monitoring point? Is it necessary to obtain a precise understanding of variability with time? Is it a discharge point?
- The duration into the future over which data will be required from that point. This should take into account the life of the operation, which includes planning, construction, operation, decommissioning, closure, and after closure;
- Expected variability in quality or flow at that point (surface points are more variable and can change in minutes whereas groundwater is a slow-moving medium and significant changes in water quality are not expected in days or even months unless significant dewatering or infiltration occurs); and
- The available monitoring budget.

For Eskom, the monitoring frequency will be stipulated by the WUL. If a WUL has not been issued, monitoring frequency must be based on the risk assessment. Good practice at active or newly built power stations and mining operations should be every three months for ground and surface water. For other operations, such as gas turbines, six-monthly monitoring during the high and low rainfall seasons should be sufficient.

C13: Data management through storage, processing, and validation

Data management is especially important as a continuation of systematic groundwater monitoring, as it improves access and exchange of data, uniformity in storage and processing, and integrity of the data.

Introduction to data management

Data management is a broad term that, when applied to hydrogeological data, covers the life cycle of data from “cradle to grave”. This incorporates how data are managed from the point of collection through reporting the data to stakeholders and all of the intervening steps. These intervening steps include storage, processing, analysis, and validation.

The purpose of a data management system for Eskom is to allow for the effective use of the data while ensuring its integrity and providing a centralised repository for storage. One of the major consequences of not having a data management system is that the data cannot be fully trusted because it has not undergone any rigorous or defined validation efforts. Without a data management system, erroneous data can be introduced, and errors can be inserted into existing data.

The aspects of data management presented here are:

- Data storage;
- Data processing;
- Data presentation; and
- Data validation.

Whereas the first three processes are data handling processes, data validation is a quality assurance process aimed at improving data integrity. Data validation is a very important activity in relation to groundwater monitoring as it assures the quality of the data sets collected through the monitoring programmes.

Data storage

Standardisation of data format

Very often at Eskom, data is in different formats, meaning that their immediate use is inhibited until some form of data normalisation is performed. This concern can be overcome by adopting a consistent electronic data format (EDF). A key part of selecting a suitable EDF is ensuring that its use will not lock the user into one software system but will allow the user to switch freely between systems if he or she so chooses.

Data types

Raw hydrogeological data can be described as being point data. Point data is the data that is generated at a specific geographical point. In hydrogeological terms, this data may take many forms. Examples are:

- Geological data, such as borehole logs;
- Hydrogeological data, such as depths to water and yields;
- Construction data, such as casing, piezometer, borehole development, and costs;
- Type of equipment, such as pumping equipment and recorders;
- Geophysical data, including surface and borehole measurements;
- Hydraulic properties of the aquifer(s), such as transmissivity and storage;
- Water abstraction and groundwater level records;
- Hydrochemistry; and
- Other information, such as topography and surface drainage.

Ideally, all of the information listed above should be stored electronically and in a central repository so that it can subsequently be processed in preparation for its presentation.

Data processing

Data processing is the mechanism by which point data are transformed into spatial information, time series, or statistics. The processing of data should allow for the interpretation of the groundwater resource. The type of data processing that would be applied to the database for Eskom should include the following:

Groundwater levels

Common ways of presenting groundwater level data are by means of contour maps (spatial image) or hydrographs (time series). Groundwater level contour maps show the water level elevation with respect to a reference level, usually mean sea level. Contour maps may be of a single date or show the average value over a period, and they may show groundwater levels or depth to groundwater. Water level values should be plotted on the map along with the borehole identifier and should be plotted separately for each distinct hydrostratigraphic unit. The date or period of measurement(s) should be shown on the map.

Groundwater chemistry

Water quality diagrams should be constructed to assess the water type. Classification and evaluation of water types are key components to understanding hydrogeology and should not be overlooked. It is recommended that at least a graphical representation of the major ion chemistry be prepared using interpretive plots such as Pie, Piper, expanded Durov, Stiff diagrams, and Time-series plots. These plots can help characterise the groundwater and illustrate changes in the hydrochemical facies. Care should be taken to evaluate the water chemistry of samples for similar dates because of the temporal characteristics of the water. A water sample collected from a non-arid environment will likely exhibit different characteristics at the end of summer than during the rainy season.

C14: Data validation

Data validation is an integral process of a groundwater data management strategy. Its purpose is to ensure the integrity of the data and ensure that errors are not introduced during the transmittal, reduction, storage, and subsequent manipulation. Validation of data is performed within various stages of the groundwater data management process.

Standard operating procedures

Standard operating procedures (SOPs) are reports or manuals that describe the protocols for collecting and analysing data. Their purpose is to improve data collection and data quality, including uniformity, consistency, and completeness of data sets. The protocols will enable Eskom technical personnel to understand and replicate the work at hand and force the consultant to conduct complete and thorough surveys. SOPs should be established at the outset of an investigation to establish that work has been conducted to a consistent and scientifically defensible standard.

Field data collection

Certain steps can be taken in the field to ensure that basic hydrogeological information is captured. One common method for capturing this basic data is to ensure that Eskom field data sheets contain mandatory fields.

Laboratory quality assurance and quality control (QA/QC)

Laboratory QA/QC procedures involve the process of running a series of diagnostic checks on the data to ensure its integrity. This task is the responsibility of the analytical laboratory and should include the following:

- Does the data meet the reporting limits?
- Do the sample identifiers match those sent into the laboratory?
- Do the methods analysed match the inventory?
- Have all analyses been delivered for each sample?
- Do the units of the result match the sample matrix?
- Were any additional methods run?
- Are the analysed identifiers correct?
- Is the logic correct for the reporting limit, minimum detection limit, and result?
- Do the result qualifiers meet the logic requirements?

There are specific steps that the consultant or Eskom can undertake to supplement the diagnostic checks performed by the laboratory. These steps are listed below:

- The COC, which contains instructions to the laboratory regarding analysis of field samples, should be reviewed for completeness, accuracy, and legibility no later than one day after the samples have been sent to the laboratory;
- Any errors in or adjustments to the COC must be immediately corrected and the laboratory must be informed of such errors or changes;
- The person responsible for communication with the laboratory should contact the laboratory at least once before the end of the holding times to ensure the work is proceeding as planned;
- When data packages are received from the laboratory, the data package will be reviewed to ensure that the laboratory has provided all the information requested on the COC;
- Laboratory data should be received in the prescribed electronic format;
- The person in charge should review the laboratory QA/QC data to ensure that all precision, accuracy, and completeness protocols have been achieved; and
- If there is a reason to doubt laboratory results, have at least some of the analyses done by a second laboratory?

Data quality validation

These are checks performed by the consultant beyond any internal checks by analytical laboratories.

<u>Water level validation</u>

This type of validation may be performed by visual inspection of the data and is intended to catch errors. Some examples in the case of groundwater level data are:

- A recorded depth to water that is greater than the depth of the borehole;
- Errors because of a wrong reading (mistakes in readings by 0,5 or 1,0 metres);
- Errors because of a change in the height of the measuring point; and
- Errors because of assigning the groundwater level measurement to the wrong borehole or screen.

The visual inspection usually identifies suspect groundwater levels, which can be confirmed as erroneous only by comparing with other groundwater levels measured in the same area at the same time.

<u>Water quality validation</u>

Concerning groundwater, quality data, and specific data, checks can be conducted beyond the steps described for determining the integrity of data from the laboratory. Omitting these checks may lead to incorrect interpretation of data. The following are some basic checks that employ common-sense evaluation of the data.

- Because groundwater is electrically neutral, the ratio of cations and anions (in meq/ℓ) should be one (1). Although rarely one, a tolerance of 5% is accepted in most cases. If a balance of one is achieved, it does not necessarily mean that the analysis is correct. It is possible that there is more than one error and that they cancel each other out;

- Ensure that all major ions have been analysed. An omission of one may account for an unexpected cation/anion ratio;
- The numerical value of the TDS (mg/l) should be in the order of 70% of the EC (μS/cm);
- Na and Cl ratio: Normally, in sodium-dominated waters, most of the Na is associated with Cl, and thus, the ratio between Na and Cl (in meq/ℓ) should remain between 0,8 and 1,2;
- EC and TDS ratio: Fresh-water conductivity (EC, in μmhos/cm) and TDS (TDS in mg/ℓ) usually obey the following relationship: TDS = EC x a. Where 'a' ranges from 0,55 to 0,9, the constant 'a' is usually high for chloride-rich waters and low for sulphate-rich waters; and
- COD and BOD ratio: Values measured for COD should always be higher than BOD values.

C15: Data reporting and presentation

Data reporting and presentation (often called data deliverables) are one result of a groundwater data management system. This stage could be considered the most important component of the system because it is by distributing these reports that the foundation is set for raising awareness of groundwater-related issues. The availability and accessibility of reports enable wide distribution to stakeholders, either to the public through publications such as water quality reports, within the government to highlight issues such as water usage and contamination issues, or to research institutions and universities. Dissemination of data also helps raise awareness of policy and research issues, and as such, distribution of data should be viewed as a core process.

Two fundamental types of groundwater reports exist. These are a data report and an interpretive report.

Data reports

A data report is exactly as the name implies, purely a transmittal of (validated) data without any interpretation. The purpose of this report is to distribute data to interested parties, and the report generally consists of tabulated and graphical representations of the data. The specific use of the report and the audience determine the frequency, information, detail, and content of the publication. For example, a one-time data monitoring report prepared for stakeholders could only contain tabulated and graphical data compared to WUL or relevant DWS guidelines.

In contrast to this one-time report, regulatory compliance may require reports to be submitted regularly, for instance, quarterly reports of groundwater quality. The data report would include graphical, tabulated, and time-series presentation of data that would not be present in the first example. This regulatory report should be compared to WUL or relevant DWS guidelines and be used to highlight risk areas based on the WUL and guidelines.

For the contents, the report should describe:

- The purpose and scope of the report;
- The datasets used (locations, periods, etc.);
- The monitoring date;
- Monitoring procedure;
- Monitoring network design;

- Quality assurance and controls;
- Field measurements, such as temperature, pH, EC, DO;
- Groundwater and surface water quality;
- Groundwater levels and contours;
- Compare results with relevant WUL, RQOs, background, end land-use objectives, or relevant water quality guidelines, such as sensitive receptors (for example, drinking water);
- Spatial and temporal trends;
- Identify issues of access during the monitoring event;
- Identify and delineate receptors;
- SOPs; and
- Laboratory certificate of analyses.

Certain basic rules should be considered for the graphical and tabulated presentation of data, which are:

- Be clear, concise, and legible;
- Ensure that only relevant data are presented; and
- Be certain that necessary headings, labels, legends, and notes are included to increase understanding of the data.

In general, the reports to be compiled and/or submitted to Eskom must contain the results of the investigation conducted, indicating the data collected and the progress made in addressing the gaps identified during the site visits/field investigations. It must also include recommendations for improving the water and waste management systems and address any potential or existing contamination problems noted during the interpretation of the collected data.

Interpretive reports

An interpretive report uses the data report as a foundation to help provide a conceptual understanding of the hydrogeology and the evolution of groundwater quality, such as source control measures influencing contamination or plume movement over time. For the contents, the report should describe:

- The purpose and scope of the report;
- The datasets used (locations, periods, etc.);
- The methods of reducing and interpreting the data;
- The models/formulas used, their purpose, limitations, and assumptions;
- The results obtained;
- Spatial and temporal trends, including a discussion on plume movement;
- SOPs; and
- Laboratory certificate of analyses.

In addition, the report should:

- Compare results with relevant WUL, RQOs, background, end land-use objectives, or relevant water quality guidelines (for example, sensitive receptors – drinking water);
- Identify issues of access during the monitoring event;

- Identify and delineate receptors;
- Highlight risk areas or contamination concerns;
- Update CSM and risk assessment; and
- Provide conclusions and recommendations.

Distribution and accessibility of data and reports

The distribution of groundwater data to decision-makers, the public, and other stakeholders is vital to the success of a monitoring programme. By developing the ability to communicate information about the groundwater system to such an audience, the following may be achieved:

- Data and programme deficiencies can be identified and solutions put forward to address them;
- Transparency and accountability for the work can be demonstrated;
- An environment of sharing can be fostered; and
- A commitment to the aim of the work can be demonstrated.

C16: External review

Eskom relies heavily on the services of external providers to provide groundwater services. It is recommended that the sites consider appointing an independent party to evaluate the quality of services provided by the external provider. This could be done either annually or at the end of the contract.

D: Output of groundwater monitoring

Water monitoring is a legal requirement and can be used in negotiations with authorities for permits, etc. The most common environmental management actions require data, and thus the objectives of water monitoring are to provide this data through the following:

- A properly constructed monitoring network entailing source, pathway, impact, background, and system response monitoring boreholes;
- Correctly constructed boreholes;
- Definition of the monitoring parameters;
- Definition of the monitoring frequency;
- Data management through storage, processing, and validation;
- Data reporting and presented clearly and concisely, highlighting risks, or non-compliance; and
- External review of the quality of work.

E: Groundwater monitoring record

Borehole/Sampling point ID: ______________________________

Borehole/Sampling point co-ordinates: S_________________________E_________________________

Area #:____

Sampling point description: ____

Facility name: ____

Date:____ _________/_____________/_____________

Borehole depth:________mbgl Depth to water:_______mbgl Borehole diameter:________________mm

Casing material:______________ Sampling method Used:_______________________________________

Sampled time:____

Sampling crew:__________________,____________________,___________________,_______________

Type of pump:____

Weather conditions:____

Borehole condition:____

____

____

____

____

____

Photo

Notes/Issues/Field observations

____

____

____

____

Field parameters taken:____

Sample delivered to ______________________________ by _____________________________________

Lab delivery date_____________________/_____________/_____________

Signature ______________________________ by _____________________________________F

F: Samples and field parameters

Sample point ID	Time	Water level (mbgl)	Volume purged/ bailed (ℓ)	Casing height (m)	Container volume (ℓ)	Sample depth (mbgl)	EC (ms/m)	DO (mg/l)	Temp (ºC)	Sample description

3.6 Groundwater Sampling Guideline (GWG05b)

Introduction

Groundwater quality is characterised by a large number of parameters, including physical, chemical, and biological types. The interest in these parameters differs from the objectives of the analysis, and therefore the sampling and monitoring procedures will differ.

These objectives may be of a general type, for instance, “general groundwater characterisation” related to the actual situation and the potential for use, or they may be more specific, such as conducting studies of groundwater quality under the influence of contamination or remedial measures. The complexity of groundwater quality problems usually increases with the intensity of groundwater development, and so does the need for more specific data collection procedures.

Purpose

The purpose of this guideline is to ensure that there are clearly defined controls in place to evaluate consultant sampling and subsequent analysis. The intended use of the guideline is for Eskom personnel to evaluate sampling procedures as well as to guide consulting scientists on Eskom sampling procedures and analysis. The guideline must be applied at all Eskom operations that require groundwater sampling.

Designing a groundwater sampling plan

It is important to prepare a good sampling plan. The plan will describe where, what, why, how, and when Eskom requires sampling and who will be doing it. The sampling plan should be prepared in consultation with stakeholders and field and laboratory technicians.

When designing a sampling plan, issues of possible hazards, as well as standard behaviour at the sampling site, should be considered. Following a standard operating procedure (SOP) will minimise the risk of accidents, enhance the data quality, and ensure the safety of the sampling crew.

A groundwater sampling plan should be built around the following questions:

- Why are you fielding sampling?
- Who will use your data?
- How will the data be used?
- How will the data be obtained?
- What will you sample?
- What data quality do you require?
- What methods will you use?
- Where will you sample?

- How will the sample be preserved?
- When and how often will you sample?
- Who will be involved and how?
- How will the data be managed and reported?
- How will you ensure your data are credible?
- What potential hazards are associated with the sampling?
- How can these hazards be mitigated?

Sample analysis

Water samples must be analysed by a recognised analytical laboratory that uses approved analytical procedures. When permits have been issued, permit conditions will specify analyses and constituents to be tested. The range of elements that may be found when analysing a waste environment is very extensive. For this document, the required analysis is discussed separately:

- Comprehensive analysis; and
- Indicator analysis.

A: Comprehensive analysis

For all new sites and first-time monitoring at existing sites, a comprehensive analysis is required. It is essential that accurate background levels be established at the outset for as wide a range of constituents as possible. This will usually include a complete macro-analysis and an analysis for trace elements, such as chromium and mercury at power stations with selected isotopes at nuclear facilities.

The comprehensive analysis should be repeated on the closure of the operation and during the operational period at least every three to five years or as guided by the groundwater risk posed.

B: Indicator analysis

Indicator analysis may be performed once comprehensive analyses have been completed. This process may continue until undesirable trends are uncovered. This will keep analytical costs to a minimum but still provide enough information upon which further action can be initiated, if necessary. Depending on the type of waste handled, so-called “contamination indicators” for Eskom may be identified. Examples are the following:

- General and special variables for discharge of Eskom effluent into public streams, such as pH, EC, TDS, SO_4, Fe, Al, Mn, COD;
- The so-called sewage variables, such as pH, TDS, COD, NH_4, NO_3, PO_4, *E. coli;*
- Hazardous waste disposal variables, such as pH, TDS, COD, VOC, THM, Cr^{6+};
- General waste disposal variables, such as COD, Cl, NO_3, NH_4;
- Mine contamination variables, such as pH, EC, TDS, SO_4, Fe, Al, Mn;
- Ash disposal facilities, such as pH, Na, K, Cl, Mg, EC, TDS, SO_4, Fe, Al, Mn;
- Coal stockyard contamination variables, such as pH, EC, TDS, SO_4, Fe, Al, Mn;
- Coal-fired power station contamination variables, such as pH, EC, TDS, SO_4, Fe, Al, Mn;

- Nuclear power station contamination variables, such as specified isotopes, pH, EC, TDS; and
- Hydrocarbon contamination variables, such as Gasoline Range Organics (GRO), Diesel Range Organics (DRO), Polycyclic Aromatic Compounds (PACs) and Polychlorinated Biphenyl (PCBs) for transformer areas.

Frequency and duration of sampling

In instances where permits have been issued, permit conditions will specify the frequency of analyses and constituents to be tested. If licences have not been issued, frequencies should be based on the initial risk assessment.

At any groundwater sampling facility, whether permitted or not, initial sampling should be done at a frequency high enough to obtain statistically valid background information. For any long-term monitoring facility, three initial sampling exercises, all within 90 days and not less than 14 days apart, are suggested. Depending on the variation among these values, future sampling may be planned. A three-monthly sampling frequency will be sufficient in most instances.

Good practice at active or newly built power stations should be every three months for ground and surface water. The duration of sampling will be driven by the risk posed. If the risk is insignificant, sampling could be discontinued after consultation with the DWS.

The comprehensive analysis should be repeated on the closure of the operation and during the operational period at least every three to five years or as guided by the risk posed.

Sampling procedure

The sampling process comprises a series of linked steps, which are discussed below.

A: Preparation

Planning for a sampling run is essential for time-efficient fieldwork. The following shall be completed at the office before embarking on a sampling event:

- The owner of the boreholes, or the designated responsible officer, shall be notified in advance of the intended sampling date(s) and time, where applicable; and
- The applicable database records, proposal or report recommendation shall be consulted to ensure that samples are collected for the applicable laboratory analysis. These data sources should also be used to verify agreed monitoring positions as requested by Eskom or as recommended.

The sampler must obtain at least the following information:

- GPS co-ordinates of the boreholes and/or a clear sitemap showing the monitoring (sampling) positions;
- The sampling sequence – from least to most contaminated (where applicable);

- Depth of sample, if available;
- The essential equipment needed for sampling major cations, anions, and metals must be packed before leaving for sampling:
    - Water level recorder (dip meter or TLC meter);
    - Tape measure;
    - Suitable diameter cleaned bailer(s) with a clean cord when required;
    - Sampling bottles (1 ℓ where applicable);
    - Labels for the sampling bottles;
    - Preservation fluids;
    - Filtering equipment (for analysis of metals);
    - Cooling boxes for samples collected during the day and adequate ice to cover all sample bottles after sampling;
    - Sampling and COC forms;
    - Permanent marking pen;
    - Absorbent towel;
    - Protective clothing to adhere to site requirements (when requested);
    - Parameter probes (EC, pH, DO, ORP), when required;
    - Sample pump (purging only); and
    - Flow-through cell (purging only).

B: Sampling methods for inorganic groundwater parameters

Eskom can employ two main methods of inorganic sampling to obtain a representative groundwater sample. These are by purging or stratified sampling, which will be discussed below.

B1: Purging (Removing stagnant water)

The specified sampling procedure should be followed:

1. The order of sampling must be from the (expected) least contaminated boreholes to the most contaminated holes;
2. Record borehole number, time, date, and any other relevant observations on the sampling form;
3. Remove the borehole cover carefully, inspect the borehole, and record abnormalities observed;
4. Measure and record the collar height of the borehole above general ground level;

5. Measure the depth of the static groundwater level to an accuracy better than 1 cm. (Water levels should be recorded from the collar height unless specified otherwise.);
6. Rinse the electronic water level meter with deionised water;
7. Clean all sampling equipment if necessary;
8. Lower the pump inlet into the well, ensuring that it is not stuck;
9. Connect the pump outlet to the flow-through cell and place probes into the cell;
10. Switch the pump on and take a water sample from the outlet once the parameters have stabilised;
11. Rinse the sample bottle with the cap on. Empty the bottle. Carefully fill the sampling bottle with the sampled water, ensuring that the bottle is filled to the brim with no air trapped;
12. If sampling by means of a flow-through cell is not required, the well should be pumped until the volume of water removed equals at least three well volumes. If the hole can be pumped dry, then a sample should be taken before the water level approaches the pump inlet. A bailer may also be used for purging instead of a pump in this case;
13. If boreholes that are already equipped with pumps are sampled (for example, private boreholes), then the pump should be started and samples collected after an extended period, ensuring that the water sampled is derived from the borehole and not from water stored in the piping;
14. In the case of sampling for metal analysis, it is essential that the sample bottle is only opened when ready to fill and that it is not emptied or rinsed, as it contains preservative acid. While filtering, fill the sampling bottle with the sampled water, ensuring that the bottle is filled to the brim with no air trapped;
15. If samples are collected for bacteriological analysis, the appropriately preserved sample bottles should be used. If samples are collected from taps, the tap outlet should be sterilised to a practicable extent before sampling by holding an open flame near the tap outlet;
16. Replace the cap and dry the bottle with clean absorbent paper/cloth;
17. Take field measurements such as pH, EC, temperature, and DO;
18. Attach a clean label to the bottle and write the following information on the label using legible capital letters:
    a. Site and project name;
    b. Sample (borehole) number;
    c. Date;
    d. Constituent to be analysed;
    e. Name of the project manager;
    f. The laboratory that will analyse samples; and
    g. Sample depth.
19. Preserve the sample on ice or in a cooler box;
20. Complete the COC, leaving no blanks;

21. Rinse the bailer with deionised water;
22. Carefully repack all equipment, ensuring that it is not contaminated during travel;
23. Replace the borehole seal;
24. Ensure that the site is in good order before leaving; and
25. Submit all samples to the laboratory as soon as possible, preferably never more than three days after sampling. All samples collected for bacteriological and Cr^{6+} analysis should be submitted to the laboratory within 24 hours.

B2: Stratified sampling or specific depth sampling

The specified sampling procedure should be followed:

1. The order of sampling must be from the (expected) least contaminated boreholes to the most contaminated holes;
2. Record borehole number, time, date, and any other relevant observations on the sampling form;
3. Remove the borehole cover carefully, inspect the borehole, and record abnormalities observed;
4. Measure and record the collar height of the borehole above general ground level;
5. Measure the depth of the static groundwater level to an accuracy better than 1 cm. (Water levels should be recorded from the collar height unless specified otherwise.);
6. Clean all sampling equipment if necessary;
7. Before collecting a bailed sample at a new site, consider conducting an EC profile down the hole to detect changes in EC. Compared with the construction logs of monitoring boreholes, EC profiles can be used to determine the optimum sampling depth of each hole. The sample should be taken at a depth where the EC reaches a maximum;
8. Lower the bailer to the prescribed depth and appropriately grab the sample as described for the specific bailer;
9. Raise the bailer to the surface and rinse the sample bottle with some of the sampled groundwater. Carefully fill the sampling bottle with the sampled water, ensuring that the bottle is filled to the brim with no air trapped;
10. In the case of sampling for metal analysis, it is essential that the sample bottle is only opened when ready to fill and that it is not emptied or rinsed, as it contains preservative acid. While filtering, fill the sampling bottle with the sampled water, ensuring that the bottle is filled to the brim with no air trapped. All samples collected for metal analysis should be filtered and preserved unless otherwise specified by the project leader;
11. Should samples be taken for bacteriological analysis, the appropriately preserved sample bottles should be used;

12. Replace the cap and dry the bottle with clean absorbent paper/cloth;
13. Take field measurements such as pH, EC, temperature, and DO;
14. Attach a clean label to the bottle and write the following information on the label using legible capital letters:
    a. Site and project name;
    b. Sample (borehole) number;
    c. Date;
    d. Constituent to be analysed;
    e. Name of the project manager;
    f. The laboratory that will analyse samples; and
    g. Sample depth.
15. The sample label should be covered with tape (for example, Sellotape) to prevent damage to the label;
16. Preserve the sample on ice or in a cooler box;
17. Complete the COC, leaving no blanks;
18. Rinse the bailer with deionised water;
19. Carefully repack all equipment, ensuring that it is not contaminated during travel;
20. Replace the borehole seal;
21. Ensure that the site is in good order before leaving; and
22. Submit all samples to the laboratory as soon as possible, preferably never more than three days after sampling. All samples collected for bacteriological and Cr^{6+} analysis should be submitted to the laboratory within 24 hours.

B3: Sampling method for organic groundwater parameters

Organic sampling that can be employed by Eskom to obtain a representative groundwater sample is discussed below:

1. The order of sampling must be from the (expected) least contaminated to the most contaminated boreholes;
2. Record borehole number, time, date, and any other relevant observations according to the “water sampling form”;
3. Remove the well cover carefully, inspect the borehole, and record abnormalities (if any) observed;
4. Check the physical condition of the borehole (that is, casing, missing cap, manhole cover, concrete around the manhole);
5. Measure and record the collar height (if applicable) of the borehole above general ground level to an accuracy better than 1 cm;

6. Measure the depth of the static groundwater level to an accuracy better than 1 cm;
7. Lower the bailer to the air/water interface and appropriately grab the sample as described for the specific bailer;
8. Raise the bailer and observe and record the presence of floating free petroleum products (if any);
9. Lower the bailer to sampling depth and sample once more;
10. Carefully fill the sampling bottle with the sampled water, ensuring that the bottle is filled to the brim with no air trapped;
11. Replace the cap and dry the bottle with clean absorbent paper;
12. Attach a clean label to the bottle and write the following information on the label using legible capital letters:
    a. Site and project name;
    b. Sample ID number (that is, first two letters of the client's name, first three letters of the site name, and borehole number);
    c. Date;
    d. Constituent to be analysed as specified by the project manager/leader;
    e. Name of the project manager/leader; and
    f. Name of the sampler.
13. Preserve the sample on ice in a cooler box during and after sampling;
14. Complete the water sampling forms, leaving no blanks;
15. Clean all sampling equipment using the dedicated soap;
16. Carefully repack all equipment, ensuring that it is not contaminated during travel;
17. Replace the borehole cap to its original form;
18. Ensure that the site is in good order before leaving; and
19. Return all samples to the office as soon as possible, preferably not more than two days after sampling.

B4: Quality assurance/quality control

QA/QC is a set of operating principles adopted to help produce data of known, consistent, and defensible quality. The QA/QC process checks the accuracy and precision of field sampling procedures and laboratory analyses and is done by taking duplicate and blank samples.

Quality assurance

QA is the policies, procedures, and actions established to provide and maintain a degree of confidence in data integrity and accuracy. For a sampling programme to successfully meet its objectives, a rigorous and thorough programme of checks, comparisons and communication must be implemented. To achieve consistent data collection, a QA system must be followed.

Quality assurance should be done through SOPs that provide a detailed description of the protocols for collecting and analysing data. Their purpose is to improve data collection and data quality, including uniformity, consistency, and completeness of data sets. The protocols will enable technical personnel to understand and replicate the work at hand and force them to conduct complete and thorough surveys. SOPs should be established at the outset of an investigation to establish that work has been conducted to a consistent and scientifically defensible standard.

Quality control

QC is a sample or procedure intended to verify the performance characteristics. Water sampling QC should focus on ensuring that the results obtained by analysing samples represent the groundwater, as it was when the sample was collected.

Therefore, if there is any significant change in or contamination of the sample because of containers, handling and transportation, it will be picked up by QC.

Blanks

A blank is a portion of deionised water carried through all or part of the sampling and analytical process and is designed to indicate contamination.

Duplicate samples

These are taken to test for analytical precision in the laboratory and put through the same filtering, storage and analysis processes. One in every 10 to 15 sites should be sampled in triplicate to provide the following set of samples:

Original
Duplicate
Spiked duplicate

Anion-cation balance

The accuracy of the laboratory analysis can be readily checked by looking at the anion-cation balance. Since water is neutrally charged, the sum of anions should equal the sum of cations. The anion-cation balance is normally expressed as a percentage.

$$\text{Ion balance} = (\Sigma C - \Sigma A)/(\Sigma C + \Sigma A)/100$$

Where ΣC is the sum of cations and ΣA is the sum of anions

If the anion-cation balance is >5%, it indicates an error in analysis, and the results should not be relied on for subsequent interpretation.

Sample control

COC procedures and documentation demonstrate sample control. This gives confidence that the samples are representative of the sampled water and are imperative if the samples are to be used in legal proceedings or if there is any suspicion that they might be tampered with at any stage of the process. COC documentation is used to trace possession and handling of a sample from collection through to analysis, reporting and disposal.

C: Example of a COC form

COC FORM																		
PROJECT DETAILS																		
Site Name:									Laboratory used									
Eskom Site Represenative:									Required Analysis									
Sampling Leader:									Number of Samples						Other:			
Custodian 1:								Custodian 2:		Custodian 3: Controller					Custodian 4: Transporters		Custodian 5: LAB	
Name:															Date		Date	
Signature:																		
Sample Number	Vol.	Sample Date	Sample Time	Preservative	Analysis Required	Specific Analysis	Sampling Method	Date	Reason	Date	Selected Yes	Selected no	Sampling Leader to select samples and sign			All samples tansported to the laboratory		All samples received

3.7 Aquifer Vulnerability Assessment Guideline (GWG06)

Introduction

Aquifer vulnerability assessment indicates the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer. Stated in another way, aquifer vulnerability is a measure of the degree of insulation that the natural and manmade factors provide to keep contamination away from groundwater.

- Vulnerability is high if natural factors provide little protection to shield groundwater from contaminating activities at the land surface; and
- Vulnerability is low if natural factors provide relatively good protection and there is little likelihood that contaminating activities will result in groundwater degradation.

Purpose

The purpose of this guideline is to ensure that there are clearly defined process controls in place so that Eskom personnel unfamiliar with hydrogeology will be able to evaluate an aquifer vulnerability assessment. The guideline is to be applied at all Eskom operations that have the potential for groundwater impacts. The site characterisation determines the level of detail to which the vulnerability assessment is to be constructed.[6]

Conducting an aquifer vulnerability assessment

An overview of conducting an aquifer vulnerability assessment is discussed under the headings below.

A: Vulnerability assessment objectives and principles

Aquifer vulnerability relates to several factors, the most important of which are:

- Climate, precipitation, and surface water run-off;
- Nature and composition of the unsaturated zone, in the case of unconfined aquifers;
- Aquifer characteristics, such as hydraulic conductivity, water quality and regional groundwater flow directions, and degrees of confinement in the case of confined aquifers; and
- Liner design, leachate management, and other precautionary or control measures.

Vulnerability assessment and vulnerability mapping are sometimes used interchangeably to distinguish between areas of greater and lesser vulnerability. The purpose of the vulnerability assessment is not to create scientific insight but to provide a decision-making tool based on the best available data and good scientific judgement.

[6] Eskom, 2014. Site Characterisation Guideline

B: Vulnerability assessment procedure

Numerous methods are available to assess vulnerability. This guideline, however, only focuses on describing the aquifer vulnerability process. For Eskom sites should utilise appropriate software to conduct comprehensive aquifer vulnerability assessments. For less detailed vulnerability assessments, the DWS Aquifer Vulnerability Map of South Africa can be used.

B1: Importance of the CSM

The first and most critical component of a vulnerability assessment is developing a suitable, detailed CSM. The CSM is arguably the most important step in the whole vulnerability exercise as it defines the answers to the questions posed during the vulnerability assessment.

B2: Climate, precipitation, and surface water run-off

The primary source of groundwater is precipitation, which infiltrates through the surface of the ground and percolates to the water table, referred to as recharge. Thus, recharge is the main driver to transport a contaminant vertically to the water table and horizontally within the aquifer. In areas where the aquifer is unconfined, recharge to the aquifer usually occurs more readily, and the contamination potential is generally greater than in areas with confined aquifers.

B3: Nature and composition of the unsaturated zone

Unsaturated zone flow and transport processes are generally complex and difficult to measure, in part because of the large amount of natural variability found in soils, sediments, and rock. Hence, soil properties (for example, infiltration capacity, permeability, soil type) only allow the analyst to approximate actual transport processes.

B4: Aquifer characteristics

The aquifer characteristics exert major control over the route and path length along which a contaminant must flow. The path length is an important control in determining the time available for attenuation processes such as sorption, reactivity, and dispersion, and the effective surface area of material contacted in the aquifer. The route that a contaminant takes can be strongly influenced by fracturing or by any other feature, such as an interconnected series of solution openings, which may provide pathways for easier flow.

B5: Precautionary or control measures

An evaluation of the control measures, such as liner design, leachate management, and other precautionary or control measures to create a zone or barrier between the waste and the underlying aquifer, must be done.

C: Vulnerability assessment frequency

A vulnerability assessment should be done for all new operations that have waste or products stored on a temporary or permanent basis that could have a potential impact on surface or groundwater quality by leaching into or coming in contact with water.

For existing operations, such as newly built coal-fired power stations, operational coal-fired power stations, and dysfunctional mines, vulnerability assessment frequencies should be reviewed based on the following:

- Knowledge obtained regarding new critical receptors;
- New waste facilities built;
- Waste facilities expanded;
- Contamination observed through unidentified leakages; and
- Contamination sources newly delineated.

D: Output of the aquifer vulnerability process

A report must be drawn up, complying with the following minimum requirements:

- CSM;
- A detailed description of the climate, precipitation, and surface water run-off;
- A detailed description of the nature and composition of the aquifer characteristics;
- A detailed description of the nature and composition of the unsaturated zone;
- Evaluation of the precautionary or control measures such as waste facility design or liner design;
- Description of the aquifer vulnerability using a worst-case scenario approach describing the vulnerability to specific contaminants in the long term when continuously discharged or leached, taking into consideration the following:
  - Depth to the water table;
  - Recharge because of rainfall;
  - Aquifer media;
  - Soil media;
  - Topography;
  - Impact on vadose zone;

  - Conductivity;
  - Leaching potential;
  - Absorption;
  - Transformation of contaminants through natural attenuation; and
  - Precautionary or control measures;
- Listing of aquifer protection measures to be implemented.

3.8 Hydrocensus Guideline (GWG07)

Introduction

A hydrocensus is a site familiarisation exercise and collection of important groundwater data from the study area and surrounding environments. It comprises a census of key boreholes, springs, and any other groundwater-related information. The extent (intensity and area covered) of the hydrocensus will depend upon the level of the study (national, local, or site-specific) and the particular requirements of the study, but must provide wide coverage of information far enough outside Eskom's operations to allow an overview of the aquifer system(s) to be captured at the necessary level of detail.

Purpose

The purpose of this guideline is to ensure that there are clearly defined process controls in place to evaluate a hydrocensus for Eskom personnel unfamiliar with hydrogeology. The guideline is to be applied at all Eskom operations that have the potential for groundwater impacts. The site characterisation determines the level of detail to which the hydrocensus is to be conducted.[7]

Conducting a hydrocensus

A: Hydrocensus objectives and principles

Existing and historical database data rarely provide adequate information on the current distribution of water sources and the water quality within an area. Therefore, it is valuable to gather additional information from users of groundwater systems and surface water bodies through a hydrocensus to collect field data to develop a more complete understanding of the hydrological systems within a study area. During the hydrocensus, it may also be important to record the interactions between groundwater and surface water. A risk-based approach should be followed to identify the type of data that should be collected. The information needs that will be addressed through the hydrocensus could be established by asking simple questions, like:

[7] Eskom, 2014. Site Characterisation Guideline

- Why do we need data?
- How will we obtain this data?
- What must the data represent?
- How will we use the data?

The site-specific operation can use the hydrocensus data to determine the prevailing hydro-geological conditions, order of magnitude of existing groundwater use and dependence, areas of intensive irrigation, list receptors, etc. The success of any hydrocensus is almost entirely dependent on the co-operation of the local communities, mines, industries and private landowners. Eskom should thus ensure that prior and considered communication is undertaken through public participation channels to inform landowners of the proposed hydrocensus and quality. The following steps are usually part of a hydrocensus:

B: State the problem

The description should include study objectives, the regulatory context, groups who are involved or have an interest in the study, and why the hydrocensus is required.

C: Identify inputs

The next step is to identify the different types of information needed to resolve the problem. Data from previous studies or investigations may be available, or new data may need to be collected. If a previous hydrocensus has been completed, it must be repeated to evaluate the change during the lapsed time.

D: Define the boundaries of the hydrocensus

The spatial and temporal boundaries of the study area are defined, and the data collection process is placed within this context. The boundaries should be far enough to include sensitive environments/users relevant to Eskom, potential Eskom groundwater impacts and impacts from neighbouring landowners, such as mining and industrial activities.

Factors, such as seasonal or daily variations, as well as weather and temperature conditions that may affect the data collected, must be considered. The availability of sampling equipment and personnel should also be identified by identifying obstacles to data collection, such as access to private property. Eskom should notify all owners within the identified boundaries before the hydrocensus exercise to allow for all sites with the identified boundaries to be visited. The details of the owners should then be given to the person who will conduct the hydrocensus.

E: Planning

Planning for a hydrocensus is essential for time-efficient fieldwork. The following should be completed before embarking on the hydrocensus:

- The owner of the boreholes or designated responsible officer shall be notified in advance of the intended hydrocensus and time, where applicable;
- The applicable database record, proposal, or report recommendation shall be consulted to ensure that samples are collected for the applicable laboratory analysis. These data sources should also be used to verify the agreed hydrocensus area as requested by the client or as recommended; and
- Sitemap showing the hydrocensus area to be covered.

F: Collect field data

A decision should already have been made on what data needs to be collected and the area over which the data is to be collected. The parameters that will be measured will vary depending on conditions prevailing at specific operations and the type of data needed to develop a model or for monitoring. The person conducting the hydrocensus should obtain at least the following information:

- GPS co-ordinates of the surface and groundwater features;
- Photo of the borehole;
- Owner details and dependence;
- Current use;
- Reported yield;
- Pump size/description and abstraction rates;
- Water tank size;
- Reported or measured borehole depth;
- Static water level;
- Field measurements of pH and conductivity;
- Collection of water samples from key selected boreholes or springs for quality analysis;
- Existing equipment;
- Possible information that can influence measurement data;
- Unsaturated zone;
- Current and future land use;
- Surface water quality should also be considered as part of the hydrocensus for use in surface water/groundwater interactions;
- Slug test (only if required);
- Identify potential contamination sources (for example, waste dumps, mining activities, waste water treatment works, intensive rural settlement, feed lots, irrigation areas);
- Concerns raised by owners; and
- Record all data on standard hydrocensus data sheet (See K: Hydrocensus Data Sheet).

G: Collation, manipulation, and analysis of data

Once the data has been collected and the results of the sample analysis have been received, they need to be entered into a database. Once in the database, the data can be transformed, manipulated, and presented in various forms. Geographically referencing the data and mapping usually proves valuable in interpreting the data. The hydrocensus report shall include the operational details and theoretical assumptions of the sampling and analysis plan.

H: Hydrocensus frequency

A hydrocensus should be done for all operations that have waste or products stored on a temporary or permanent basis that could have a potential impact on surface or groundwater quality and quantity by leaching into or coming in contact with water or any large-scale dewater activities. The following frequencies are proposed for Eskom's operations:

- For existing operations, such as newly built coal-fired power stations, operational coal-fired power stations, and dysfunctional mines, the hydrocensus should be reviewed every second year during operation;
- Before mothballed or decommissioned operations are reinstated;
- When knowledge is obtained regarding new critical receptors;
- When new waste facilities are built, waste facilities expanded, contamination is observed through unidentified leakages, or when contamination sources are newly delineated; and
- When large-scale abstraction is intended.

J: Output of a hydrocensus

A report presenting the hydrocensus information is to be used as a planning and management document, with the following minimum requirements:

- Tables of field data.
    - GPS co-ordinates;
    - Photo of the hydrocensus point;
    - Owner details and dependence;
    - Current use;
    - Reported yield;
    - Pump size/description and abstraction rates;
    - Water tank size;
    - Reported or measured borehole depth;
    - Static water level;
    - Field measurements of temperature, pH, and conductivity;
    - Collection of water samples from key selected boreholes or springs for quality analysis;
    - Existing equipment such as pump description; and
    - Possible information that can influence measurement data.

- Surface water quality should also be considered as part of the hydrocensus for use in surface water/groundwater interactions;
- Slug test results and interpretation;
- Identification of potential contamination sources (for example, waste dumps, mining activities, waste water treatment works, intensive rural settlement, feed lots, irrigation areas);
- List of concerns raised by owners;
- Description of the groundwater levels, flow directions, and discharge zones;
- Description of the unsaturated zone such as depth and flow;
- Distribution of springs, seepage zones, and wetlands;
- Distribution of land use (for example, irrigation, mining, waste dumps, urban areas);
- Identification of impacts (for example, dewatered or polluted areas);
- Description of the water quality distribution throughout the aquifer(s);
- Status quo of current groundwater situation surrounding the Eskom property; and
- Recommendations on the way forward.

K: Hydrocensus data sheet

Borehole/Sampling point ID:________________________________

Borehole/Sampling point co-ordinates: S__________________________E__________________________

Area #:____

Sampling point description: ____

Facility name: ____

Date:____ _________/_____________/_____________

Borehole depth:________mbgl depth to water:_______mbgl borehole diameter:________________mm

Casing material.:______________ Sampling method Used:____

Sampled time:____

Sampling crew:__________________,____________________,___________________,_______________

Type of pump:____

Weather conditions:____

Borehole condition:____

____

____

____

____

____

Photo

Notes/Issues/Field observations

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____

____

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Field parameters taken:____

Sample delivered to ________________________________ by _______________________________________

Lab delivery date______________________/_____________/_____________

Signature ________________________________ by ________________________

3.9 Conceptual Site Model Guideline (GWG08)

Introduction

A conceptual model may be defined as a simplified version of a real-world system (here, a groundwater system) that approximately simulates the relevant excitation-response relations of the real-world system. A groundwater CSM is a descriptive representation of a groundwater system that incorporates an interpretation of the geological and hydrological conditions that describe the system's composition, the transport processes that take place in it, the mechanisms that govern them, and the relevant medium properties. (See Figure 4 for an illustrative example).[8] It consolidates the current understanding of the key processes of the groundwater system, includes the influence of stresses, details the gaps in the existing knowledge base, and assists in understanding possible future changes/impacts.

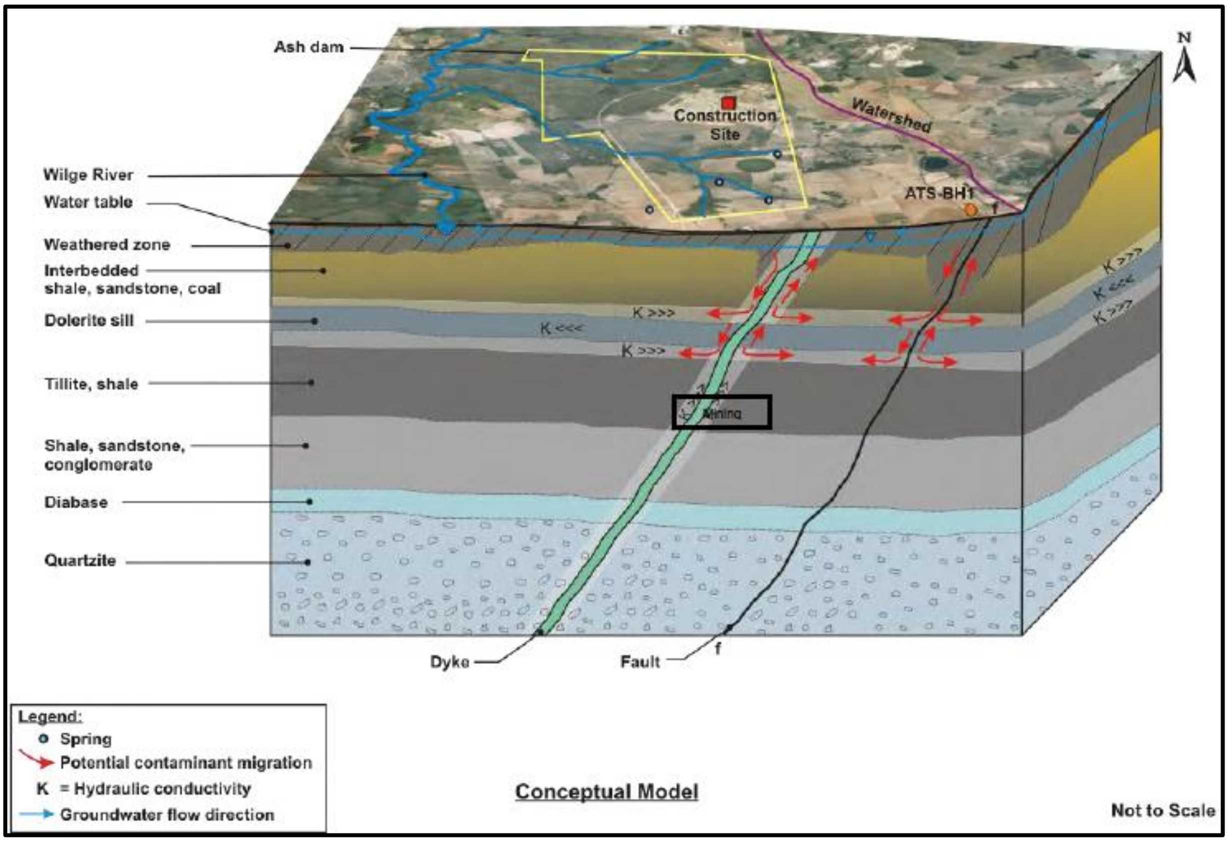

Figure 4: Schematic cross section of a conceptual site model (Taken from Contamination Investigation Kusile Power Station Construction Site, January 2012)

[8] Groundwater Dictionary was developed by the Institute for Groundwater Studies, University of the Free State, and funded by the Department of Water Affairs and Forestry, Directorate: Water Resource Planning Systems, Second Edition

Purpose

The purpose of this guideline is to ensure that there are clearly defined process controls in place to evaluate the construction of the CSM for Eskom personnel unfamiliar with hydrogeology. The guideline is to be applied at all Eskom operations that have the potential for groundwater impacts. The level of detail to which the CSM is to be constructed will be determined by the site characterisation process.[9]

Construction of the CSM

A: CSM objectives and principles

Developing an appropriate conceptual model is required to ensure that the groundwater evaluation/assessment achieves its objectives. The conceptual model development process may need to include people with a range of skills (hydrology, hydrogeology, climate, soil, etc.) and represents the key point in a groundwater assessment process.

Besides playing an important role in the preliminary analysis of the groundwater system, the model is the basis for designing a groundwater monitoring programme. Data collected for the conceptual model, either existing or new, should be analysed to indicate potential impacts on receptors. The development of a conceptual model should be one of the first actions of the site characterisation, even if this first attempt is very simplified.

It is considered critical that an initial CSM be fully developed, described, and documented in a conceptual model report that Eskom must sign off before any further work, such as sampling, analysis, data review, modelling, etc., is allowed to proceed. If the conceptual model is flawed, the whole prediction exercise will also be flawed.

B: CSM procedure

The level of complexity of the conceptual model should be appropriate to both the objectives of the site, its characteristics, and available data. In the early phase of groundwater assessment, when basic data on these items is usually scarce, it may only be possible to produce a rough concept of the real system. Later on, the level of complexity that can be depicted will increase as more data becomes available.

The CSM must be based on on-site visits, review of available data, and physically describe those aspects that would have a bearing on an impact prediction.

B1: Inventory of data

The data inventory phase often includes the following steps:

- Collection and review of published documents about the topography, hydrology, hydrogeology, and related information of the area investigated. This can be sourced from the DWS website or the Council of Geosciences. Previous surface water, groundwater and geotechnical reports can also be used;

[9] Eskom, 2014. Site Characterisation Guideline

- Collection and review of site-specific data. This may concern data about the groundwater systems(s) in question (lithological and geophysical borehole logs, pumping test reports, etc.), data on the groundwater system (groundwater levels and groundwater quality), groundwater-related data of the surface water systems (base flow and spring flow) and, if necessary, data on precipitation and evaporation; and
- Collection of new information about the groundwater system. This could vary from a rapid reconnaissance survey, such as a hydrocensus, to a more detailed field investigation with drilling and pumping tests.

Studying published material on analogous systems (for example, web search for papers) may be useful, especially when too little information on the groundwater system at hand is available.

See Groundwater Site Characterisation Guideline (GWG01).

B2: Specification of the hydrogeological framework

Geological formations form the basic structure of the CSM. Groundwater flows through this structure from infiltration zones to discharge zones. The hydrogeological framework usually consists of zones with relatively high permeability (aquifers), zones with limited permeability (aquitards), and zones with virtually no permeability (aquicludes). As groundwater tends to take the way of least resistance, the bulk of groundwater flow is through the aquifers. Also, most boreholes for groundwater level and quality monitoring will be installed with their screens in the zones of highest permeability (the aquifers). The establishment of the hydrogeological framework is, therefore, essential information for the design of a groundwater monitoring programme.

Large-scale hydrogeological maps exist for South Africa.[10] These maps and cross sections show the hydrogeological framework of regional areas, the type of permeability (porous, fractured, and fissured) and often groundwater levels and groundwater flow directions.

For the CSM, the hydrogeological framework will have to be deduced from site-specific geological maps and cross sections. However, the information from geological maps and cross sections is seldom ready to directly represent the conceptual model. The following situations may occur:

- Regional geological maps do not exist ordo not provide a sufficient level of detailed information because of their large scale. Additional data from borehole logs and groundwater monitoring reports will then have to be collected and interpreted. Geophysical reports and information on the genesis of geological formations should also be used to create the conceptual model;
- Further schematisation or simplification may be desirable. For instance, if discontinuous and thin low-permeability layers separate aquifers, they may be mapped together as a single groundwater system, often under combined names. Similarly, less permeable layers may be combined as a single aquitard, for instance, if intermediate sand layers are relatively unimportant; and

[10] http://www.dwaf.gov.za/Groundwater/Documents

- Geological maps and cross sections may also contain information that is not necessary to design a regional groundwater monitoring programme. Unnecessary details should be left out, thus simplifying the overall concept.

The maps representing the conceptual model should be balanced and realistic at a site-specific scale.

Special attention should be given to the area where deep groundwater systems are exposed at the surface. These aquifers may come to the surface outside the target area or catchment, even in neighbouring countries. If that is the case, a considerable part of the recharge of the aquifer may come from outside the catchment. In practice, this often leads to a lack of data, which imposes limits on recharge and water-balance calculations.

If hydrogeological maps and cross sections do not yet exist, it is recommended that the conceptual model of the hydrogeological framework be visualised using the following items:

- A contour map (or maps), showing the extent and thickness of the unsaturated zone, major groundwater systems, as well as the lineament of fault zones;
- A minimum of two cross sections perpendicular to each other, crossing the key parts of the groundwater systems and showing the sequence of aquifers and aquitards as well as the hydrological base; and
- A table (or tables) listing the sequence of aquifers and aquitards from top to bottom, the type of rocks, and calculated or estimated values of their hydraulic parameters (for example, average and range). These values can also be shown on the maps.

B3: Analysis of groundwater flow

Groundwater flow systems are especially important for studies of the origin of groundwater and its interaction with its environment. A groundwater system may consist of several groundwater flow subsystems, small and shallow ones embedded in large and deep ones (See Figure 5 for an illustrative example). Shallow flow systems are usually drained by small streams, whereas the larger ones discharge into the major rivers or the sea. These flow systems are separated by “soft” groundwater divides or impervious layers. Groundwater flow is gravity- or pressure head-driven, causing groundwater to flow from areas of relatively high groundwater level under recharge zones towards the lower discharge zones. Path lines in a groundwater flow system connect the recharge zone with the discharge zone. The course of these lines is influenced by the hydraulic properties of the subsoil, which makes aquifers the preferential flow path. This mutual relation between groundwater flow systems and the hydrogeological framework is scale-dependent. Several small groundwater flow systems may be found in shallow aquifers. Similarly, large and deep groundwater systems may penetrate several aquifers and aquitards.

Studies of groundwater flow systems and their path lines provide essential information for analysis of the evolution of groundwater quality, the possible impact of contaminants and the effects of environmental measures. Residence times in large groundwater systems may be up to tens of thousands of years. Natural groundwater quality is usually the result of the chemical interaction of groundwater with the aquifer matrix over a very long period. This long relation of the water to the chemistry of its environment can be used to distinguish different groundwater quality types. Small and shallow groundwater flow systems have relatively short flow lines and travel times. The quality of their water may show all types of recent influences.

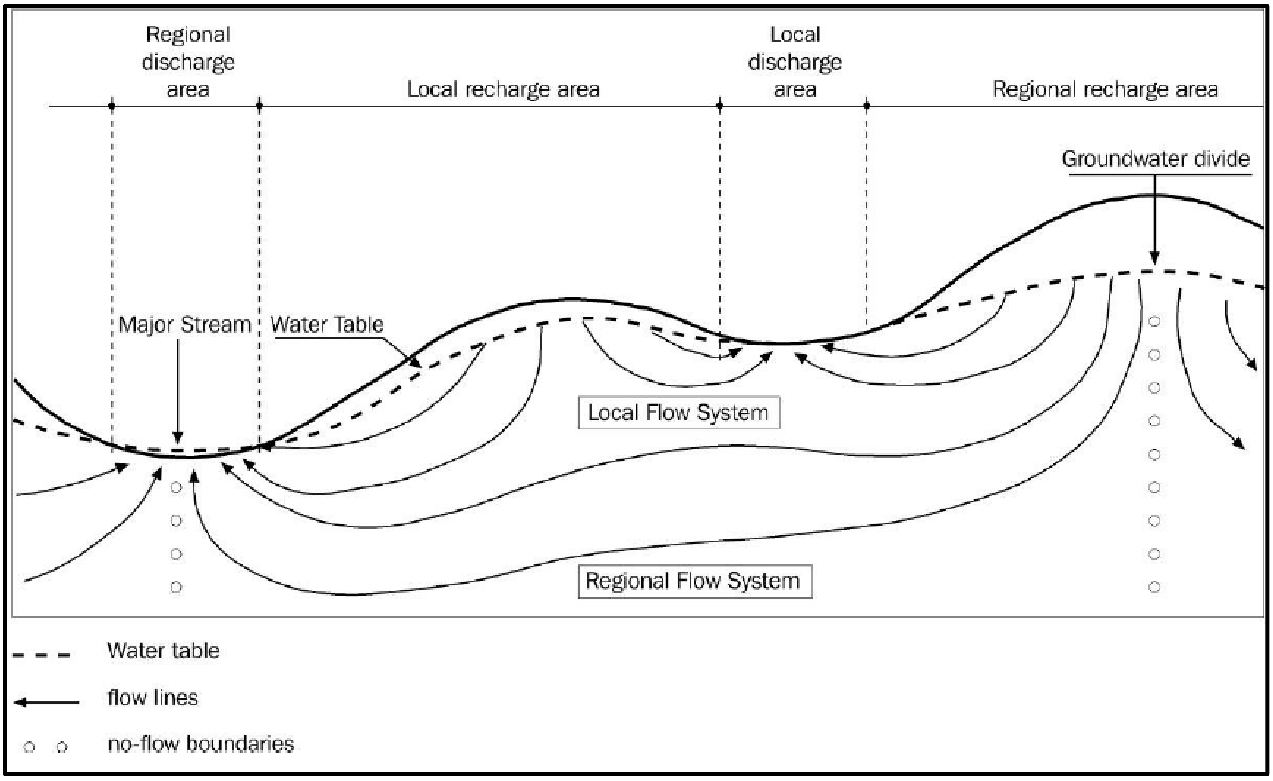

Figure 5: Schematic cross section showing groundwater flow systems (Taken from DWS Groundwater Dictionary)

Shallow versus deep flow systems

Unconfined aquifers with shallow groundwater table. In unconfined aquifers with a shallow groundwater system, there may be a direct interaction between surface waters and the ground-water body. Where rivers, springs or dams drain the groundwater system, the level of the surface water body roughly corresponds with that of the water table (Figure 6a). Only the hydraulic resistance of a river or dam bed (entrance resistance) may cause a small difference in these levels, which is usually negligible at a regional scale. A similar situation may occur where surface water feeds the groundwater system (Figure 6b). However, in recharge situations, one should be aware that an unsaturated zone might be present underneath the surface water bed, disconnecting the surface water level from the groundwater table (Figure 6c). In aquifers with shallow water tables, groundwater divides will often correspond roughly with surface water divides.

Unconfined aquifers with deep groundwater system(s). In areas with unconfined aquifers and a thick unsaturated zone (for example, a water table deeper than 20 m), drainage channels may only discharge surface water and have no relation with the groundwater body. The groundwater system will then interact with perennial rivers. In the area between the rivers, boreholes of sufficient depth can be used to monitor the groundwater levels. The groundwater level measurements at these observation points constitute the basic data for studies of groundwater flow.

Confined aquifers. In confined aquifers, groundwater levels measured in boreholes represent the hydraulic head at the depth of the screen. Monitoring boreholes or boreholes constitute the only way of recording the hydraulic heads in these aquifers.

Even in other countries, deep confined aquifers may come to the surface outside the target area or catchment. If that is the case, groundwater system analysis may become more difficult, and monitoring boreholes in the border regions will become important.

The above relation between surface water and groundwater levels can be used to draw the contours of the groundwater table map. In addition, observation points of surface water levels can be used to supplement the monitoring network of groundwater monitoring points.

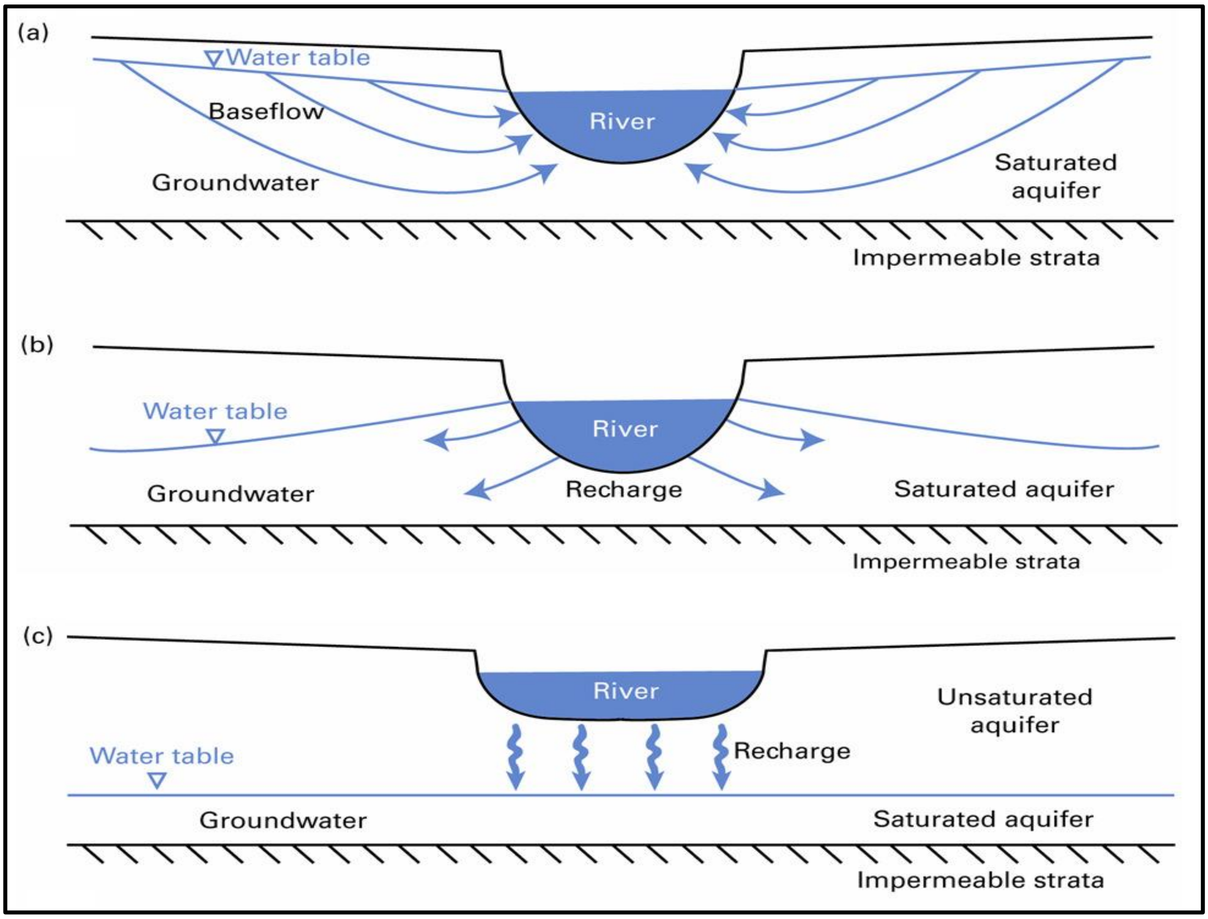

Figure 6: Examples of groundwater-surface water interaction (Taken from the DWA Groundwater Dictionary)

Quantification of groundwater flow and storage

Groundwater balance calculations can be applied to quantify the different components of groundwater recharge and discharge and the accompanying changes (increase or decrease) in groundwater storage in a selected period. The groundwater balance may provide increased insight into the magnitude of different components and show where data is insufficient.

The groundwater balance should also help identify whether the aquifer is sustainable in its current situation and to estimate the potential of the groundwater system for further development. Calculating a water balance is an important step, and in most cases it should be possible to make a reasonable estimate of the key components. If this is not possible, then it suggests that the level of confidence in the conceptual model is likely to be low. Typical components of a water balance are given below.

Inflows (*Increasing storage)*	**Outflows (*Decreasing storage*)**
Direct recharge via rainfall	Discharge to rivers, oceans, and streams
Recharge from surface water bodies	Evapotranspiration
Leakages from storage facilities, such as ash dumps	Abstraction
Infiltration from irrigated land	Exposed ground increasing evaporation
Lateral groundwater inflows	Lateral groundwater outflows

Increasing storage (rising groundwater heads) occurs when the total inflows exceed the total outflows in the period considered. Decreasing storage occurs in the opposite case. Note that many of these components are hard to measure directly and may need to be estimated (that is, using per capita water consumption or generic pipe/sewer leakage rates).

B4: Assessment of groundwater quality

A review of available hydrochemical data, such as monitoring reports, will provide important insight into the status of groundwater quality in the aquifer, the chemical processes and changes occurring, and its possible causes. Chemical changes may be because of recharge from rainfall, leakage from surface water, inflows from other aquifers, (considerable) evaporation, saline intrusion, or contamination. Changes in groundwater quality along groundwater flow lines are also caused by chemical interaction between groundwater, soil, and aquifer material.

Interpretation of the groundwater quality data will help determine the origin and age of the water, thus supporting groundwater flow analysis, identifying potential threats (contamination, etc.), and studying the perspectives and limitations of further groundwater development.

Aquifers with shallow groundwater flow systems

Most shallow groundwater flow systems have short flow lines and travel times. This makes them vulnerable to rapid changes in groundwater quality, both in space and time, caused by local differences in land use. Experience has shown that groundwater quality may vary significantly between nearby boreholes. In contrast, samples taken from springs or streams draining the groundwater body will tend to show average values representative of a part of the system or the system as a whole. Where numerous similar, shallow groundwater systems extend over a large area, there may be many similar, shallow systems at short distances, differing little from one another.

To be cost-effective, data collection in such a region should be conducted based on a well-prepared plan that considers similarities and differences between these systems. That plan for data collection may include a limited number of pilot areas (units) selected based on the aquifer situation and differences in land use. Simple land-use divisions could be urban, agriculture with and without irrigation, pastures, forests, and natural vegetation. The data collection plan may form the starting point for a future monitoring programme.

Aquifers with medium-deep and deep groundwater flow systems

It is only possible to collect groundwater samples from aquifers with deep groundwater systems from deep boreholes and large, base flow-dominated rivers (and occasionally springs) draining them. As the groundwater systems are usually large and deep with long flow paths and large travel times (hundreds to thousands of years), human influences on the water quality of the systems are generally limited to the upper zones. Trends in groundwater quality along flow paths will be important for demonstrating the natural processes occurring in these aquifers. For a good regional picture, regular distribution of boreholes would be ideal. However, the availability of boreholes may differ widely in these deep aquifers.

Coastal aquifers with saline groundwater

The fresh/saline interface comes close to the surface near the coast and dips to greater depths away from the shore (Illustrative Figure 7). The “interface” consists of a brackish, transitional zone with a thickness that may vary from some metres to tens of metres, depending on the dynamics of the groundwater flow system. Under natural conditions, the fresh/saline interface may be at rest. However, groundwater withdrawal from the upper fresh water body may cause the interface to move inland and upwards, endangering the water boreholes and the environment. Therefore, groundwater boreholes close to the coast should be checked for the quality of their water, especially the chloride content. If records of deep screens are already available, they may show chloride levels rising with time, which is a fair indication of saline intrusion. Unfortunately, reliable information about the depths of boreholes and their screen section(s) is often difficult to obtain.

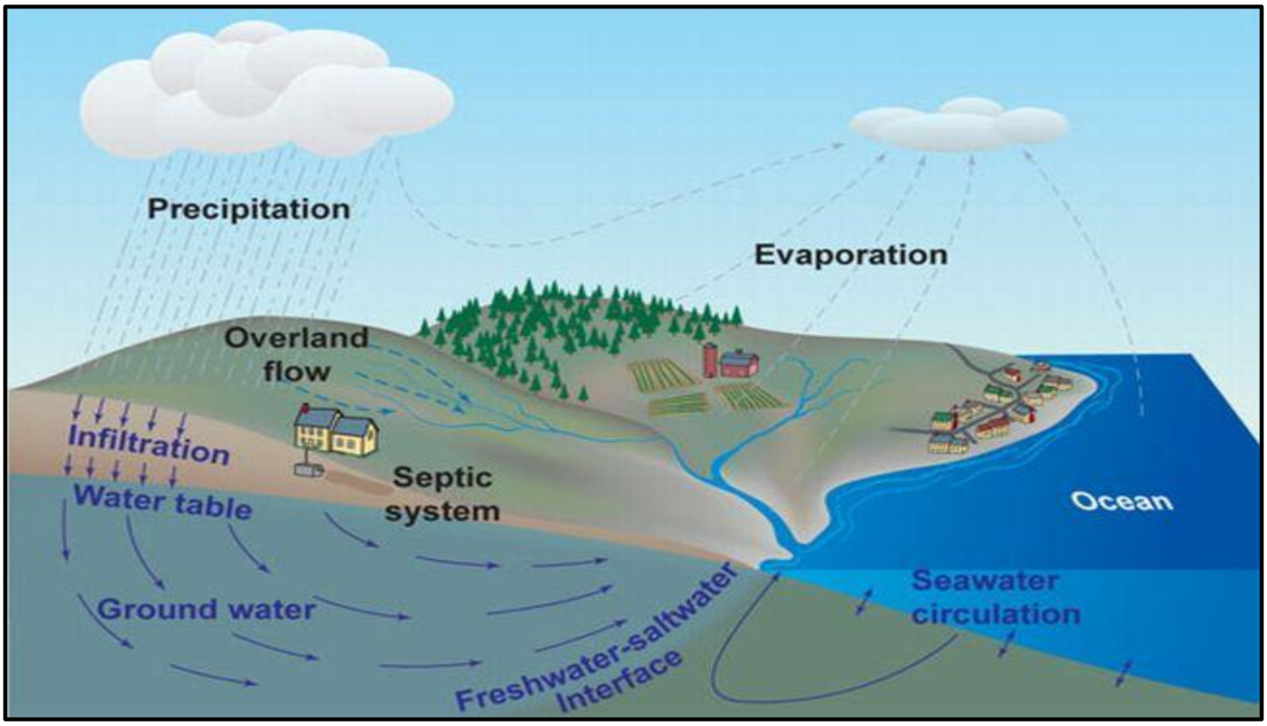

Figure 7: Fresh/Saline interface

B5: Constant evolution of the CSM

The development of the conceptual model is not necessarily a linear process. Preliminary model simulations can be conducted to test elements of the conceptualisation and highlight additional data that may be required. Therefore, the CSM should be constantly updated with newly obtained groundwater data such as hydrocensus information, aquifer tests, water quality data, and borehole logs.

C: CSM frequency

A CSM should be done for all new operations that have waste or products stored on a temporary or permanent basis that could have a potential impact on surface or groundwater quality and quantity by leaching into or coming into contact with water or large-scale dewatering activities. The following frequencies are proposed for Eskom's operations:

- For existing operations, such as newly built coal-fired power stations, operational coal-fired power stations, and dysfunctional mines, the CSM should be reviewed every second year during operation;
- When knowledge is obtained regarding new critical receptors;
- Before mothballed or decommissioned operations are reinstated;

- When new waste facilities are built, waste facilities expanded, contamination is observed through unidentified leakages or when contamination sources are newly delineated; and
- When large-scale abstraction is intended.

D: Output of the CSM process

The report presenting the conceptual model of the aquifer should be used as a planning and management document with the following minimum requirements:

- Description of the groundwater levels, flow directions, and discharge zones;
- Description of the unsaturated zone, such as depth and flow;
- Description of the lithological composition (for example, distribution of formations), which has a bearing on groundwater occurrence and the base of the groundwater system;
- Details regarding aquifer boundaries and compartments;
- Presence of features of importance to groundwater occurrence and movement (e.g. fractures, cavities, faults etc.);
- Piezometric levels of confined aquifers;
- Distribution of springs, seepage zones, and wetlands;
- Description of inflow and outflow zones;
- Analysis of groundwater flow and mechanisms;
- Quantification of groundwater flow and storage through a groundwater balance;
- Recharge and evapotranspiration potential;
- Distribution of land use (for example, irrigation, mining, waste dumps, urban areas);
- Identification of contamination sources and impacts (for example, dewatered or polluted areas); and
- Description of the water quality distribution throughout the groundwater system.

The above should be detailed in a minimum of two cross sections perpendicular to each other, crossing the key parts of the site and groundwater system.

3.10 Numerical/Analytical/Risk-based Groundwater Modelling Guideline (GWG09)

Introduction

A groundwater model is a numerical representation of a groundwater flow system that attempts to mimic the natural processes in nature. It is a simplified version of a natural system, compiled with geological, hydrogeological, hydrological, and meteorological data, which utilises a governing equation to incorporate all this data to simulate the hydraulic properties of the groundwater system.

Models are utilised to provide a quantitative understanding of a groundwater system in terms of existing conditions as well as induced stresses, which inherently aids in identifying cost-effective and efficient solutions to groundwater contamination and management challenges at Eskom.

Purpose

The purpose of this guideline is to ensure that there are clearly defined process controls in place to evaluate the groundwater model for Eskom personnel unfamiliar with groundwater modelling. The guideline is to be applied at all Eskom operations that have the potential for groundwater impacts. The level of detail to which the groundwater model will be constructed will be determined by the planning, conceptualisation and design phases.[11]

The modelling process

The modelling process is discussed under the headings below.

A: Model planning

During this stage of the process, the intended use of the model should be defined. This entails the description of modelling objectives and defining which questions should be answered by the model based on the Eskom objectives required.

A1: Intended use of the model

It is never possible for one model to answer all questions on groundwater behaviour. For example, a model designed to simulate regional-scale groundwater flow cannot be expected to predict local-scale groundwater processes (for example, groundwater interaction with one stream). Similarly, a local-scale model of impacts from contamination cannot be extrapolated to predict the impacts of dewatering and contamination of the entire catchment. Therefore, in the planning stage, at the outset of a modelling project, it is necessary to understand the intended use of the model clearly so

[11] Eskom, 2014. Site Characterisation Guideline

that it can be designed, constructed, and calibrated to meet the Eskom-particular requirements of the problem at hand.

A2: Defining modelling objectives

Modelling objectives should be prepared early in an Eskom modelling project as a statement of how the model will contribute to the successful completion or progress of the overall project. The modelling objectives should be defined as follows:

- Establish the context and framework within which the model development is being undertaken;
- Guide how the model will be designed, calibrated, and run; and
- Provide criteria for assessing whether the model is fit for purpose and whether it has yielded the answers to the Eskom-specific questions it was designed to address.

Often the objectives will involve the quantitative assessment of the response of heads, flows, or solute concentrations to future stresses on the aquifer system from Eskom's sources. However, in some cases, the objective may not be to quantify a future response. Rather, it may be to gain insight into the processes that are important under certain conditions, to identify knowledge gaps, and inform where additional effort should be focused to gather further information.

A3: Initial consideration of investigation scale

It is necessary to define the spatial and temporal scales considered important within the overall project scope initially. The spatial scale depends on the extent of the groundwater system of interest, the location of potential receptors (for example, a groundwater-dependent ecosystem) or the extent of anticipated impacts. The timescale of interest may relate to planning or development periods and/or system response periods (including system recovery, such as natural attenuation after closure). Further and more detailed consideration of model scale and extent occurs during the conceptualisation stage and is confirmed in the design stage of the project.

A4: Model confidence-level classification

A target model confidence-level classification should be agreed upon and documented at an early stage of the Eskom project to help clarify expectations. The classification can be estimated from a semiquantitative assessment of the available data on which the model is based (both for conceptualisation and for calibration), how the model is calibrated and how the predictions are formulated.

The initial assessment of the confidence-level classification should be revisited at later stages of the project, as many of the issues that influence the classification will not be known at the model planning stage.

Factors that should be considered in establishing the model confidence-level classification are discussed below. Many of these factors are unknown at the time of model planning, and, as such, the guidelines recommend reassessing the model confidence-level classification regularly throughout a modelling project. The level of confidence typically depends on:

- The available data (and the accuracy of that data) for the conceptualisation, design, and construction of the model. Consideration should be given to the spatial and temporal coverage of the available datasets and whether or not these are sufficient to fully characterise the aquifer and the historic groundwater behaviour that may be useful in model calibration;
- The calibration procedures that are undertaken during model development. Factors of importance include the types and quality of data incorporated in the calibration, the level of fidelity with which the model can reproduce observations, and the currency of calibration, that is, whether it can be demonstrated that the model can adequately represent present-day groundwater conditions. This is important if the model predictions are to be run from the present day forward;
- The consistency between the calibration and predictive analysis. Models of high confidence-level classification should be used in predictions in a manner that is consistent with their calibration. For example, a model calibrated in a steady state only will likely produce transient predictions of low confidence. Conversely, when a transient calibration is undertaken, the model may be expected to have a high level of confidence when the time frame of the predictive model is less than or similar to that of the calibration model; and
- The level of stresses applied in predictive models. When a predictive model includes stresses that are well outside the range of stresses included in calibration, the reliability of the predictions will be low, and the model confidence-level classification will be low.

A4: Defining exclusions

In the course of the modelling process, it may be found that specific features or areas of the model have a particularly low level of confidence. This may arise, for example, when the particular application or model area has insufficient reliable data on which to base calibration, when the model code may be unsuitable for a particular application or when the model was not developed for that purpose and, hence, outcomes are likely to be unreliable. In such cases, it should be noted that certain model outputs are likely to be particularly uncertain and therefore should not be relied upon. The modellers should provide an explicit statement of exclusions to help avoid inappropriate model use in the current project or any future projects that make use of the model.

A5: Review and update

In many Eskom modelling projects, the conceptualisation, calibration, and predictive analysis will be updated and revised as more information becomes available and modelling results illustrate the need for such revisions. It may be necessary to revise expectations of the confidence levels associated with the model outputs. This may be required if, for example, model calibration is more difficult than expected and the final calibrated model is less constrained than originally envisaged. Conversely, an upgrade in model confidence-level classification is also possible when additional data is obtained that improves the calibration of model parameters.

In some cases, the modelling objectives themselves will need to be revised or updated. This is rarely required if the overall project objectives remain unchanged but may be appropriate if the model is required to address additional issues that may arise during the project or when an existing model is applied in a new project.

A6: Model ownership

The planning stage is an appropriate time for the modeller and Eskom to agree on several issues about the future ownership and ongoing maintenance of the model. An agreement on intellectual property is a key aspect that both parties should understand at the outset. The discussion should extend to an agreement on how the model will be archived, including the data-file formats, the physical location of model files, long-term custodianship, and third-party access to the model.

B: Model conceptualisation

The first and most critical component of any modelling exercise is developing a suitable detailed CSM. The CSM is arguably the most important step in the whole modelling exercise as it defines the questions that need to be asked, the design of the model, the tools and techniques to be applied in the prediction, and the assumptions and data values that will be used in the modelling exercise. Conceptualisation is based on what is known about the system and its responses both under historic stresses and in its current condition. The conceptualisation must be strongly linked to the modelling objectives by providing a view of the possible range of impacts that may occur over the period of interest.

To perform this conceptualisation, data collection and analysis is required and is described as follows:

- Confirmation of the location and availability of the required data;
- Assessing the spatial distribution, richness, and validity of the data;
- Data analysis is commensurate with the level of confidence required. Detailed assessment could include complex statistical analysis together with an analysis of errors that can be used in later uncertainty analysis;
- Developing a model project database. The data used to develop the conceptualisation should be organised into a database, and a data inventory should be developed, including data source lists and references;
- Evaluation of the distribution of all parameters/observations so that model calibration can proceed with parameters within agreed and realistic limits. Parameter distributions for the conceptual model are sometimes best represented as statistical distributions;
- Justification of the initial parameter value estimates for all hydrogeological units; and
- Quantification of any flow processes or stresses (for example, recharge, abstraction).

Some of the compiled information will be used during the conceptualisation and during the design and calibration of the model. This includes the data about the model layers and hydraulic parameters and observations of hydraulic head, water table elevation, and fluxes.

C: Model design and construction

Model construction means implementing the model design, generally using commercial software, so that simulations can be performed. For numerical models, construction usually involves setting up the model in a GUI (Feflow, Visual Modflow, etc.), which acts as a front end or preprocessor for the numerical algorithm itself. The steps involved depend on the type of model and the modelling software chosen for the project. Most software packages work on a GIS-based GUI for the model construction. Commonly, numerical models should be constructed in the following sequence:

- Define the model domain and boundary conditions. This is commonly achieved by defining model boundaries, such as water divides or streams where a zero-flow condition exists, or a flow rate is known. Additionally, the domain is also defined by the depth of the aquifer of which the hydraulic characteristics are known. The model domain should encompass the investigated area;
- Create a grid or mesh to provide spatial discretisation in each model layer. Numerical models commonly work on finite difference cells (MODFLOW code), finite elements (FEFLOW code), or finite volumes (MODFLOW-USG code). These volumes are assigned specific parameters and attribute to define the aquifer properties and discretise the model into different hydrogeological zones to simulate the conditions in nature, which are known from the available data and CSM;
- Create model layers. This is commonly performed to simulate the differing hydrogeological layers in an aquifer found in nature. Differing geologies, weathering depths, and secondary structures are commonly found within an aquifer and strongly influence its flow characteristics. Therefore, these features must be included in the initial quantification and simulation and is an important defining factor for aquifer geometry;
- Define the distribution of model parameters to represent hydrogeological properties. Defining the parameters representing hydrogeological properties creates a numerical representation of the natural system and is important for the numerical solution produced by the simulation. The spatial distribution of these parameters strongly influence model calculations and should be defined as precisely as possible, with the data and CSM available; and
- Select time-stepping options, choose appropriate numerical solvers, and set convergence criteria. The model can be constructed to include temporal solutions based on time steps. Therefore, the modeller can define specific time steps and a period in which specific activities, such as abstraction or potential contamination, could take place at a site that does not necessarily allow steady-state conditions to be reached in an aquifer to understand the influence of impacts in a specified time scale. Additionally, time steps can also be defined to understand the influences of natural processes, such as recharge, on a system in a specified time frame. The choice of a numerical solver is directly linked to the objectives of the model, as the correct solver should be chosen for the correct application. An example of this would be the combined modelling of saturated and unsaturated model areas. Not all solvers are equipped to handle this type of calculation. Therefore, the correct solver choice is imperative to obtain results from a simulation. Additionally, depending on the level of precision required, the model convergence criteria should be adjusted accordingly. Smaller convergence figures may provide more precise solutions.

D: Model calibration and sensitivity analysis

D1: Calibration

Calibration is a process, following model design and construction, by means of which parameters are adjusted until model predictions fit historical measurements or observations so that the model can be accepted as a good representation of the physical system of interest. Calibration is often followed by sensitivity analysis to test the robustness of the model to changes in parameters during the calibration period.

The calibration process is also known as model fitting, history matching, parameter estimation, and the inverse problem. During calibration, the modeller first understands how changes in model parameters affect the capability of a model to simulate the groundwater system and fit historical measurements.

While automated calibration using computer software is available, it is still the most common practice for calibration to be attempted by trial and error. The model is run initially for the period when historical data is available, using initial estimates of all model parameters, or a steady-state solution is used for single parameter observations of natural conditions. Modelled heads and possibly fluxes are compared with observations, either numerically, graphically, or spatially on a map.

A commonly used measure of correspondence between measured and calculated values is a correlation scatter plot, which can indicate the accuracy of calculated hydraulic heads or fluxes upon visual inspection.

However, a more scientific numerical representation of calculation accuracy is statistical measures, such as the mean residual error. The mean sum of residuals uses absolute values of errors and is sometimes preferred because it places less weight on measurements that appear to be outliers. It can also include weights. The value calculated using this method indicates the degree of correspondence between measured and calculated parameters, the acceptability of which is dependent on the confidence level selected but should always be as close to zero as possible.

D2: Sensitivity analysis

During trial-and-error calibration, sensitivity analysis involves changing a model parameter by a small amount to establish how model predictions are affected by that change. Manual sensitivity analysis requires changing a single model parameter, rerunning the model to obtain a new set of predicted heads and fluxes, and observing the effect of the change, either visually or numerically, by differencing. In this context, a true sensitivity (derivative) is never calculated. The emphasis is on determining how sensitive the model is to each parameter, using a nontechnical interpretation of sensitivity.

A similar interpretation applies when best estimates of parameters have been found, whether by trial and error or automated calibration. At this time, the same approach can be applied to predictions, either during the calibration period (in the past) or during predictive scenarios (in the future). Time-series plots of heads or fluxes, contour plots, and tabulations of any kind of model predictions can be prepared using values of model parameters that are slightly higher or lower than the best estimates. These are compared visually with those based on the best estimates of parameter values. Hydrographs of predicted heads can include measurements of heads to provide a visual indication of goodness of fit with different parameter values. Care should be taken to choose increments in parameters that are sensible.

During automated model calibration, the search algorithm computes sensitivities of the objective function to changes in all parameters and uses them to guide the search. When the best estimates are found, these sensitivities are used to estimate the uncertainty in the best estimates. This type of sensitivity can be examined using PEST and similar software to gain insights into the calibration process. If a particular sensitivity is small, the available data used in calibration provides no information about that parameter. If a modeller tries to estimate a specific yield in a steady-state problem, the sensitivity of the objective function will always be zero. This clearly indicates that calibration will provide no information about specific yield.

Sensitivity analysis is related to uncertainty analysis, which is carried out following the stage of predicting the future behaviour of a system. In uncertainty analysis, sensitivities of predictions to model parameters are combined with a (statistical) description of parameter uncertainty, leading eventually to quantitative estimates of prediction uncertainty.

E: Verification

Verification involves comparing the predictions of the calibrated model to a set of measurements that were not used to calibrate the model. The aim is to confirm that the model is suitable for use as a predictive tool. Choosing not to use some data, and reserving it for verification, is a good idea in principle but may not make the best use of available data.

Verification of a model is difficult. Some people argue that groundwater modelling has dubious value because models cannot be verified. However, without modelling, it will never be possible to predict the future behaviour of groundwater systems.

F: Model predictions

All model predictions are uncertain. The modelling process should acknowledge and address uncertainty through an appropriate uncertainty analysis. Model predictions are used to obtain the outputs required to meet the project objectives. Accordingly, this is an appropriate time for the modellers and key stakeholders to revisit the project and the modelling objectives. Predictive models must be formulated in a manner that will provide the answers to those questions posed by the modelling objectives. They should include the appropriate representations of (future) boundary conditions, stresses, and any other model features appropriate for the questions asked.

Common applications for predictive models include the simulation of anthropogenic stresses to groundwater systems, such as contaminant plume movement from contamination sources in space and time.

Contaminant plume movement should account for heterogeneity. Questions that need to be addressed regarding the role of heterogeneity include:

- How do the hydrostratigraphic units control the solute concentration distribution?
- What aquifer connections exist that may determine the solute migration pathway?
- Are there any faults, other natural subsurface features, or fabricated elements, such as long-screened boreholes or open boreholes that can act as conduits for solutes, that might need to be considered?
- How does the heterogeneity within aquifers control the spreading of solutes, and how will this heterogeneity be represented in the model?

It is common practice in groundwater flow modelling to include hydraulic head maps in a report or a presentation. However, such maps have limited value in modelling studies of variable-density systems because, in contrast to uniform density systems under isotropic conditions, the hydraulic head gradient does not indicate the direction of groundwater flow. Therefore, rather than presenting the head contours to depict groundwater flow directions, reports on the results of variable-density models should present flow vectors or streamlines to visualise groundwater flow patterns.

If normalised concentrations are presented, (for example, as is sometimes done to compare simulations with variable concentration ranges), it should always be clear what concentration was used to normalise the values. Visualisation of contaminant plumes can be difficult and typically requires specialised visualisation software that allows slicing and extrusion of contours. A colour legend to indicate the concentration contour values is required when filled contours are presented. The red shades preferably refer to high concentrations and green shades to low concentrations.

G: Checking model results

All model results should be checked to ensure that there are no obvious errors. A series of checks are suggested that are equally applicable to all model runs (not only predictive runs). Checks should not be limited to those model results that are of direct importance or significance to the particular problem being addressed. It is the spurious model features, or so-called artefacts, in parts of the model that are not being directly reported that are commonly missed. It is important to assess, and if necessary, remove, modelling artefacts, as they can significantly reduce the value or accuracy of the result being sought. The following checks should be done on the model results:

- Water levels are representative of the real system;
- Concentrations are representative of the real system;
- The presence of anomalous boundary fluxes;
- Recharge because of rainfall does not exceed rainfall; and
- Model storage changes are not dominated by anomalous head increases in cells that receive recharge but are isolated from other cells or boundary conditions.

H: Uncertainty

Eskom management decisions will often be directly informed by model predictions. However, we now know there can be no expectation of a single ‘true’ model; thus, model results are uncertain. Understandable reporting of underlying uncertainty provides the necessary context to decision-makers, as model results are used for management decisions. This, in turn, forms a mechanism using groundwater models that inform a risk-management framework because uncertainty around a prediction provides the basis for estimating the probability or likelihood of some event occurring. Given that the consequences of management decisions vary, it follows that the extent of and resources devoted to an uncertainty analysis may depend on the consequences. A qualitative, limited uncertainty analysis may be sufficient for informing a decision for events with low impact. On the other hand, for events with a high impact, the risks may be better assessed and associated decisions made using more robust and comprehensive uncertainty analysis.

I: Numerical/Analytical/Risk-based groundwater modelling output

Model reporting encompasses all communication of conceptualisation, model design, construction, performance, and outputs from predictions. This is traditionally achieved through a written technical document compiled as a staged or phased report. This report should at least include detail on the conceptualisation and design, the calibration of the model, and the model predictions. Staged reporting of key model aspects makes it possible to change or remediate the direction of the project and allows the model team to align the expectations of the client and a stakeholder with what is achievable within the project. It also allows the overall report to be prepared progressively throughout the study, with opportunities for progressive reviews, which should benefit the quality of the final report. All steps and assumptions should be clearly and thoroughly detailed in each report to make the information accessible to all stakeholders and any other interested parties.

The structure of these guidelines can be used as a template for reporting many modelling projects. Some of the important aspects that need to be addressed in a model report include:

- Model objectives;
- CSM;
- Model code, design, and construction;
- Status quo of the groundwater flow and quality before impact prediction;
- Model calibration and sensitivity analysis;
- Uncertainty analysis;
- Predictive modelling identifying potential impacts during the operations as well after the closure of the operation;
- The influence of mitigation measures on potential impacts to assist Eskom in managing risk;
- Highlighting of risk areas where receptors may be impacted and when;
- Gap analysis;
- Model assumptions, capabilities, and limitations;
- Conclusions and recommendations; and
- Review report.

The conclusions are linked to the objectives and describe the degree to which the modelling succeeded in meeting the objectives, along with highlights from the results. Conclusions can lead to recommendations for preferred management/mitigation options.

Additionally, data visualisation is important in the reporting phase. The groundwater modelling process collects or generates much spatial and temporal data and information. Traditional graphics, such as time series and scatter plots, maps, contour maps, cross sections, and schematic sketches or diagrams of conceptual models, are often the most suited and intuitive tools to communicate groundwater data.

J: Reviews

Three levels of review should be undertaken: a model appraisal by a non-technical reviewer within Eskom to evaluate model results, an in-depth peer review by experienced hydrogeologists and modellers, and a post-audit review involving a critical re-examination of the model when new data is available or when the model objectives change. The post-audit review may happen long after the modelling project has taken place.

Review checklist:

- Are the model objectives and model confidence-level classification clearly stated?
- Are the objectives satisfied?
- Is the conceptual model consistent with objectives and confidence-level classification?
- Is the conceptual model based on all available data, presented clearly, and reviewed by an appropriate reviewer?
- Does the model design conform to best practice?
- Is the model calibration satisfactory?
- Are the calibrated parameter values and estimated fluxes plausible?
- Do the model predictions conform to best practice?
- Is the uncertainty associated with the predictions reported?
- Is the model fit for purpose?

The questions in the checklist are intended to be generic and widely applicable. Reviewers should apply their experienced judgement on whether a question is applicable or to what degree the question needs to be satisfied in the context of the stated model purpose/objectives based on the model objectives and model confidence level.

3.11 Risk Assessment Guideline (GWG10)

Introduction

Groundwater risk assessment entails understanding the generation of the groundwater hazard, the probability that the hazard will occur, and the consequences if it should occur, that is, understanding the complete cause-and-effect cycle. The most basic risk assessment methodology is based on defining and understanding the three basic components of the risk, that is, the source of the risk (source term), the pathway along which the risk propagates, and finally, the target that experiences the risk (receptor). Therefore, the risk-assessment approach aims to describe and define the relationship between cause and effect. In the absence of any one of the three components, it is possible to conclude that groundwater risk does not exist.

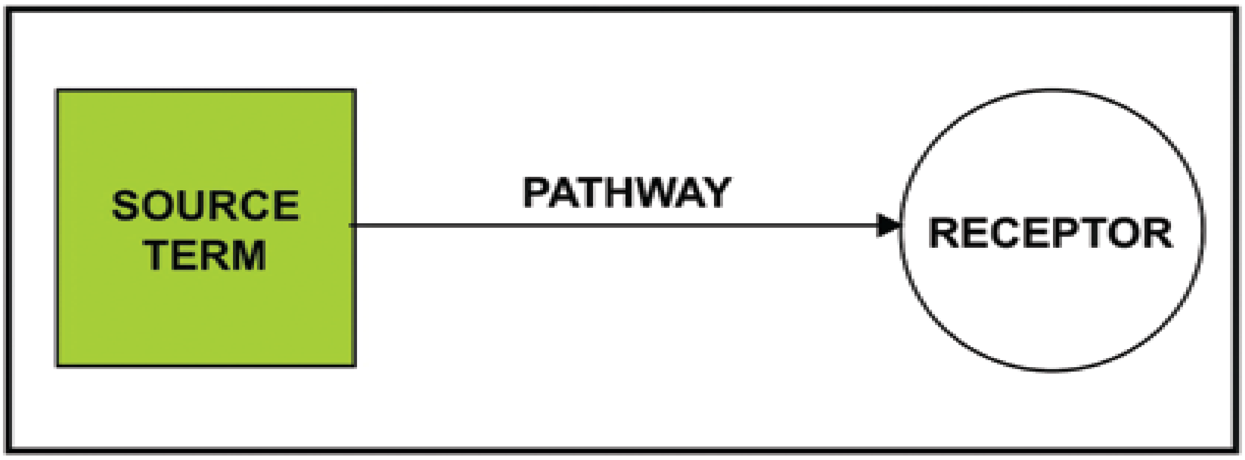

Figure 8: General groundwater risk assessment components

(Taken from BPG: Impact Prediction, 2008)

Purpose

The purpose of this guideline is to ensure that there are clearly defined process controls in place to assist Eskom personnel unfamiliar with hydrogeology to evaluate and conduct a groundwater risk assessment. The intended use of the guideline is for Eskom personnel to evaluate a groundwater risk assessment and to provide guidance for consulting scientists on conducting an Eskom groundwater risk assessment.

Conducting a groundwater risk assessment

A: Risk assessment objectives and principles

A complete groundwater risk assessment should assess the three components: the source, the pathway, and the receptor. Generally, at Eskom's operations, multiple source terms, pathways, and receptors exist, and a full site risk assessment may require a fully integrated assessment where the various source terms, pathways, and receptors are considered (see illustrative Figure 12 and Figure 13).

A typical example can be seen in Figure 13 below. An opencast mine with various decant points serves as the source term. The receiving watercourses (Bosmanspruit and Klein Olifants River) and private boreholes (Piet's pump) used for irrigation are the critical receptors. In such a predefined scenario, the assessment is greatly simplified. Through an appropriate screening-level assessment, the critical receptor, be it the irrigation farmer, potential endangered endemic fish species in the Klein Olifants River, or both, could be defined.

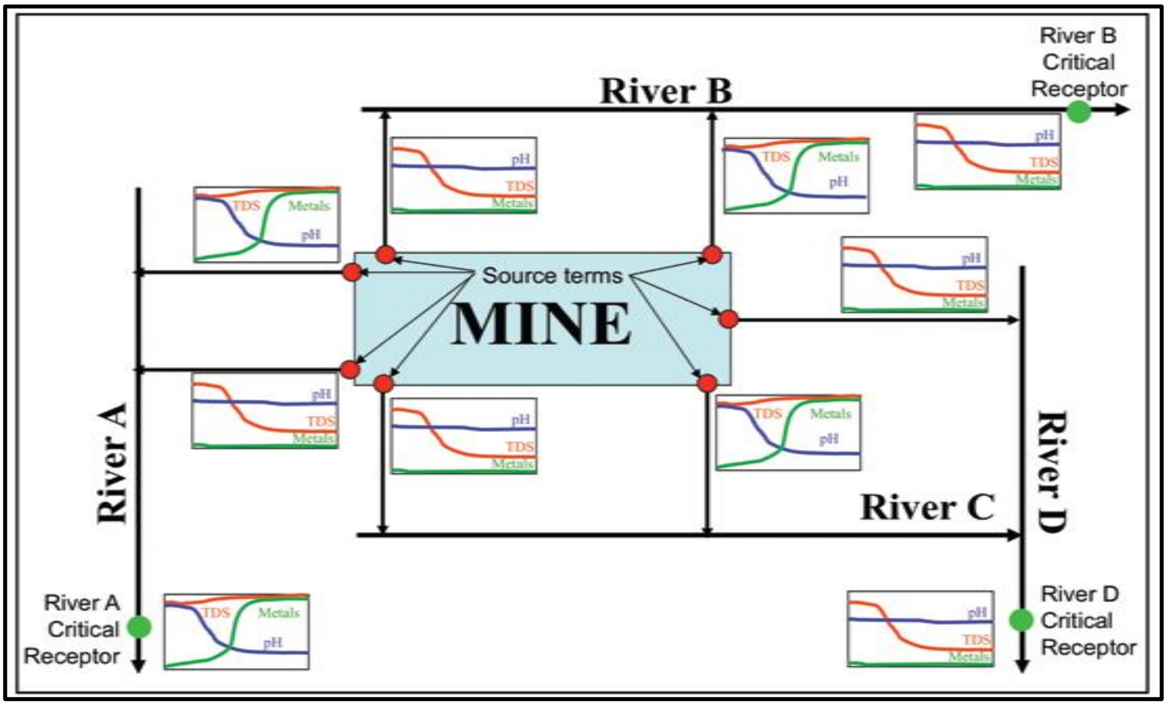

Figure 9: Risk assessment for multiple source terms and receptors
(Taken from BPG: Impact Prediction, 2008)

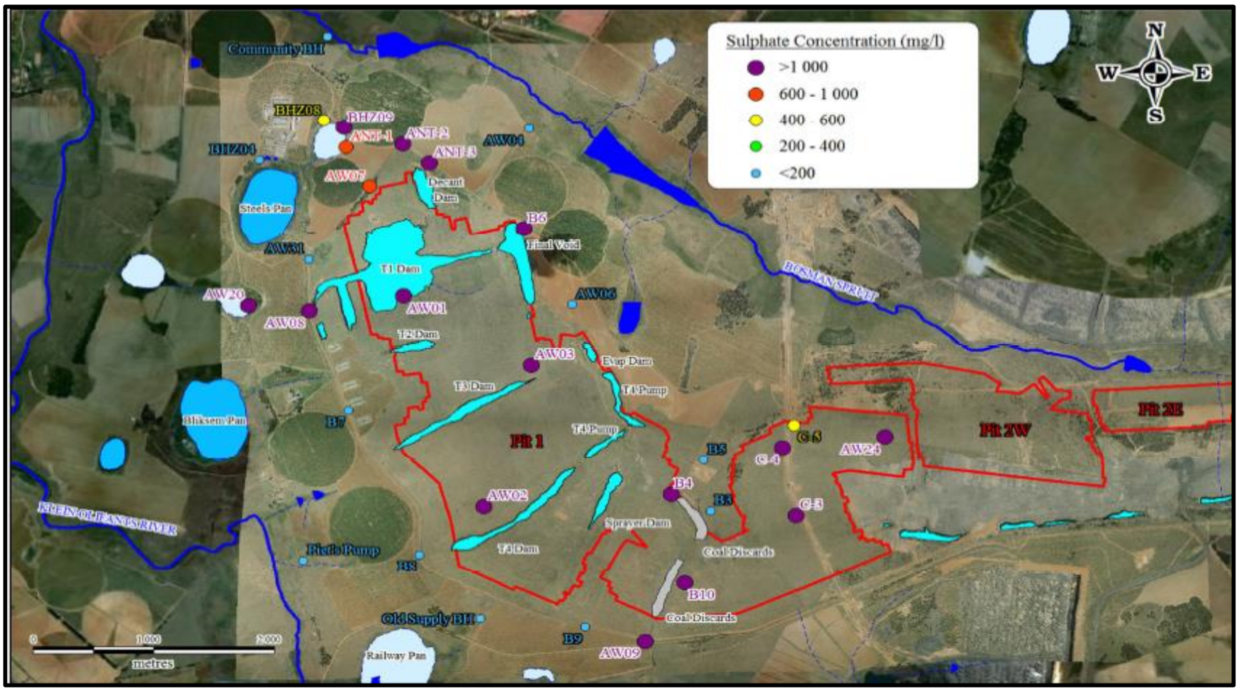

Figure 10: Sources and receptors at Arnot Defunct Colliery

(Taken from UFS, Water Management Plan, 2013)

B: Risk assessment procedure

A quantitative risk assessment is technically very complex and should be conducted by SACNASP-registered hydrogeologist. An initial screening-level assessment should be undertaken to determine the critical receptor(s) for a particular source term, which would be the most severely impacted. A fully integrated quantitative risk assessment should use the 'source-pathway-receptor' model and involves the following components:

- Assessing of the source terms and properties of the chemical substance (solubility, infiltration potential, toxicity, etc.);
- Identifying and confirming the beneficial uses in the vicinity of the site through a hydrocensus and review of expected land use;
- Determining groundwater flow direction and the potential exposure of the receptors to the chemical substances (for example, the site may be located hydraulically down-gradient of a sensitive receiver and an assessment has demonstrated that impacted groundwater will migrate towards the receiver); and
- Assessing the impact on water quality in the receiving environment compared to DWS water quality criteria.

Eskom requires that a quantitative risk assessment be performed in the following circumstances:

- Where ecosystem protection is the principal beneficial use and harm to water resource/ecosystem may occur; and
- The beneficial uses of the groundwater are for a potable water supply, and harm to a water user may occur.

Sites identified through the risk assessment process as having a high risk to human health or the environment will be considered a priority site and may require immediate remediation by Eskom.

The CSM will help define the sources of potential impact, the pathways for groundwater impact and receptor (the receiving (potentially impacted) environment). The level of complexity of the risk assessment should be appropriate to both the objectives of the site, its characteristics, and available data.

B1: Importance of the CSM

The first and most critical component of a risk and impact assessment is developing a suitably detailed CSM. The CSM is arguably the most important step in the whole risk assessment exercise, as it defines the questions that need to be asked, the design of the sampling programme, the tools and techniques to be applied in the prediction, and the various assumptions and data values that will be used in the risk assessment.

B2: Defining the source term

In the context of predictions of impact on the water resource at Eskom's operations, the source term could include any of the following:

- Effluent or dirty water dams;
- Contaminated stormwater dams and channels;
- Coal stockyards;
- (Engineering) wash bays;
- Ash management systems (dry and wet);
- Sewage treatment works;
- Mechanical and electrical workshops;
- Contractor yards;
- Chemical storage tanks;
- Solid waste disposal sites;
- Opencast pits and underground mines;
- Quantity of water such as decant;

- Conveyor coal and ash spillages;
- Fuel storage facilities;
- Hazardous waste storage facilities; and
- Any other potential source of impact.

It is important to note that the various source terms described above are all very complex facilities for confidently predicting their behaviour into the future. The future behaviour of the source terms is determined by three primary driving forces:

- The geochemistry of the material within the reaction pathway;
- The hydraulic characteristics of the source, which liberate and mobilise the chemical reaction products; and
- Source management.

The approach to defining the behaviour of the source term will always start with the definition of the key questions that need to be answered for the source term:

- Will any waste material be generated that has the potential to contaminate?
- What is the level of toxicity of the waste? The potential for different wastes to pollute water resources differs greatly, depending on the composition of the waste and its potential for degradation over time. South African legislation broadly classifies waste under two categories, namely general and hazardous waste. Between these two categories lies a continuum, with a transition from what could be described as non-toxic to toxic. When referring to a level of toxicity, the constituent itself must be considered and also the potential user of the water, for example, human, animal, aquatic life, or irrigation;
- What quantity of waste will be produced? Toxicity and quantity of waste go hand in hand. Experience has shown that it is easier to dispose of, manage, and contain small quantities of waste than large quantities. The risk for groundwater contamination is usually greater at large waste disposal facilities, where it is often impossible to prevent groundwater contamination because of the nature and scale of operations;
- What is the potential for leachate generation? By using synthetic liners, it is theoretically possible to completely contain leachate from a waste site. This is, however, mostly impractical and very costly. It is also generally accepted that all liners leak to some extent, whether it be greater or lesser. In reality, therefore, leachate that is generated at a disposal site may eventually reach the groundwater regime;
- Is there a potential to separate and manage waste streams according to their contamination potential?
- Are there any potential positive or negative consequences of storing and/or disposing of these waste materials in any particular fashion, on their own or in any combination?
- How would alternative techniques and layouts affect the potential impact on the identified receptor water resource (surface and groundwater balance and quality)?

- 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 operation and after closure?
- What final rehabilitation should be undertaken for the different waste storage facilities to meet long-term risk management objectives for the water resource?
- What will the long-term impact be at the critical receptor for the contaminants of concern?
- What additional water management (covers, infiltration reduction measures, etc.) or treatment measures must be instituted to reduce the contaminant loads from the source terms or to intercept the pathways to ensure that the critical receptor is not harmed?
- The following tools should be used to define the source term:
    - Waste classification, using DWAF, 2005 Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste, Third Edition;
    - Geochemical sampling and analytical programme. Bulk samples and waste streams from pilot studies and application of static and kinetic analytical procedures to these samples and comparison with actual data of other similar operations. Consider simplified mathematical modelling;
    - Hydraulic infiltration models or estimates detailing time-based infiltration rates during and after closure of the operation;
    - Geohydrological models that incorporate regional groundwater and surface water hydrology and quality that presents detailed time-based water quality profiles at the critical receptor for at least 100 years or until the water quality at this point has reached stable conditions;
    - Water balance models that will assist in defining and driving water management strategies;
    - Geochemical models (oxidation rate, speciation, and mass balance) detailing time-based chemical change during and after closure of the operation; and
    - Engineering designs of the waste facilities.

The output from defining source term characterisation should be presented in the form of graphs (with datasets) that show how seepage volumes and quality (for the various contaminants of concern) vary into the future.

It needs to be recognised that source terms are dynamic and could exhibit a variable quality over time, because of changes in hydrology and chemistry. An impact assessment that defines the source term as a constant static feature over time is unlikely to be realistic and would be inappropriate for anything other than the most basic screening-level assessment.

B3: Defining the pathway

In Eskom's context and for potential impacts on the water resource, the groundwater pathway through which contaminants could move would most typically be one or more of the following:

- Movement through the vadose (unsaturated) zone;

- Movement through an aquifer; and
- Movement through mining voids (underground or open-cast).

In the context of defining the pathways, it is important to note that the pathways may have the following features:

- Hydraulic conduit (pathway) for the mobilisation and movement of the contaminants of concern from the source term to the receptor;
- Attenuation of contaminants, the release of new contaminants, and alteration of the chemistry of the discharge from the source term through a variety of chemical reactions; and
- Habitat for receptors, such as wetlands, rivers, etc.

The detailed pathway assessment that will follow from the conceptual model may need to make use of a combination of the following tools:

- Aquifer testing;
- Geohydrological models (possibly with consideration of attenuation mechanisms);
- Hydrology/Runoff models; and
- Water quality models for surface water systems.

The output from the pathway characterisation should be presented in the form of graphs (with datasets) that show how water quality (for the various contaminants of concern) varies into the future at the critical receptor. Given that hydrology changes on a seasonal and annual basis, it follows that these changes will also affect the water quality at the receptor. Therefore, it is 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 through continuous monitoring.

B4: Defining the receptor

As the final component of the risk assessment, the receptors in the context of the water resource would-be users of the water resource itself and typical examples could be the following:

- Groundwater user abstracting contaminated groundwater through a borehole for domestic use, livestock watering, or irrigation;
- Aquatic fauna and flora in a receiving watercourse; and
- Any water user abstracting water from an impacted watercourse.

13.3.2.4.1 Identification of risk, probability of occurrence, and consequence of occurrence

While various mechanisms can be used to evaluate the effect of various contaminants of concern on the various receptors, the common approach in groundwater risk assessments would be to use published or regulatory water quality criteria for the receptor (user) of interest.

If the linkage between the source and the receptor is established, the DWS series of water quality guidelines for the various recognised water users that incorporate consideration of dose-response information should be used to quantify the consequence of the risk. Unless a unique critical receptor is identified for a risk assessment, it would be appropriate to make use of:

- Published DWS water quality guidelines based on use and frequency of use;
- Any specific RQOs that derive from a reserve determination; or
- Consultation with affected water users/receptors.

Please note that groundwater risk because of Eskom operations does not exist at an operation if the chemical substances present on or below the surface of the site are the result of the natural environment and are not present as a result of the activity that has occurred at the operation.

The DWS guidelines tend to be conservative, relaxed guidelines that would require a more detailed risk assessment, using typical dose-response modelling to illustrate the consequence to the critical receptor based on the toxicology. 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.

As it is generally impractical and unnecessary to consider the full range of potential receptors that may be affected by any particular source term, it is appropriate to define a critical receptor, which is usually the water user that is the closest to the source term or that is the most sensitive to contaminants produced by the source term. In determining the critical receptor, it is also necessary to consider potential future receptors. The critical receptor should be clearly defined in the conceptual model and agreed upon with the affected parties and DWS before a detailed risk assessment through dose-response modelling is undertaken.

B5: Potential for groundwater usage

The potential for groundwater utilisation from a specific aquifer may change with time, and a groundwater resource that presently seems unimportant may, in future, be a valuable asset. Furthermore, new receptors, such as informal settlements, may change the risk profile of the site over time.

C: Risk assessment frequency

Eskom requires that a quantitative risk assessment be performed in the following circumstances:

- Where ecosystem protection is the principal beneficial use, and harm to a water resource/ecosystem may occur; and
- The beneficial uses of the groundwater are for a potable water supply, and harm to a water user may occur.

Sites identified through the risk assessment process as having a high risk to human health or the environment will be considered a priority site and may require immediate remediation by Eskom.

Therefore, a risk assessment should be done for all new operations that have waste or products stored on a temporary or permanent basis that could potentially affect surface or groundwater quality or quantity, either by dewatering activities, leaching into, or coming into contact with water. The following frequencies are proposed for Eskom's operations:

- For existing operations, such as newly built coal-fired power stations, operational coal-fired power stations, and dysfunctional mines, risk assessments should be reviewed every second year during operation;
- Before mothballed or decommissioned operations are reinstated;
- When knowledge is obtained regarding new critical receptors; and
- When new waste facilities are built, waste facilities expanded, contamination is observed through unidentified leakages, large-scale dewatering occurs, or when contamination sources are newly delineated.

D: Output of the risk assessment process

A report with the following minimum requirements should be submitted:

- CSM;
- Definition of all contaminant sources;
- Definition of the groundwater pathway in space and time;
- Definition of the receptor;
- Natural environmental background water qualities;
- Identification of risk identify the probability of occurrence and consequence of occurrence;
- Risks ranked in terms of probability and consequence based on DWA water quality criteria and background water qualities; and
- Risk management and mitigation plan.

3.12 Pollution Source Management Guideline (GWG11)

Introduction

The groundwater impacts of Eskom operations can be significant, persistent, and expensive to remediate or manage. Therefore, all reasonable efforts must be made to prevent pollution and minimise impacts. Pollution-prevention strategies can be effectively planned, developed, and implemented in the pre-operational, operational, and closure phases of Eskom's operations. Effective pollution prevention reduces the management and financial burden associated with remediation during the operational and especially closure phases.

Purpose

The purpose of this guideline is to ensure that there are clearly defined process controls in place to evaluate pollution source management for Eskom personnel unfamiliar with groundwater management measures. The guideline is to be applied at all Eskom operations that have the potential for groundwater impacts.

Pollution source management

Pollution prevention is the foundation of the hierarchy of decision-making used by DWS to protect the water resource from waste impacts. This hierarchy is based on a precautionary approach using the following order of priority for wastewater:

1. Pollution prevention;
2. Minimisation of impacts through water reuse, reclamation, and treatment; and
3. Discharge or disposal of wastewater through a site-specific risk-based approach in which the polluter pays.

In the first instance, the core of integrated water management at Eskom operations should be to implement pollution-prevention measures optimally. If these measures do not address all the water management issues, the operation should, secondly, develop and implement appropriate water reuse and reclamation strategies. These strategies may include a greater or lesser degree of water treatment to render the water suitable for reuse. If there is still a residual water management problem, then the operation could evaluate and negotiate options with DWS for the discharge of such water to the water resource.

The abovementioned fundamental principle of pollution prevention can be elaborated upon by way of defining several secondary principles:

1. Prevention is better than cure, and good planning reduces the environmental and financial liabilities;
2. Sustainability is a key principle, as it would ensure a positive legacy for future generations, not a liability;

3. Use and impact as little water as practicably possible;
4. The closer a pollution-prevention system is to the source, the more effective it is likely to be;
5. Pollution prevention is a planning and design process that is considered and applied for each life cycle phase of the operation through to after closure;
6. Pollution-prevention measures must be considered and applied throughout the entire operation process chain through to waste disposal;
7. Passive pollution-prevention systems are preferred to active systems because of their generally more robust nature, often with a lower risk of failure;
8. If measures are properly applied during the full life cycle, post-closure risks and liabilities are reduced;
9. Pollution prevention is not the endpoint, and minimisation of residual impacts through recycling, treatment, and/or safe and secure disposal will most likely be required;
10. Apply closure pollution-prevention measures during the operational phase and monitor the performance to validate pollution-prevention performance; and
11. Continuous improvement of pollution-prevention systems should be monitored, assessed, and improved on an ongoing basis.

Eskom pollution source management should be based on passive management principles, for example, the need for ongoing intervention and active management is minimal, but not zero. Examples of passive measures include stormwater diversion berms and drains, the lining of pollution control dams, finger drains under ash disposal facilities, and toe paddocks around such facilities. Passive pollution-prevention measures are essentially based on good planning and design to prevent a pollution problem from arising, rather than relying on active intervention to intercept and treat contaminated water. However, situations are often encountered where active impact minimisation management measures are required to supplement the passive pollution-prevention measures.

A: Pollution source management procedure

The individual steps incorporated in the pollution-prevention assessment procedure are discussed below.

A1: Identify and characterise all potential pollution sources

The initial step in identifying pollution-prevention options is first to understand where all the potential sources of pollution of the operation are located. Once these sources have been defined, it is necessary to qualitatively characterise the sources to understand the potential modes and pathways of pollution that may arise from each and the receptors that may be affected by the pollution. Risk assessment techniques can be applied to do this.

A2: Identify pollution-prevention alternatives for each pollution source

There are normally several alternative options that could be considered to prevent pollution from any pollution source. These options would ultimately influence either the water balance or the factors affecting water quality, or both. In most cases, a suitably qualified person with reasonable experience will be capable of identifying and specifying an appropriate set of alternative pollution-prevention options that should be considered, particularly as these are most often quite logical countermeasures that derive from knowledge of the potential pollution sources, materials, and their mode of pollution.

A3: Assess location for fatal flaws and enhanced pollution potential

Correct location of components of an operation is often one of the most important pollution-prevention decisions that can be made. In undertaking this step, a sound understanding of the conceptual model and receptors of potential pollution is required. This is especially true for the placement of waste disposal facilities that generally have a perpetual footprint.

Location of facilities is also very important from a stormwater management perspective, where a conscious effort needs to be made to minimise the size of the area that produces dirty runoff while maximising the size of the area that produces clean runoff. This will require conscious assessment and design intervention to group facilities that cause dirty runoff together into a restricted number and size of catchments. This consideration will also ensure that waste material with a pollution potential is not used for activities such as road building, resulting in a much larger contaminated runoff and seepage footprint.

A4: Consider water balance in terms of pollution prevention

Pollution prevention most often entails applying measures that modify the water balance and/or factors that affect water quality. In general terms, it can be stated that successful pollution-prevention alternatives typically reduce the volumes of water that come into contact with sources of pollution, while impact minimisation alternatives will typically reduce the volumes of contaminated water that can migrate along transport pathways to potential receptors.

Each of the pollution-prevention alternatives identified should be assessed and characterised in terms of the effect that the strategy would have on the system's water balance and how this effect serves to prevent or minimise pollution. This assessment should be undertaken quantitatively so that alternatives can be properly compared against each other. However, it must be emphasised that the alternative that has the biggest positive impact on water balance or quality is not always the alternative that should be implemented. This could be for practicality, cost-benefit, or water quality considerations.

It is also important to emphasise that the water balance calculations will be subject to uncertainty because of many factors such as natural variability in model input parameters, model simplifications, and the unpredictability of future hydrological and climatic conditions. This uncertainty is a natural feature of predictive modelling and does not invalidate the modelling. It simply requires that the extent and effect of the uncertainty be understood, quantified, and stated.

A5: Assess factors affecting water quality

Factors affecting water quality are typically more complex and difficult to determine and quantify because the chemical and microbiological factors that affect water quality are inherently more complex than those that affect water balance. It is also important to emphasise that the geochemical and water quality calculations will be subject to uncertainty because of many factors, as described previously. This uncertainty is a natural feature of predictive modelling and does not invalidate the modelling. It simply requires that the extent and effect of the uncertainty be understood, quantified, and stated.

For operations still in the planning phase, it is important that samples of material that would find its way into the residue deposits be identified and that this material undergoes the necessary geochemical characterisation to support the water quality evaluations. Where it is necessary to assess the water quality impacts of facilities that have a very long-term presence, such as waste residue deposits, it is necessary to evaluate the water quality implications of alternative pollution-prevention options in a quantitative and not just qualitative manner, using appropriate assessment techniques.

A6: Define temporal impacts profile

It is necessary to evaluate the potential pollution impacts that will persist for at least 100 years (or such other time as is agreed with the relevant authorities) after the closure of those facilities. These time-based or temporal impact profiles should be prepared for all alternatives being considered. This ensures that a pollution-prevention option with the best short-term benefit but poor long-term benefits is not inadvertently selected.

A7: Define the acceptable level of impact criteria

To assess which pollution-prevention options are appropriate, it is necessary to establish an understanding of what level of impact is considered acceptable by using a risk assessment process and to agree on this with DWS and interested and affected parties. The criteria that denote an acceptable level of impact will differ from operation to operation and from catchment to catchment, with new operations generally being required to comply with more stringent criteria, primarily because it is possible to optimise pollution-prevention strategies at the planning phase and to design these operations to have minimal impacts. The criteria for acceptable levels of impact can also change over the life of the operation because of other changes, such as land-use patterns, values, population and demographic changes, more stringent environmental standards, etc. This requirement is also often driven by the fact that water is in short supply, and there is a higher need for water reuse and reclamation.

It is also important, when considering the criteria for an acceptable level of impact, to take account of the temporal variation in impact for those operations and facilities that have very long lifetimes. The level of uncertainty in the impact predictions must also be considered so that error margins can be applied to account for this uncertainty.

A8: Implement preferred pollution-prevention option

Where a preferred pollution-prevention option can be identified and agreed upon that fully addresses the pollution risks associated with that facility without the need for additional impact minimisation measures, and provided it is a practical and affordable option, this option should be defined and documented in the EMP, IWWMP, and Integrated Water Use Licence and closure plan. It should be remembered that the implementation of such a pollution-prevention option should be accompanied by an appropriate monitoring and auditing programme to ensure that the desired pollution-prevention objectives are being met and to identify the need for any additional impact minimisation measures.

A9: Consider mitigation measures required

Where no pollution-prevention option can be identified that fully meets the criteria for acceptable levels of impact, the best option that partially addresses the pollution risks associated with that facility should be defined and documented in the EMP, IWWMP, IWUL, and closure plan. It must be remembered that the implementation of such a pollution-prevention option must be accompanied by an appropriate monitoring and auditing programme to ensure that the desired pollution-prevention objectives are being met and to identify the need for any additional impact minimisation measures. As the identified pollution-prevention option only partially addresses the pollution impact, additional impact mitigation measures will need to be identified and implemented to minimise the impact further until the criteria for acceptable impact are met. The additional impact minimisation and mitigation measures are likely to entail some degree of interception and collection of contaminated water and the subsequent reuse or reclamation/treatment.

A10: Define additional actions required to ensure sustainable performance after closure

It is necessary to determine what additional actions may need to be implemented to ensure that the applied management measures continue to provide the required environmental performance after closure, considering all the above mentioned uncertainties. It is possible that the identified additional actions only need implementation at or near decommissioning and then these measures must be planned and budgeted for. This step should also define clear ongoing monitoring, auditing, and review processes that should be implemented to assess the compliance of the applied management actions with agreed performance objectives and to identify additional measures that may be required.

B: Pollution-prevention opportunities

The common thread throughout the pollution source management is to prevent or minimise pollution through applying appropriate assessment techniques, applying appropriate design, and the ongoing and effective management and re-evaluation of the installed pollution management measures.

B1: Pre-establishment of an operation

Pollution prevention starts in the planning phase of an operation by evaluating plans. It aims to understand the potential impacts of alternative working methodologies and requires a conscious effort to select, design, and implement the alternatives that maximise the ability to prevent pollution. Pre-establishment of an operation with typical pollution-prevention considerations include those shown below:

- A detailed geochemical characterisation of the material to be stored/handled should be undertaken. This will assist in differentiating between material that will be beneficiated and report to disposal facilities and the material that will report directly to waste rock dumps. Handling and placement strategies for the material should then be based on the geochemical characterisation of the material, to place the material in such a way that the long-term pollution potential is minimised;
- Locate waste residue deposits in areas where there is a minimum potential for contamination of the ground and surface water resource, and construct water management facilities to intercept and contain any contaminated runoff and/or seepage;
- Apply effective stormwater management to ensure that clean runoff is maximised and diverted to the receiving water resource, while contaminated runoff is minimised and contained for reuse within the operation;
- Apply water management measures within the operations that are aimed at minimising the potential for water quality deterioration because of the oxidation of sulphide minerals by reducing the available contact time between water and exposed sulphide minerals;
- Apply appropriate hydrological, geohydrological, and geochemical assessment techniques to the evaluation of design, ongoing operation, and rehabilitation measures for waste residue deposits to identify those options that will minimise the long-term pollution risks of such facilities;
- Apply appropriate hydrological, geohydrological, and geochemical assessment techniques to the design of closure strategies to identify those options that will minimise the long-term pollution risks of such facilities;
- Boreholes may be required in strategic locations near the pollution source to obtain information on the groundwater regime as well as for future monitoring purposes;

- Before operation, a plan that includes explicit consideration of closure and rehabilitation issues must be prepared and approved. These plans define the sequence and nature of operations and detail the methods used in closure and restoration. During operation, the plans should be updated regularly (every three to five years). All operational planning and activities should be undertaken with eventual closure in mind, in such a way that operations can end in a manner that minimises the final risks and liabilities in the post-closure phase; and
- Long-term planning and sustainability should be considered. Therefore, predictions on water quality and quantity into the future should be incorporated (predictive modelling) to ensure that reuse and reclamation plans are not affected by future processes.

B2: During operation

Pollution prevention

Deterioration of water quality must be prevented wherever possible and minimised where complete prevention is not possible:

- Rationalise the layout of all infrastructure and aspects where contaminated stormwater could be generated so that footprint size and affected catchment areas are minimised, clean runoff volume is maximised and diverted straight to natural water bodies, and contaminated runoff volume is minimised and fully retained in properly sized and located pollution control dams;
- Store all potential sources of contamination in secure facilities with appropriate stormwater management systems to ensure that contaminants are not released in the water resource through stormwater runoff. Apply effective stormwater management to ensure that clean runoff is maximised and diverted to the receiving water resource, while contaminated runoff is minimised and contained for reuse within the operation;
- Construct detailed water and salt balances that take account of climatic and operational variability. This will be used as a planning tool to ensure that all pollution control dams are adequately sized and that they are integrated into robust water reuse and reclamation strategy to ensure that captured contaminated water is effectively reused within the operations and that system spillages to the environment are avoided;
- Evaluate alternative process plant technologies, including cleaner production techniques and closed-circuit water use to reduce the pollution potential associated with the operation;
- Establish proper storage, handling, and monitoring of fuel and chemicals used on-site to minimise the risk of spillages to the environment; and
- Institute detailed monitoring systems capable of detecting pollution at the earliest possible stage at all facilities where significant pollution potential exists. This can lead to rapid and effective management actions to address the pollution source and minimise it to the fullest extent possible.

Conservation

Losses of water and consumptive use of water must be minimised:

- Ensure that seepage/overflow losses from storage facilities are minimised, for example, facilities that can affect the water resource through seepage may need to be lined. Storage facilities should be designed with sufficient capacity and operated at a level that will allow them to accommodate storm events without overflowing or spilling (capacity requirements as stipulated by GNR No. 704);
- Use raw water only for processes requiring such good water quality and for additional water requirements that cannot be supplied within the water network of the operation;
- Assess the technology being used for the design, operations, and closure of ash disposal facilities, including whether alternative technologies could be applied (particularly important for new operations) or whether the technology could be modified or improved.

Sustainability

- Develop water and salt balance projections based on geochemical investigations; and
- Long-term planning and sustainability should be re-evaluated, and therefore predictions of water quality and quantity into the future should be remodelled based on monitoring results.

B3: After closure

Other than water treatment, the opportunities to prevent pollution in the closure phase are generally limited if they have not been considered and implemented earlier in the operations.

- Remove potential sources of pollution, such as hydrocarbon contaminated soils, and dispose of such pollution sources at an authorised disposal facility; and
- Implement as many closure measures as possible during the operational phase of the operation and institute appropriate monitoring programmes demonstrate the actual performance of the various management actions during the operation, rather than after decommissioning.

3.13 Groundwater Remediation Guideline (GWG12)

Introduction

Groundwater remediation means the interim or permanent elimination through mitigation or reduction of contaminants that pose human health consequences or threats to the environment.

This guideline aims to give Eskom guidance in evaluating the need for and timing of remediation and the associated remediation process. As all remediation projects are site-specific, this guideline does not prescribe a particular remediation option. Rather, the guideline provides an outline for a decision-making process for the remediation of groundwater that will support a management decision and maintain the health and safety of the public and the environment.

Purpose

The purpose of this guideline is to ensure that there are clearly defined process controls in place to evaluate or implement groundwater remediation. The intended use of the guideline is for Eskom personnel to evaluate and oversee the remediation process.

Groundwater remediation process

Financial and technical constraints prohibit restoring all water resources to pristine conditions. For this reason, remediation strategies make use of a risk-analysis approach to rank remediation priorities.

The main driver of groundwater remediation is the complete source, pathway, and receptor situation where the risk to a receptor is considered to be unacceptable. In such a case, the risk can be addressed by removing or reducing any one of the three components. If one should remove the receptor in question or block the pathway, it would be possible to reach a situation where the risk is acceptable even without any action to remove, reduce, or remediate. Remediation can be viewed from a short-, medium-, and long-term perspective:

- In the short term, the focus must be source control and monitoring the effectiveness of the control measures.
- In the medium term, the focus should be plume control and monitoring both source control and plume control effectiveness.
- In the long term, the focus should be the management of potential receptors, possible land-use changes, monitoring of functions, etc.

A: Consideration of remediation

Before Eskom takes any remedial actions, a risk assessment should be conducted to establish whether the site poses a significant, little, or no threat to human health and the environment.

B: Stakeholder consultation and engagement

Before embarking on the remediation process, affected parties and regulators should be notified of the intention to investigate remediation action and the expected timeframes. This will require consultation with regulators and third parties affected by the pollution.

C: Defining remediation objectives

Remediation objectives, or the ultimate goals of any remediation, should be defined by the consequence to the critical receptor based on the toxicology and likely dependence/intake and can be defined as follows:

- The relative risks posed by the groundwater contamination to human health and the receiving environment;
- The actual and expected uses of the groundwater requiring remediation; and
- The social and economic value of the groundwater resource is established through stakeholder consultation.

The abovementioned should be done by undertaking the following:

- Complete site characterisation of the contaminated area to establish current and potential future use of the land or the resource; and
- Formulation of remediation objectives in consultation with regulators and I&APs for each affected component.

Dose-response modelling should be done to define the consequence to the critical receptor based on the toxicology and likely dependence/intake. Should remedial action be implemented, the dose-response modelling will be useful in setting up eventual clean-up levels. The objectives for remedial actions can be defined by the dose-response modelling results. Remediation objectives should be formulated based on the following:

- Consultation with the affected community or custodians of the critical receptor;
- Each affected environmental aspect or component; and
- The impact that will be managed or mitigated following current or expected use of the resource, corresponding with specific RQOs.

Consultation between Eskom and regulators will be required in areas where groundwater contamination requires active remedial action.

D: Options for remediation

Based on the remedial objectives, it will be necessary to review/evaluate remedial options that are available to achieve the objectives/clean-up levels.

This can be done by identifying technologies that can achieve the clean-up objectives, for example, by literature review and risk assessments. These options can normally be divided into active or passive remediation, discussed below.

D1: Active remediation

Active remediation requires human intervention to remediate contamination. Processes include mechanical (such as removal, excavation, or encapsulation), chemical (such as peroxide or persulfate injection), manual separation (such as pump-and-treat or dual-phase remediation systems), use of biological agents (such as microbes that metabolise contamination or plants that fix contamination in their wood), or flushing (such as surfactant flushing).

D2: Natural attenuation

Passive remediation relies on natural processes to remediate contamination. This process is often called natural attenuation. Passive remediation may be used at sites where no potential receptors are threatened and contaminant levels are low enough to reasonably believe that natural processes (such as dilution and/or biological ingestion) will reduce contamination to acceptable levels.

D3: Different remediation options

Source reduction or restriction

This remediation option reduces or eliminates the quantity or hazardous nature of pollutants and waste at the point of generation. Source reduction includes strategies to predict the occurrence of acid-forming materials, contaminants, and toxic metals likely to be mobilised by activities and designs operations that avoid or minimise contact with these materials and/or assure their isolation. Source reduction can also include such strategies as substitution of hazardous processes by cleaner processes.

Monitored natural attenuation

Monitored natural attenuation (MNA) is a non-intervention remediation approach that relies on natural processes such as dispersion and/or decay to reduce or attenuate contamination in soil and groundwater. MNA achieves clean-up goals through the natural reduction of contaminant concentrations. MNA is a suitable alternative when the contamination source is under control, and clean-up goals will be achieved within a reasonable timeframe. For a site to be suitable for an MNA project, a number of factors must be considered:

- Can the contaminants be effectively remediated through the natural attenuation processes?
- Is the contaminant plume stable (that is, moving in a consistent pathway), and is it expected to remain stable over the remediation period?
- Has the source of contamination been eliminated, or can it be controlled throughout remediation?
- What is the nature of the demand for the affected resource (soil and groundwater) over the time that the MNA project is in effect?
- Are reliable institutional controls available for the site, and is the institution identified as responsible for the site economically sustainable throughout the project?
- For a site to be evaluated for the suitability of MNA, it must be accurately modelled in terms of contaminant migration, with a clear and full understanding of near-site receptors and near-site land, and water use. This information is an important input to decisions on remediation alternatives and the evaluation of the effectiveness of an ongoing MNA project; and

- A site recommended for MNA must have historical data showing declining levels of contaminants in soils and groundwater. Characterisation data that demonstrate a stable or diminishing groundwater plume will probably also be required for a site to be considered suitable.

A key objective of an MNA programme is compliance with current and anticipated future regulatory criteria. Changes in regulations and allowed environmental contaminant levels should trigger the re-appraisal of an MNA project. Another important objective of an MNA project is that natural attenuation proceeds according to expectations, that is, that the contaminant plume is not migrating off-site, or if it is, those contaminant levels are within anticipated and acceptable limits. A related objective is that there is no current or future unacceptable risk to receptors of interest.

One of the key considerations is the expected timeframe for the MNA project because institutional controls will need to be maintained throughout that period. Future land use on the site (that is, residential, recreational, or industrial) must also be considered part of the remedial objectives because of the impact on the local community. Many active soil and groundwater remediation options are available that may be used:

- As an alternative to MNA;
- In conjunction with MNA to make the MNA option feasible, or
- As a contingency measure, if natural attenuation is not proceeding as planned.

Monitoring is used continually to evaluate the effectiveness of MNA during the implementation phase of the project and to determine when the endpoint or goal has been achieved. The magnitude of the effort for the monitoring programme should not be underestimated since the programme must measure the extent of a dynamic, contaminated plume in three dimensions. The degree of effort will depend on many factors, including the quality and quantity of monitoring done before the MNA feasibility study, the size and chemical/radiological nature of the plume, the complexity of the site, and the affected aquifer(s) and the extent of engineered remedies.

Because of the affinity of the soil in the saturated zone for the contaminant of interest, MNA may not reduce the concentrations in groundwater to the site-release limits when the final status survey is scheduled to be conducted during decommissioning. In this case, although MNA has resulted in benefit, additional remediation, possibly in the form of soil removal, would be required at decommissioning to achieve the site-release limits. The volume of soil removed at decommissioning could be the same as or more than that required if immediate removal had been performed. This could result in an overall increase in cost if remediation were delayed until decommissioning.

A contingency plan is needed if the objectives of the MNA programme are not being met. Caution should be exercised to set the triggers for the contingencies so that seasonal fluctuations or sampling variability does not trigger a contingency when one is not warranted.

Treatment

This refers to any method, technique, or process that changes the physical, chemical, or biological characteristics of waste materials/water in a way that eliminates harmful characteristics, recover energy, or use materials in the waste materials, leaves them capable of being reused or safely contained, or reduces their volume.

Augmented monitored natural attenuation

With augmented MNA, one or more natural attenuation mechanisms would be augmented (that is, enhanced) with treatment. For example, adsorption of contaminants to the aquifer matrix could be decreased and dispersion increased by injecting surfactants or chelating agents in areas of high contaminant concentration. Pump and treat could then be used to remove the mobilised contaminants and reduce the volume of contaminants remediated by MNA. Conversely, soil or contaminant chemistries can be adjusted so that contaminants can be held in place by the soil and decay away with decreased risk of off-site migration. This form of augmented MNA would require that the soil and contaminant chemistries and contaminant flow path are well understood.

Pump and discharge

Pump and discharge as a method of groundwater remediation generally involve the following approach:

- Boreholes designed as extraction points are constructed to be screened in the saturated zone in the area of contaminated groundwater;
- Submersible pumps are placed in the boreholes and used to pump contaminated groundwater to monitoring tanks, where samples can be taken to quantify the amount of radioactivity discharged; and
- The extracted water is then discharged through the normal plant liquid effluent discharge pathway.

A properly designed pump and discharge system can redirect groundwater flow from the source area to the extraction boreholes rather than allowing it to flow to down-gradient areas. This keeps the contamination from spreading and contaminating or increasing the contamination levels in down-gradient areas. As pumping continues, contamination levels in the source area and groundwater can be reduced as the overall source term of the contamination is reduced.

Pump and treat

Pump and treat is similar to pump and discharge as a method of groundwater remediation, except that the level of treatment is generally more extensive. Boreholes designed as extraction points are constructed to be screened in the saturated zone in the area of contaminated groundwater. Submersible pumps are placed in the boreholes and used to pump contaminated groundwater to feed tanks or directly through the processing equipment to monitoring tanks where samples can be taken to quantify the amount of contaminant discharged. The treated water is then discharged through the normal plant liquid effluent discharge pathway.

A properly designed pump and treatment system can redirect groundwater flow from the source area to the extraction boreholes rather than allowing it to flow to down-gradient areas. This keeps the contamination from spreading and contaminating or increasing the contamination levels in down-gradient areas. As pumping continues, contamination levels in the source area and groundwater can be reduced as the overall source term of the contamination is reduced.

D4: Develop and screen alternatives for remediation

Many factors affect the ability to remediate an area during the operation so that the site-release limits are achieved at decommissioning. To determine viable remediation options for the situation being evaluated, each technology that may be viable during operation and at the time of decommissioning is evaluated based on the following factors:

Impact on operations and occupational safety

The location of the contaminated area will influence the types of viable remediation strategies and the timing of the remediation. Assess the contamination location for systems, structures, and components that may influence remediation. For example, if a contaminated area is located under a power station, source removal options may not be possible during operation without influencing operations.

Natural attenuation or pump and discharge options would be included with those evaluated in this situation. Conversely, if removal of the contaminated area is unobstructed by structures or equipment, removal can be included with the options evaluated. The availability of adequate space to conduct remediation without influencing operability and safety should be considered.

Thus, remediation options should be evaluated for their potential impact on operations and occupational safety. Select options that will not adversely influence these factors outside of acceptable risks. The ability to conduct the remediation during scheduled outages or at the time of decommissioning to minimise the impact on operations safety should be considered.

Effectiveness and ability to meet remediation limits

Evaluate and select remediation options that will meet the remediation objectives and remediation criteria. An acceptable period for remediation should also be considered. The extent of contamination (vertical and horizontal) in soil and/or groundwater and whether this contamination may migrate off-site will also influence the applicability of remediation options.

D5: Preparation of an action plan

Based on the remedial objectives and options, a remediation action plan should be developed describing the potential applicability of the remediation options and the potential impact of the remediation options on the operation of the site as well as a detailed analysis (including risk assessment) of remediation options. The preferred remediation alternative should be selected using the following criteria:

- Ability to meet remediation objectives;

- Ability to meet regulatory and community standards;
- Environmental, engineering, and economic criteria (best practical environmental option);
- Timeframes of implementation;
- Cost implications; and
- Ability to facilitate future use.

Different technologies may need to be combined over different timescales to achieve the objectives. Differences between options for the short, medium, and long term must be highlighted in the action plan, for example:

- Short-term objectives and available options to achieve these objectives;
- Medium-term objectives and available options to achieve these objectives, including monitoring and maintenance requirements; and
- Long-term objectives and available options to achieve these objectives, including monitoring and maintenance requirements.

Backup options for engineering interventions must also be indicated and included in the action plan for possible implementation if monitoring results indicate the need for further intervention.

D6: Implementing remediation and monitoring effectiveness

Once the best available option has been implemented, processes should be in place to monitor and verify that the remediation is progressing as anticipated and that it is meeting (or will meet) the remediation objectives. If the remediation is not progressing as planned, a contingency plan for alternative remediation strategies should be implemented.

Procedures and processes should be developed based on the remediation objectives and limits defined. This should include chronological trigger criteria (expected concentrations at various times after the remediation option has been implemented) that allow the success of the remediation to be evaluated throughout its implementation. It is also important that the benefits expected are achieved, and the cost monitored to ensure that the selected option remains cost-effective. Exceeding the chronological trigger criteria during the monitoring of the remediation may also indicate that additional areas or higher levels of contamination are present than those estimated for a remediation area. In the process of performing a remediation evaluation, likely, a projection of any expected changes to soil and groundwater concentrations will be made. In some cases, these projections form an important basis for the cost/benefit evaluation performed as part of the remediation evaluation.

In addition, if a remediation option is implemented during the operation of the site, expected changes to soil and/or groundwater concentrations may be projected. To confirm the accuracy of the remediation evaluation, monitoring to confirm that the projections of the effect of the option(s) chosen should be performed.

E: Output of the remediation process

The output of the remediation process is discussed step by step below for easy interpretation.

E1: Consideration of remediation

- Based on the Groundwater Risk Assessment:

E2: Indicate intention to embark on the remediation process

- Consultation with regulators;
- Consultation with third parties affected by the groundwater contamination;
- Consultation with other authorities, for example, provincial Department of Environmental Affairs;
- Indication of approximate timeframes for the execution of remediation;
- Consensus on the initiation of remediation investigations; and
- Agreed investigation outline and schedule.

E3: Provide definition of remediation objectives

- Current status of contamination and relative risks;
- Outline of remediation objectives, including final clean-up levels; and
- Written confirmation of objectives from regulators.

E4: Give options for remediation

- Evaluation of remediation options;
- Preferred remediation option and back-up option; and
- Motivation submitted to DWS with reasons why the technology has been chosen.

E5: Supply remediation action plan

An action plan for short-, medium-, and long-term implementation of the preferred remediation option.

E6: Implement remediation and monitoring effectiveness

Implement the best available option and monitor to verify that the remediation is progressing as anticipated and meets or will meet the remediation objectives is necessary.

4. Acceptance

This document has been seen and accepted by the Eskom Environmental Steering Committee members.

5. Revisions

Date	Rev.	Compiler	Remarks
December 2021	1 (Standard)	Z Mkhize	Document was changed to a standard and is no longer a guideline.
March 2017	2 (Guideline)	Z Mkhize	The document was due for review – changes made to make the contents page active with links.
March 2014	1 (Guideline)	M Matimolane	Ground Water Governance Guidelines were needed by the business to ensure that the groundwater resource is protected.

6. Development team

Zama Mkhize – Risk and Sustainability – Groundwater Management Portfolio
Felicia Sono – Generation Water Centre of Excellence
Dr Steve Mathetsa – RT&D
Peter Nelson – Generation Peaking Environmental Management
Lehlogonolo Moreoane – Generation Lethabo Environmental Management
Zoe Ngamlana – Assurance and Forensics
Dumisani Sibeko – Eskom Rotek Industries
Bonginkosi Nyembe – Generation Engineering

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Name	Qualification
Motshewa Matimolane	BSc Chemical Engineering
Pamela Mabece	Hons BSc Environmental Management
Gerhard Gericke	MSc Chemistry
Lehlohonolo Mokhahlane	MSc Hydrogeology
Jayne Mammatt	CA (SA)
Dr Ferdi Linde	PhD Hydrogeology
Dr Ahee Coetsee	PhD Hydrogeology
Dr Matthias Retter	PhD Hydrology
Dr Giep du Toit	DSc Flow Dynamics

Prof. Ingrid Dennis	PhD Hydrogeology
Brian Hayes	MSc Environmental Engineering
Jacs van Rooy	BSc Biochemistry
Morné Burger	MSc Hydrogeology
Lize Redelinghuys	LLB
Bradley Hornby	MPhil Environmental Science