REHABILITATION MANAGEMENT GUIDELINES FOR WATER RESOURCES

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LIST OF ACRONYMS

AMD	Acid Mine Drainage
ARS	Artificial Recharge Strategy
BAR	Basic Assessment Report
BPGs	Best Practice Guidelines
CARA	Conservation of Agricultural Resources Act
CD: WEM	Chief Directorate: Water Ecosystems Management
CMAs	Catchment Management Agencies
DALRRD	Department of Agriculture, Land Reform and Rural Development
DCOGTA	Department of Cooperative Governance and Traditional Affairs
DEA	Department of Environmental Affairs
DEA&DP	Department of Environmental Affairs and Development Planning
DEDTEA	Department of Economic Development, Tourism and Environmental Affairs
DEA	Department of Environmental Affairs
DFFE	Department of Forestry, Fisheries and Environment
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EA	Environmental Authorization
ECA	Environment Conservation Act
EMP	Environmental Management Plan/Programme
EPA	Environmental Protection Agency
EWRs	Ecological Water Requirements
EIA	Environmental impact Assessment
GA	General Authorization
GAC	Granular Activated Carbon
GDEs	Groundwater-Dependent Ecosystems
GIS	Geographic Information System
GRDM	Groundwater Resource Directed-Measures
GWBF	Groundwater Contribution to Baseflow
IWQM	Integrated Water Quality Management
IWRM	Integrated Water Resource Management
MAR	Managed Aquifer Recharge
MBBR	Moving Bed Biofilm Reactor
MPRDA	Mineral and Petroleum Resources Development Act
NEMA	National Environmental Management Act
NGS	National Groundwater Strategy
NWA	National Water Act
NWRS	National Water Resource Strategy
NW&SMP	National Water and Sanitation Master Plan
PRB	Permeable Reaction Barriers
RQOs	Resource Quality Objectives
RDM	Resource Directed Measures
RO	Reverse Osmosis
SA	South Africa
SAHRA	South Africa Heritage Resources Agency
SANBI	South African National Biodiversity Institute
SFR	Stream flow reduction
SDCs	Sources Directed Controls
SDS	Sources Directed Studies
UV	Ultraviolet
WHO	World Health Organisation
WMA	Water Management Area

WML	Waste Management License
WULA	Water Use License Application
WUL	Water Use License
WRC	Water Research Commission
WWTW	Wastewater Treatment Works

GLOSSARY OF TERMS

Groundwater is defined as a water resource or aquifer, whereby an aquifer is a geological formation which has structures or textures that hold water or permit appreciable water movement through them.

Baseflow is defined as the portion that contributes to the stream by delayed sources and groundwater and it is considered the lowest discharge of the stream in the dry season.

Diffuse pollution - (or "non-point source pollution") Pollution that originates from wash-off over a relatively large area. Diffuse pollution sources can be divided into source activities related to either land or water use, including failing septic tanks, agricultural and improper animal-keeping practices, and urban and rural runoff.

Ecological Water Requirements (EWRs) is the flow patterns (magnitude, timing, and duration) and water quality needed to maintain a riverine ecosystem in a particular condition. This term is used to refer to both the quantity and quality components.

Effluent is the municipal sewage or industrial wastewater (untreated, partially treated, or fully treated) that flows out of a wastewater treatment works, septic system, pipe, etc.

Eutrophication - (from the Greek *"eutrophos"* meaning *"well-nourished")* Is the process of over-enrichment of waterbodies with minerals and nutrients, which (at the right temperatures, substrate availability, flow velocity and light penetration) increasingly induce primary production, e.g., algal and macrophyte growth. Eutrophication can be regarded as either a natural aging process in waterbodies or an aging process that can be accelerated by anthropogenic activities.

Interflow is the rapid flow of water along the unsaturated/vadose zone flow paths and has the potential to infiltrate the subsurface and move both vertically and laterally before discharging into other water bodies.

Integrated Water Resource Management (IWRM) is a process for co-ordinated planning and management of water, land, and environmental resources. IWRM takes into account the amount of available water (surface and groundwater), water use, water quality, environmental and social issues as an integrated (combined) whole to ensure sustainable, equitable and efficient use.

Monitoring - periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.

Non-point source pollution - See "Diffuse pollution."

Point source pollution - pollutant loads discharged at a specific location by means of pipes, outfalls, or conveyance channels inter alia delivering wastewater from municipal and industrial Wastewater Treatment Works. Point sources can also include pollutant loads contributed by tributary.

Rehabilitation means an action of restoring using a set of interventions designed to optimize the functionality of a system.

Remediation involves restoration of areas that historically have had unacceptable impacts and of underground water resources or areas where impacts on such resources have become unacceptable

According to the NWA, the **Reserve** is the quantity and quality of water required to satisfy basic human needs and to protect aquatic ecosystems, in order to secure ecological sustainable management of significant water resources. The Reserve, therefore, consists of two distinct components: (1) basic human needs and (2) the Ecological Water Requirements, (EWRs).

Resources Directed Measures (RDM) focus on the quantity and quality of the water resource itself, regarding it as an ecosystem rather than a commodity. RDMs comprise Classes, Reserve and RQOs as components.

Resource Quality Objectives (RQOs) are a numerical or descriptive (narrative) statement of the conditions which should be met in the receiving water resource, in terms of resource quality, in order to ensure that the water resource is protected. They might describe, amongst others, the quantity, pattern, and timing of instream flow; water quality; the character and condition of riparian habitat, and the characteristics and condition of the aquatic biota.

Runoff is the flow of water occurring on the ground surface when excess rainwater, stormwater, meltwater, or other sources, can no longer sufficiently rapidly infiltrate in the soil. Surface runoff replenishes groundwater and surface water resources as it percolates through soil profiles or moves into streams and rivers.

Source: In water resource management, "source" refers to the source of an impact, usually on a water resource. The relationship between "Source" and "Resource" is similar to the relationships between "Cause" and "Effect" or "Aspect" and "Impact," as per the ISO 14001 definitions. The "Resource" or the "water resource" is part of the receiving environment

Wastewater is any water used from domestic, industrial, commercial, or agricultural activities, surface runoff or stormwater, which may contain physical, chemical, and biological pollutants.

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EXECUTIVE SUMMARY

In South Africa, groundwater is recognized as one of the strategic water sources. It is estimated that more than 50% of communities in the country depend on groundwater for domestic needs, especially those living in arid and semi-arid areas (DWS, 2016). However, groundwater resources are affected by over-abstraction, water quality attributed to contamination and climate change which are the three main categories of impacts causing groundwater resource degradation.

To address the impacts on groundwater resources, the Directorate Sources Directed Studies (SDS) in the Department of Water and Sanitation (DWS) initiated a project in 2020 for the development of Rehabilitation Management Guidelines (RMGs) for Water Resources (*i.e.,* groundwater resources). The project responds to one of the objectives of the Chief Directorate: Water Ecosystems Management (CD: WEM) to conduct sources directed-studies to ensure water resource protection.

There are various activities relating to groundwater resources rehabilitation in the country, however, there seems to be a lack of a coordinated approach for such practices to guide on rehabilitation management approaches. It is for this reason that the DWS is developing RMGs for groundwater resources using a combination of sectors and their respective specific impact types (*i.e.,* domestic, mining, industrial, solid waste, agricultural and forestry sectors) following a phased approach, namely; diagnostic, planning and assessment, setting of the rehabilitation objectives, execution, monitoring, evaluation, and reporting phases. The following are key aspects covered in the guidelines:

- Description of the sectors contributing to pollution (*i.e.,* domestic, mining, industrial, solid waste, agricultural and forestry sectors);
- Description of the impact types emanating from the various sectors;
- Legal Considerations - applicable legislation to be considered for undertaking site-specific rehabilitation activities; and
- Step-by-step guidelines on measures/interventions for executing rehabilitation - planning, design, implementation, and monitoring.

Rehabilitation Management Guidelines have therefore been developed for the control and management of water resources as per impacting activities summarised below.

Over-abstraction of groundwater resources is caused by mismanagement of the resource which influences frequent aquifer failure, which in turn leads to the drying up of boreholes. Groundwater over-abstraction does not only result in aquifer depletion and water-quality degradation but also impacts the ecological integrity of groundwater-dependent ecosystems *i.e.,* streams and wetlands and results in significant losses of habitat and biodiversity especially when there is a strong connection between surface and ground water resources. The current RMGs have been developed for the control and management of groundwater over-abstraction activities for domestic uses.

Mining activities have an impact on water quality. Acid mine drainage (AMD) is one of the most serious and potentially enduring environmental problems for the mining industry. Mining has a major water quality issue as it adversely impacts the environment and water resources. AMD causes a reduction in water resource pH, which mobilise the increases of the availability of dissolved metals for uptake by organisms and fish. RMGs have been developed for the management of AMD water decanting from gold and coal (including metals like silver, copper, and zinc) opencast and underground operations.

Industrial effluent emanates from various industries and percolates through soil into groundwater. The composition of the industrial effluent falls into one or more of the following categories: dissolved organics, suspended solids, priority pollutants (*e.g.,* phenols), heavy metals, colour, nutrients (nitrogen and phosphorus), microbial contamination, oil and grease, refractory compounds, and volatiles. These contaminants, if untreated, affects human, animal, and aquatic lives. The RMGs have been developed in this report for the management of industrial effluent ingressing into groundwater.

Leachate is a strong reducing liquid produced from landfills that percolates through the soil into groundwater if there is no liner present or if the functioning of the liner system is compromised. Leachate typically contains some of the following examples of metals *i.e.,* Lead (Pb), Cadmium (Cd), Chromium (Cr), and Nickel (Ni), and during its percolation through the soil it reacts with Iron (Fe), and Manganese (Mn) to reduce them into more soluble species, thus increasing their concentration in groundwater. Rehabilitation Management Guidelines have been developed in this report for the management of leachate ingressing into groundwater from landfill sites.

Inputs such as fertilisers during irrigation processes may have a negative impact on groundwater quality especially where the water table is high (*i.e.,* shallow groundwater levels), otherwise the quality of interflow is affected where the water table is low. Anthropogenic activities such as irrigation may influence the chemistry of groundwater and determine the level of contaminants in groundwater. Common contaminants associated with agricultural activities include elevated concentrations of Nitrate (NO_3-). Irrigation return flows also contribute to buildup of salts causing salination. RMGs have been developed in this report for the management of elevated concentrations of Nitrate (NO_3-) in groundwater.

Forestry-related activities uses interflow and baseflow which impact surface water by lowering surface water levels and to a certain extent lowering groundwater levels because groundwater is an important contributor to baseflow. Afforestation and alien vegetation have impacts on interflow and baseflow which leads to stream flow reduction (SFR). The RMGs have been developed in this report for the over-abstraction of groundwater caused by SFR activities.

1. INTRODUCTION

1.1 BACKGROUND

In South Africa, groundwater is recognized as one of the strategic water sources. It is estimated that more than 50% of communities in the country depend on groundwater for domestic needs, especially those living in arid and semi-arid areas (DWS, 2016). Groundwater resource availability for sufficient, potable water is critical for ensuring water supply and ecosystems services, agricultural production, industrial activities, and food security in South Africa (Masindi and Abiye, 2018). Although groundwater has been habitually perceived as a safe and dependable source of water, this is often not the case since it is prone to pollution from both anthropogenic and natural processes (Masindi and Foteinis, 2021). Water quality challenges in terms of elevated levels of calcium, magnesium, and nitrate in boreholes, attributed to the agricultural practices and washing of clothes in the vicinity of the boreholes (Odiyo and Makungo, 2012) have been reported in the country.

In 2020, the Directorate Sources Directed Studies (SDS) within the Department of Water and Sanitation (DWS) initiated a project for the development of Rehabilitation Management Guidelines for Water Resources (*i.e.,* groundwater resources). The project responds to one of the objectives of the Chief Directorate: Water Ecosystems Management (CD: WEM) to conduct sources-directed studies to ensure water resource protection.

In the Situation Assessment Phase of the project, it was established that studies have been conducted in the country to explore groundwater resource remediation. Below is a list of some of the key findings from the review conducted:

- There are various activities relating to groundwater resources remediation in the country, however, there seems to be a lack of a coordinated approach for such practices to report and evaluate their effectiveness;
- Data emanating from research studies and initiatives undertaken in the country on groundwater resources rehabilitation is available, although limited;
- Groundwater remediation that exists in the country is dominated by artificial recharge which requires large volumes of water which the country does not always have. Moreover, it is impossible to apply artificial recharge technology everywhere in the country as it is dependent on the specific types of aquifers *i.e.,* fractured aquifers, alluvial aquifers etc. which do not occur necessarily everywhere.
- Acid Mine Drainage (AMD) treatment is another option that seems to be very expensive especially when the reverse osmosis technique is applied. This could be avoided by undertaking remediation activities concurrently with mining operations instead of waiting until a mining operation ceases; and
- Various techniques and technologies are available for use in groundwater resource rehabilitation programmes; however, the choice of their application depends on their respective advantages and limitations, and the type of contamination prevalent.

The Situation Assessment Phase concluded that although studies on groundwater resource rehabilitation are prevalent in the country, practical guide on the application of the outcomes emanating from such studies has been limited, possibly due to the unavailability of comprehensive water resource rehabilitation guidelines. There is a need for a coordinated approach to sustain groundwater remediation practices through development of such guidelines.

1.2 DEFINITIONS, CONCEPTS AND REMEDIAL TECHNIQUES

According to the National Water Act (NWA) (Act 36. of 1998), groundwater is defined as *a water resource or aquifer, whereby an aquifer is a geological formation which has structures or textures that hold water or permit appreciable water movement through them.*

The word rehabilitation means an action of restoring using a set of interventions designed to optimize the functionality of a system. Some authors argue that the precise meaning of the word “rehabilitation” can mean very different things to different people, contending many forms and conceptions depending on the context and the field in which the term is used such as the field of health services, and criminal justice, just to name the few examples (Bonnechère and Van Sint Jan, 2019; Antonio and Price, 2021). For the purpose of report, groundwater resource rehabilitation can be understood as an act of restoring the functionality of an aquifer and its characteristics to continue deriving benefits associated with that system. A similar term “remediation” is also frequently used to describe the same action of restoring functionality of a system. According to DWAF (2000), “remediation involves restoration of areas that historically have had unacceptable impacts and of underground water resources or areas where impacts on such resources have become unacceptable”. Although the terms rehabilitation and remediation may be used to describe similar actions, depending on the choice of a user, these terms are often used interchangeably in practice. Therefore, in this report, the term rehabilitation has been adopted because remediation or restoration implies a return to a natural pre-impact state which is often not achievable.

Sustainable management of groundwater should aim to prevent groundwater from becoming severely depleted or highly polluted, as prevention is always less expensive than trying to remediate problems once they have occurred. However, sometimes groundwater degradation may have to be mitigated with technical measures, either because the aquifer will not recover on its own, or because other pressures are of a nature that groundwater will continue to be exploited from an increasingly degraded system. A key aspect of any rehabilitation programme is a clear agreement on the targeted end point and on how it will be monitored and measured. Rehabilitation measures can be applied **in situ** (introducing oxygen, nano particles, or bacteria to help speed up natural biogeochemical processes) or ex-situ (commonly pumping contaminated groundwater to the surface and treating it or erecting barriers to contain contaminated groundwater) (Smith *et al*., 2016). **Bioremediation, chemical**, and **physical** methods are examples of approaches for groundwater rehabilitation technologies (Azubuike *et al*., 2016; Pi *et al*., 2020; Zhang, *et al*., 2020). The choice of groundwater rehabilitation method depends on a good understanding of the hydrogeologic regime.

1.3 LINK BETWEEN GROUNDWATER AND SURFACE WATER RESOURCES

1.3.1 Groundwater and Surface Water Interaction

Groundwater is an important contributor to baseflow. Baseflow is defined as the portion that contributes to the surface water resources by delayed sources and groundwater (Hall 1968), and it is considered the lowest discharge of the stream in the dry season.

To this end, rehabilitation guidelines for surface water resources (rivers, wetlands, estuaries, lakes and dams) have been developed across the board for characteristics of watercourses, namely; **hydrology (surface flow, surface runoff** and **interflow), geomorphology, water quality, habitat,** and **biota (Figure 1). Groundwater** as defined by NWA is a **water resource (i.e., aquifer)** and not a **characteristic of watercourses.** However**, groundwater flow** is that component of groundwater that is viewed by the DWS as a characteristic of watercourses and as such will be covered in the current guidelines.

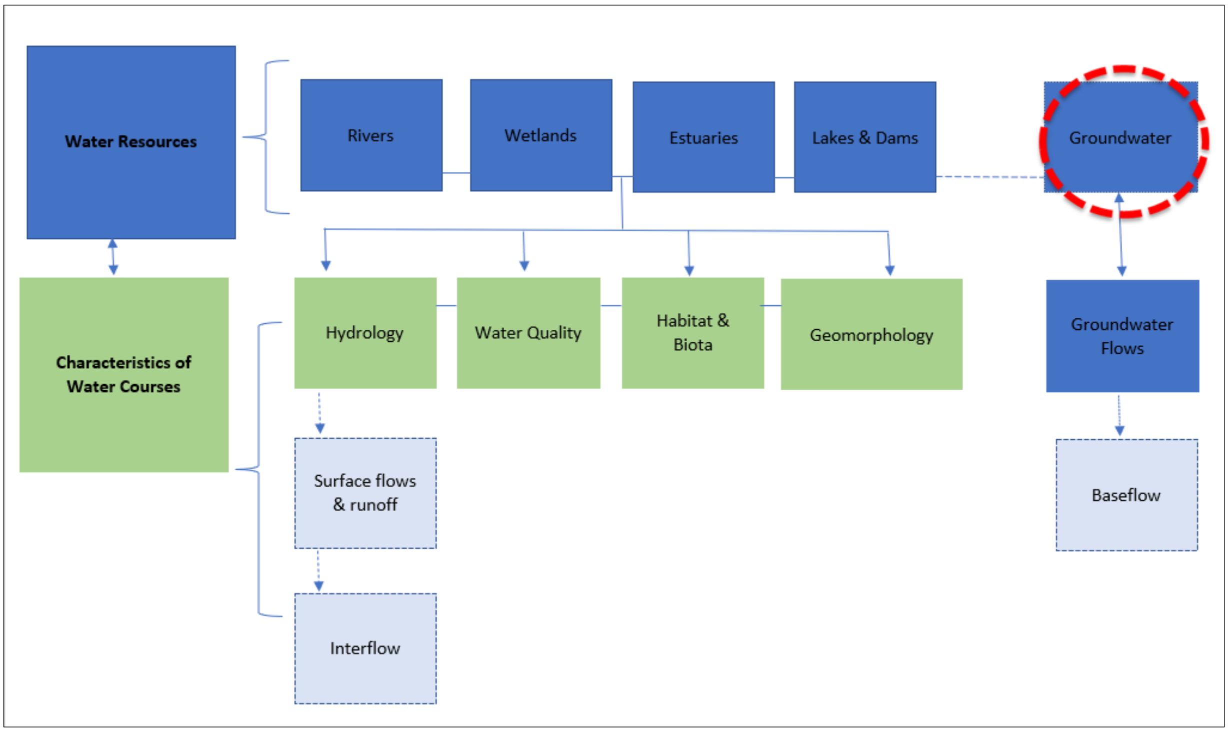

Figure 1: Diagram depicting the link between water resources and characteristics of watercourses.

According to Tóth (1970) and Sophocleous (2002), **groundwater flows** are influenced by three main hydrogeological factors described in **Table 1**; namely, topographical, geological, and climatic effects – these factors have effects on groundwater flows as water flows from high elevation to low elevation and high pressure to low pressure. Groundwater depth remains connected to topography, *i.e.,* water table (Hubbert 1940).

Table 1: Hydrogeological factors affecting groundwater flow (adapted from Hubbert, 1940)

Hydrogeological Factors	Description
Topographical effects	• Topography affects groundwater contribution to baseflow when the elevation of the water table is higher than the river water for groundwater to contribute to surface water.
Geological effects	• Unconfined aquifers contribute water to surface water when high porosities exist in the subsurface. • Confined aquifers require fractures and faults to contribute water to surface water. • Groundwater flows into surface water when the streambed is permeable enough to permit water flows into the river.
Climatic effects	• Groundwater contribution to surface water is affected by climatic changes. • High precipitation levels result in increased recharge, contributing to baseflow and maintaining river flows during dry seasons. • Temperature changes and precipitation alter regional climatic and hydrologic systems.

Groundwater and surface water interaction occurs when groundwater contributes to surface water or when the river recharges groundwater. The flow of water between the groundwater in aquifers and surface water is largely controlled by the following factors:

- **Hydraulic gradient** between the surface water level and the groundwater level;
- **Hydraulic properties** of the aquifer; and
- The **geological properties** of the material separating the aquifer from the surface water resource.

Groundwater can discharge to a stream/river in some places and leak back into the groundwater system in others. **Figure 1** is an illustrative diagram depicting the interaction between groundwater and streams/rivers.

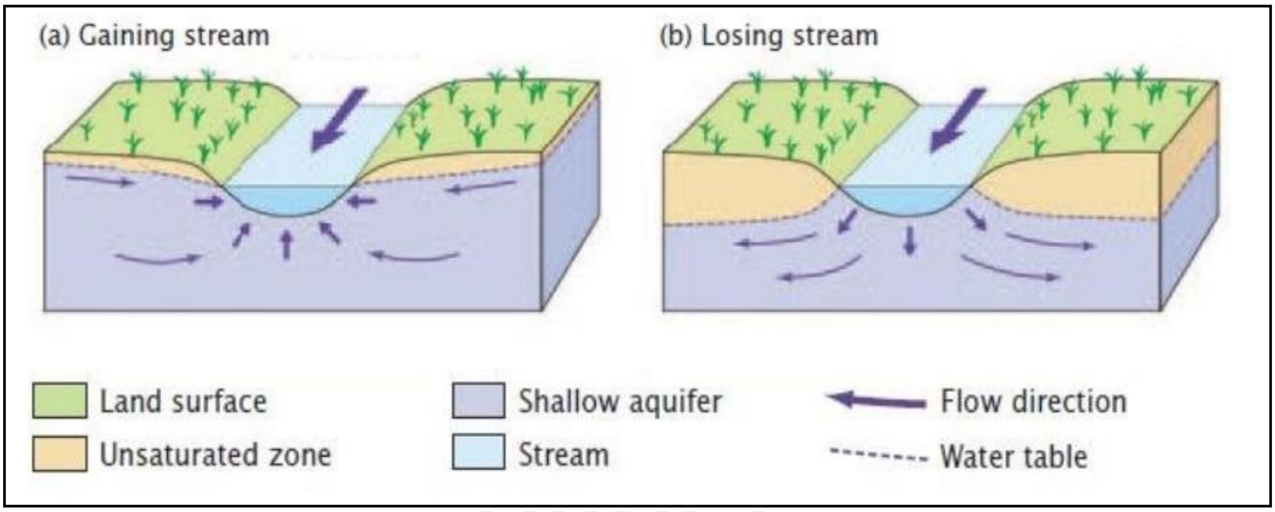

Figure 2: Illustrative diagram depicting stream/river-aquifer interactions – (a) connected gaining stream (b) connected losing stream (Winter et al., 1998).

1.4 PURPOSE FOR DEVELOPMENT OF THE GUIDELINES

The primary objective of the report is to:

- Develop Rehabilitation Management Guidelines for Groundwater Resources to ensure a coordinated approach for the implementation of site-specific rehabilitation techniques and practices applicable to South African geological conditions.

1.4.1 Conception of groundwater resource rehabilitation guidelines

The main purpose of groundwater rehabilitation is to remove waste material and/or reduce the concentration of contaminants in groundwater to acceptable levels. Groundwater rehabilitation ensures that the beneficial use of groundwater is restored within a reasonable timeframe, and it is achieved most often by combining rehabilitation techniques. The application of multiple types of rehabilitation technologies is often necessitated by a very large extent of contamination, or by various contaminants. Although drinking water is most often the beneficial use of groundwater, non-potable use such as ecological ecosystem sustainability is also possible and may trigger groundwater rehabilitation.

Groundwater is a key resource for agriculture and for many industries, it is used in industrial processes especially where surface water is limited in quantity and quality, (SGIAR, 2017; UNESCO, 2022). Groundwater use for various purposes such as domestic, agriculture, industrial, recreation, and ecosystem sustainability may not only compete in terms of groundwater quantity but quality as well.

In South Africa, water quality guidelines are available, and these guidelines were developed taking into consideration requirements for various water uses. Therefore, limits for water quality requirements differ from one water use to another. In terms of groundwater rehabilitation, one would accept that water quality limits as set in the water quality guidelines for relevant water use could be considered rehabilitation targets that would be used as end-point/indicator for a rehabilitation project. The resource quality objectives (RQOs) determined in a catchment would also have objectives for groundwater.

Groundwater rehabilitation can be undertaken with a view of environmental protection, and in such cases, environmental acceptable levels can be considered as rehabilitation targets. In general terms, the success of a groundwater rehabilitation project may be evaluated for its efficiency based on its ability to lower the concentration of a contaminant to the level of background/ambient concentration. In this context, acceptable background or ambient conditions of groundwater resources must be established to facilitate differentiation between elevated concentration levels emanating from anthropogenic activities and those emanating from natural processes such as rock-water interaction. It is important to consider that groundwater resource rehabilitation forms part of water resources protection within the broader integrated water resources management practice. Groundwater Resource Directed-Measures (GRDM) are used as one of the strategies for groundwater resources protection to ensure sustained suitability for beneficial purposes (NGS, 2016). The National Water and Sanitation Master Plan (NW&SMP) (2018) recommends that conditions or protection levels set as GRDM must be monitored for compliance. Within the context of groundwater resources protection, groundwater resource rehabilitation can therefore be initiated as a result of non-compliance with GRDM set as environmentally acceptable protection levels.

Groundwater rehabilitation guidelines are used as a reference guide based on developing materials to inform water users and regulators about groundwater resource rehabilitation. In doing so, critical aspects such as the nature and extent of the problem; rehabilitation goals; targets/levels; timeframe; methods/techniques; monitoring; evaluation; and contaminant control, are discussed in detail in Section 1.5.

1.5 APPROACH FOR DEVELOPMENT OF THE GUIDELINES

The Groundwater Rehabilitation Guidelines are developed with the aim to provide guidance to the water users on the step-by-step rehabilitation measures/interventions to be followed for executing rehabilitation with specific attention to planning, design, implementation, and monitoring for the identified impacts. **Table 2** below presents the approach followed for the development of the groundwater rehabilitation guidelines.

Table 2: Approach to be followed for development of Rehabilitation Guidelines for Groundwater Resources

Stakeholder Engagement

Phase	Description
PHASE 1: Diagnostic Phase	• The characteristics will be diagnosed to identify the cause/source of impact; and determine the level of modification and rehabilitation measures will be recommended to reinstate the conditions of the drivers. • Determine the conditions and the type, size, extent of impacts, and vegetation cover/ species on characteristics of watercourses.
PHASE 2: Planning & Assessment Phase	• Conduct planning and assessment to ensure the desired rehabilitation outcomes are achieved. • Assess and collate available information from maps & datasets on the affected watercourses. • Review and assess legal considerations.
PHASE 3: Define the Rehabilitation Objectives	• Identify and define the objectives of rehabilitation to ensure the impacts on the characteristics of watercourses are addressed.
PHASE 4: Execution	• Recommend techniques and methods to address the impacts identified. Consider the protection of water the resources ecosystem.
PHASE 5: Monitoring, Evaluation (M & E) and Reporting	• Monitor the results of the techniques and methods employed for rehabilitation to determine whether objectives are being achieved and whether there are any additional interventions required. • Evaluate the effectiveness of interventions against the achievement of rehabilitation objectives and outcomes. • Determine maintenance objectives. • Compilation of Rehabilitation Reports.

The below key factors will be considered and followed for the development of the guidelines.

1.5.1 Nature and extent of the problem

The initial stage of a groundwater rehabilitation project involves the collection of information that would give a general overview of the status in terms of non-compliance with set environmental conditions or in terms of groundwater resources pollution. A survey is done using a multi-facet approach (Pearce *et al*., 1995) to determine the nature and extent of groundwater quality deterioration in a catchment. The survey may be conducted as a feasibility study for remedial action. Feasibility studies can be instituted as an evaluation exercise to identify the appropriate response action to address groundwater contamination, and costs associated with the commissioning of a rehabilitation project (US-DOE, 1998; Lalumbe *et al*., 2022). As a case example, it has been reported that in some parts of the Lower Orange Water Management Area, currently known as the Orange WMA, groundwater quality has been deteriorating at an alarming rate in boreholes due to salinity changes from 1996 to 2012 that led to increased electrical conductivity from 220 mS/m to approximately 435 mS/m (Nkosi *et al*., 2021). Such information forms the basis for the initiation of a groundwater rehabilitation project. Information generated on general sources of groundwater contamination and types of groundwater contaminants should be summarized. International Atomic Energy Agency (IAEA) (1999) noted that any programme intended to assess and remediate contaminated groundwater must begin with the development of a structured conceptual model that embodies geology, and hydrogeology, including affected communities. Once the findings from the assessment of the nature and extent of the problem have been presented, a general approach to the management and selection of remedial actions, application of modeling, and technologies for groundwater rehabilitation would be recommended (IAEA, 1999).

1.5.2 Goals/Aims of a Groundwater Rehabilitation Project

Groundwater resource rehabilitation projects should be based on clear goals or objectives linked to the protection of human health and the environment. While protection for human health may be linked to basic human needs, the environment aspects may be linked to the ecological settings which are important for groundwater rehabilitation especially where contaminated groundwater replenishes adjacent aquifers and discharges into surface water bodies. Environmental Protection Agency (EPA) (2004) states that in determining appropriate clean-up objectives for groundwater remedies, stakeholders should consider the use, value, and vulnerability of the groundwater resource, and all potential pathways that could result in human or ecological exposure to contaminants in or from groundwater. Similarly, the current guideline for groundwater rehabilitation recommends that rehabilitation actions should be able to return the final remedies ~~in~~to their maximum beneficial use or-their predefined ambient conditions.

1.5.3 Target/Levels for a Groundwater Rehabilitation Project

Groundwater rehabilitation levels provide clear numerical targets that regulators and stakeholders can use to measure the success of groundwater rehabilitation actions. These numerical limits or concentration levels can be used as rehabilitation targets that would act as end points/indicators to cease a rehabilitation project. Groundwater resource-directed measures set objectives for the required level of protection of each resource, and these resource-based quality objectives ensure that each aspect of the Reserve[1] is not damaged beyond repair (Talabi and Kayode, 2019). This guideline recommends that target levels for groundwater rehabilitation should be based on the set environmental conditions such as groundwater RQOs to ensure that protection for both human health and the ecological ecosystem for current and future generations is realized. In the absence of predefined environmental conditions, concentration limits as set in the water quality guidelines should be considered.

1.5.4 Timeframe for Groundwater Rehabilitation Activities

The rehabilitation timeframe is an estimate of when groundwater quality will achieve a certain level at a specified location and/or the schedule developed to take action or construct a remedy designed to achieve a particular goal (EPA, 2004). Chapelle *et al*., (2003) note~~s~~ that the time required for these processes to lower contaminant concentrations to levels protective of human health and the environment varies widely between different hydrologic systems, different chemical contaminants, and varying amounts of contaminants. The establishment of reasonable timeframes must be based on realistically set rehabilitation goals.

[1] *According to the NWA, the Reserve is the quantity and quality of water required to satisfy basic human needs and to protect aquatic ecosystems, in order to secure ecological sustainable management of significant water resources. The Reserve, therefore, consists of two distinct components: (1) basic human needs and (2) the Ecological Water Requirements, (EWRs).*

This guideline recommends that groundwater rehabilitation timeframes should be reasonable, be aligned to specific goals of rehabilitation, and must be based on the following:

- Potential threat to human exposure and aquatic ecosystems;
- The potential for achieving rehabilitation goals;
- Type and extent of contamination or non-compliance with environmental background conditions;
- Hydrogeologic characteristics;
- Choice of rehabilitation technology, and its ability to remove contaminant mass under controlled conditions;
- Design and capabilities of rehabilitation project to eliminate groundwater pollution to acceptable levels;
- Public health and safety concerns associated with implementing the technology in or near a study area;
- Public perception and community preferences; and
- Resources and relative cost of implementation.

Consideration of these factors to determine acceptable rehabilitation timeframes allows efficient running of rehabilitation activities to ensure that it achieves the desired goals.

1.5.5 Control of Groundwater Contamination (Sources of Control)

Control of groundwater pollution is considered to be more appropriate than rehabilitation because once groundwater becomes contaminated, it is difficult and expensive to clean up (Talabi and Kayode, 2019). However, it is understood that in some cases prevention measures for groundwater pollution may not readily be in place which could results in groundwater quality deterioration and subsequently requirement for remedial actions. Therefore, the guideline recommends that before the initiation of the groundwater rehabilitation project, control of the source(s) of release must be ensured to reduce or eliminate, to the extent practicable, further releases of hazardous waste or hazardous constituents that may pose a threat to human health and the environment.

1.5.6 Selection of Groundwater Rehabilitation Techniques/Methods

With the advent of technology to rehabilitate contaminated sites, many remedial techniques have been developed (Devika and Rastogi, 2015). Groundwater rehabilitation can take place through the extraction of groundwater from the aquifer, treat it above the ground, and return the treated water into the aquifer. Extraction is done by pumping groundwater from a borehole or a trench and treating it with a variety of techniques characterised as ex-situ techniques. The following are some of the ex-situ rehabilitation techniques available in practice:

- *Carbon Adsorption* involves passing the contaminated pumped-up groundwater through an activated carbon-column in which contaminates get adsorbed.
- *Oxygen Sparging* is a technique that introduces oxidizing or reducing agents such as O_3, H_2O_2, and Hypochlorite) to chemically convert the toxic contaminates into less toxic compounds.
- *Steam Stripping* involves treatment by introducing steam which extracts contaminants from pumped-out groundwater. The extracted steam along with contaminates can be recovered from the condensate or treated further by incineration.

- *Ex-situ Bioremediation* is a technique that involves the treatment of pumped-up groundwater by air (biodegradation) with careful control of moisture, heat nutrients, oxygen, and pH.

All ex-situ techniques are mainly characterised by the *"pump and treat"* approach as depicted in **Figure 3.**

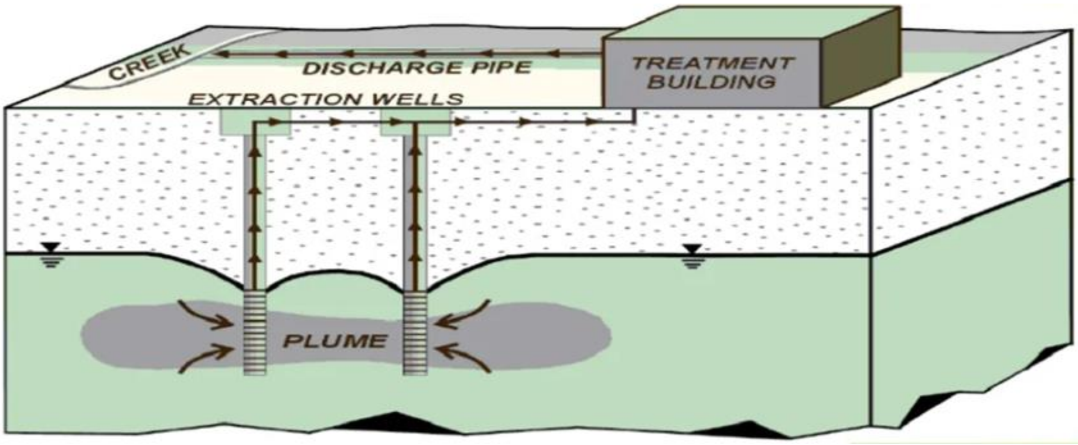

Figure 3: Ex-Situ groundwater rehabilitation technology (Adapted from Dwivedi, 2014)

Groundwater rehabilitation can also take place at the site of rehabilitation without the removal of contaminated groundwater. The following are some of the in-situ rehabilitation techniques available in practice:

- *In-situ Bioremediation* allows for on-site injection of oxygen to enhance biodegradation. This treatment also combines injection of degrading microorganisms and nutrients into the aquifer to stimulate biodegradation.
- *Thermal treatment* involves an increase in the temperature of the contaminated site to increase the mobility of pollutants, which facilitates the removal of pollutants which can also results in-situ destruction of contaminates.
- *Air Sparging* enables the injection of contaminant-free air into the subsurface saturated zone, thus enabling a phase transfer of hydrocarbons from a dissolved state to a vapor phase.
- *The phytoremediation* technique involves the use of macroscopic plants to destroy, remove immobilize, and treat contaminants. This process does not use microorganisms but plants. (Reference)

The in-situ technology is shown in **Figure 4**, while types of phytoremediation techniques are elaborated in **Figure 5**.

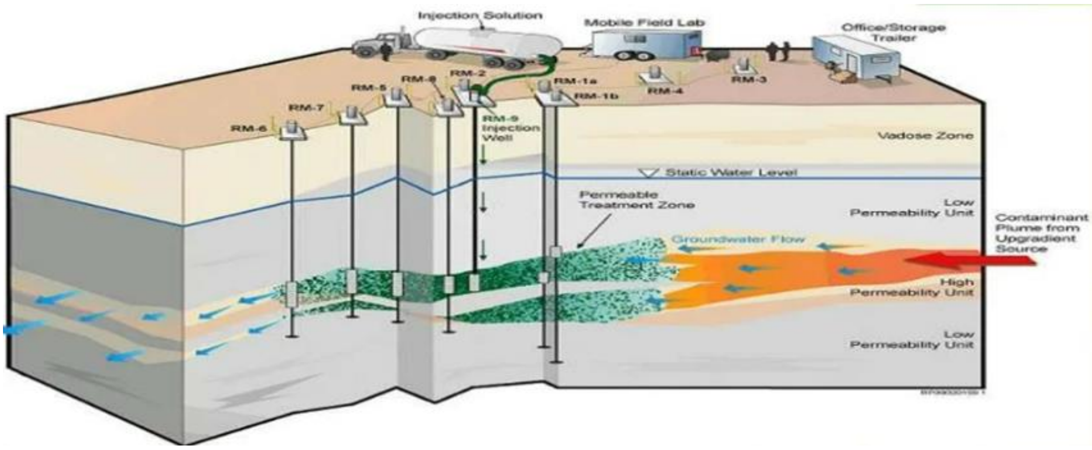

Figure 4: In-Situ groundwater remediation technology (Adapted from Dwivedi, 2014)

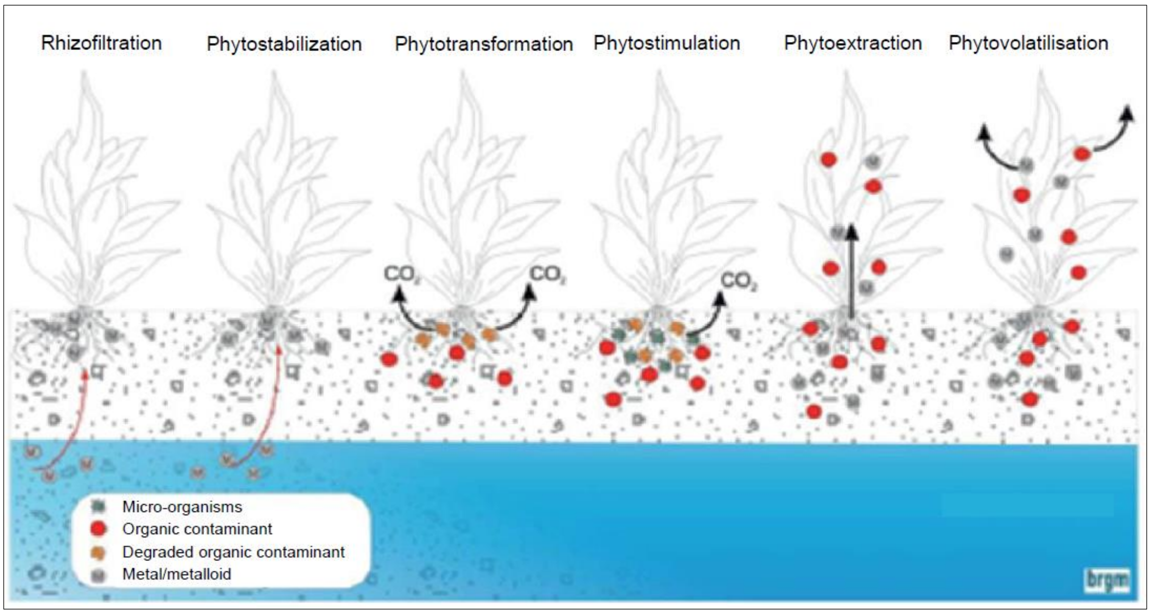

Figure 5: Different types of phytoremediation techniques (Available online at: https://www.eni.com/assets/documents/eng/enirewind/remediation/vademecum-eng.pdf)

The selection of remedial techniques depends upon several factors such as contaminant profile, aquifer profile, and feasibility profile (Dwivedi, 2014). The contaminant profile includes types of compounds (Dense Non-Aqueous Phase Liquid; Light Non-Aqueous Phase Liquid; Ammonia, Virus; Bacteria), quantity and solubility in water, toxicity, and volatility (*e.g.,* Metals), and biodegradability. The aquifer profile includes soil type (permeability, homogeneity, confined or open), groundwater flow direction, water table location, and recharge locations (seasonal rainfall). The feasibility profile relates to the cost of technology to use, and the time of project completion.

1.5.7 Removal of Groundwater from the Aquifer

Removal of contaminated groundwater is mostly done by applying "pump-and-treat" technology as a rehabilitation technique. One or more extraction wells are used to remove contaminated water from the subsurface. Pumping removes, or "flushes," additional contamination by inducing desorption from the porous media grains and dissolution of a contaminant **(Figure 7).** The contaminated groundwater is then pumped from the subsurface and directed to some type of treatment operation, which may consist of air stripping, carbon adsorption, or perhaps an above-ground biological treatment system (Brusseau, 2019).

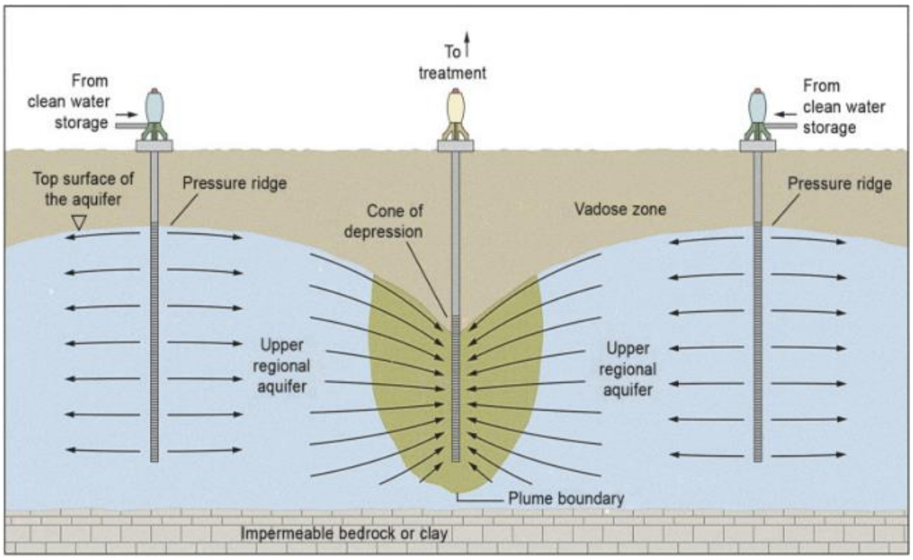

Figure 6: Ex-Situ groundwater rehabilitation technology (Adapted from Brusseau, 2019)

1.5.8 Reinjection of treated Groundwater into the Aquifers

Once contaminated groundwater has been removed from the aquifer it can be subjected to treatment to ensure that contaminants are removed. Once contaminants have been removed or lowered down to background levels, treated groundwater can then be reinjected back into the resource when it is considered safe to do so.

1.5.9 Monitoring and Evaluation of Groundwater Rehabilitation Project

EPA (2004) noted that both natural and human factors such as seasonal precipitation or nearby groundwater usage can influence the ability of a rehabilitation project to control migration of contaminated groundwater. Therefore, performance of a groundwater rehabilitation activity must be monitored. Performance monitoring can assess changes in groundwater so that project managers can modify rehabilitation actions to ensure maximum efficiency, protectiveness, and compliance. Performance monitoring can also demonstrate whether the rehabilitation technique applied is performing as expected.

Groundwater rehabilitation can be considered ~~as~~ complete when final rehabilitation objectives have been met, even though long-term controls may be required. This stage of the rehabilitation project allows for the evaluation of whether the project is successful in the elimination of a contaminant plume per unit boundary point of compliance, and whether it has controlled further releases of contaminants that might re-contaminate groundwater.

1.6 INTENDED USERS OF THE GUIDELINES

The RMGs for Groundwater Resources is a set of tools developed to ensure that clear and practical steps are provided on a wide range of rehabilitation measures/interventions that take cognisance of legal, ecological, social, and economic, issues and aspects. The guidelines are intended for all Government Departments (National, Provincial and Local), Catchment Management Agencies (CMAs), sectoral institutions (*i.e.,* higher education institutions), civil society members, non-governmental entities, private sector (agriculture, industries, mining) and all interested and affected parties involved in the water sector. The guidelines are developed at a national scale for implementation at a catchment level.

This document guides regulators, practitioners, and stakeholders on groundwater resource rehabilitation approaches with a focus on achieving positive outcomes in terms of groundwater resource sustainability rather than focusing on a particular administration process. Although groundwater rehabilitation would be largely influenced by hydrogeologic factors such as groundwater and soil contaminant mass, exposure pathways, groundwater velocity properties, permeability, and other factors, however the guidelines are developed using a combination of sectors and their respective specific impact types, and the approach illustrated in **Figure 7 below** is adopted.

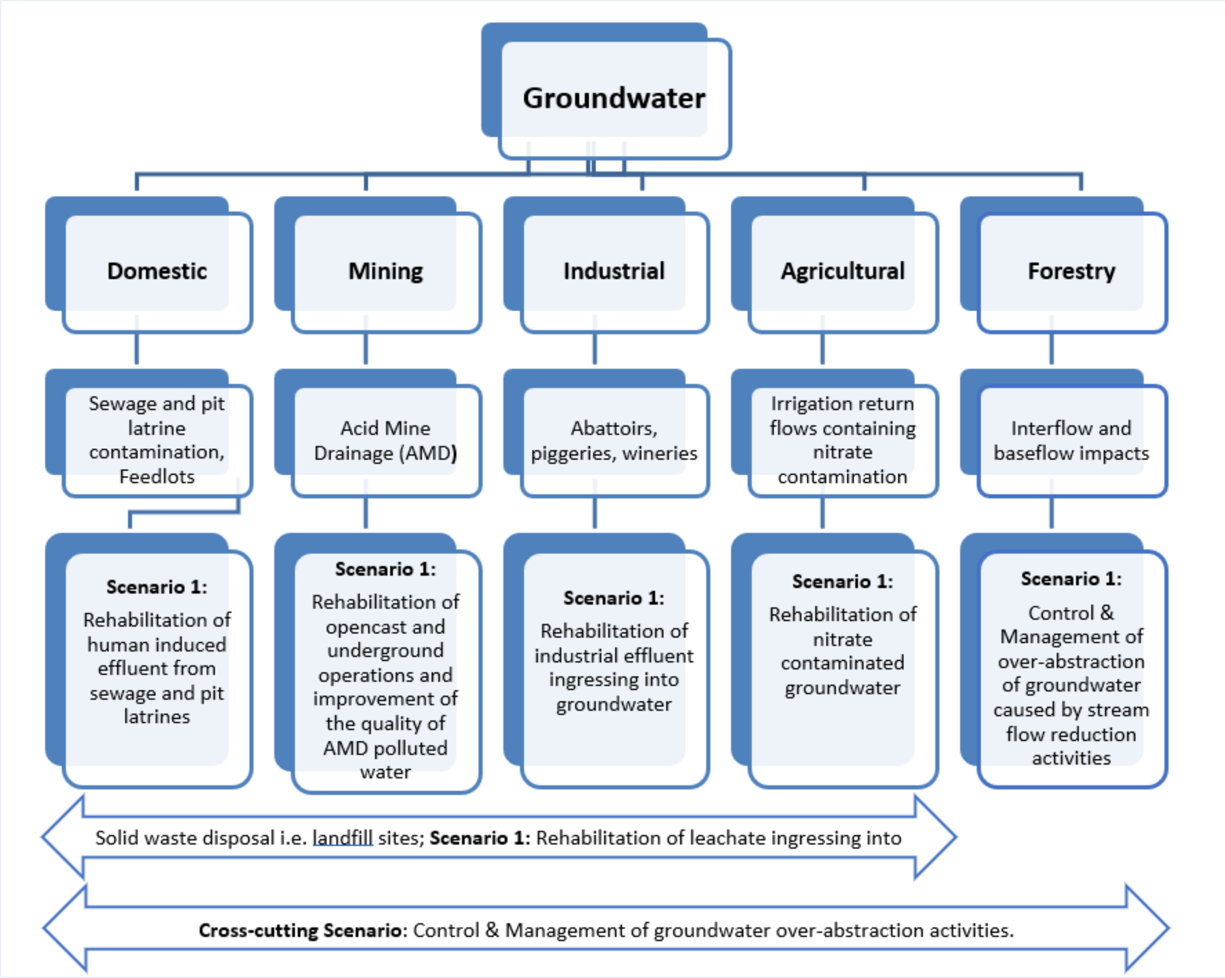

Figure 7: Illustration of the development of Groundwater Rehabilitation Guidelines per sector.

1.7 STRUCTURE OF THE GUIDELINES

The guidelines are divided into five main sections as follows:

- The opening sections contain the document signatories, document index and status, acknowledgements, table of contents, list of figures, tables, acronyms, and executive summary.
- **Section 1** provides the background of the development of the guidelines, purpose, approach, intended users, and structure of the guidelines.

- **Section 2** provides the overarching legal framework for groundwater rehabilitation.
- **Section 3** provides the overarching degradation impacts associated with groundwater resources.
- **Section 4** provides the step-by-step Technical Rehabilitation Guidelines for groundwater resources.
- **Section 5** provides recommendations and a way forward.
- The last section presents the bibliography and list of appendices.

2. LEGAL FRAMEWORK

2.1 LEGAL FRAMEWORK FOR GROUNDWATER

Groundwater resource rehabilitation activities are undertaken within the context of a legal framework to support the legitimacy of such activities. **Table 3** outlines some of the key legislative frameworks that support groundwater resources rehabilitation.

Table 3: Key legislation on groundwater resource rehabilitation in South Africa

Legal Framework	Context
White Paper on water policy of 1997 (NWP, 1997)	• Principle 16 of the NWP (1997) on water resources management approaches proposed that water quality management options shall include the use of economic incentives and penalties to reduce pollution; and the possibility of irretrievable environmental degradation because of pollution shall be prevented. • Incentives and penalties could also be used to fund rehabilitation projects for the environment or water resources that have degraded beyond natural state of recovery. The NWP (1997) does not separate water resources in terms of their types, and therefore it is in this principle where groundwater resources rehabilitation is supported.
National Water Act (Act 36 of 1998) (NWA, 1998)	• Chapter 3, Part 4, Section 19 of the NWA (1998) deals with prevention and remedying effects of pollution. Section 19(2)(e)(f) stipulates measures that must be taken to prevent any pollution of water resources from occurring, continuing, or recurring. Such measures include remedying the effects of pollution and remedying the effects of any disturbance to the banks of a watercourses. • In the case of emergency situations, where harmful substances are accidentally or negligently discharged into water resources, the NWA (Chapter 3, Part 5, Section 20) provides for those who have caused the pollution and are responsible for remedying its effects. • When the NWA is implemented especially for water resources protection, an integrated approach is adopted which encompasses protection of all types of water resources with groundwater included. It is in this context that the NWA supports implementation of measures for groundwater resources rehabilitation. • Section 21 (c) and (i), (j), and (g) are some typical water uses triggered by rehabilitation interventions or activities. It must however be noted that this will depend on the situation at hand and the approach might differ on a case-by-case basis.
Regulations regarding the procedural requirements for Water Use Licence Applications	• The purpose of these Regulations is to prescribe the procedure and requirements for Water Use License Applications as contemplated in sections 41 of the Act; as well as an appeal in terms of section 41(6) of the Act.

Legal Framework	Context
and Appeals - Government Notice (GN) R267 in Government Gazette 40713 dated 24 March 2017.	
National Environmental Management Act (Act 107 of 1998) (NEMA, 1998)	• Section 28(3)(f) of the NEMA requires that every person who causes, has caused, or may cause significant pollution or degradation of the environment must take reasonable measures such as remedying the effects of the pollution or degradation. • Considering that water resources with groundwater included form part of the environment, it is under this section of the NEMA where groundwater resources rehabilitation is supported.
National Environmental Management: Waste Act (Act 59 of 2008)	• Part 8 of the of the Waste Act provide a detailed approach for the management of contaminated land in the country. • Provide a clear set of approaches in Identification of investigation areas. • It outlines the processes that must be followed in management of contaminated land. • It also sets out information required in tools for management of contaminated land.
Minerals and Petroleum Resources Development Act (Act 28 of 2002) (MRPDA, 2002)	• The Minerals and Petroleum Resources Development Act of 2002 lays out new obligations for ~~the~~ mining and other industries in terms of the monitoring and remediation of pollution of water resources. Therefore, the Act supports remediation of polluted groundwater resources, especially pollution resulting from industrial and mining operations.

2.2 ALIGNMENT WITH POLICIES AND STRATEGIES

A guideline on rehabilitation management for groundwater resources acts as a reference material or as a standard guide controlling water resources rehabilitation activities. However, such a guide must be relevant and be aligned with existing policies and strategies. Therefore, this section provides an overview of existing policies and strategies, and it highlights the context in which these policies and strategies influence or will influence groundwater resources rehabilitation practice. Furthermore, the overview will assist in developing groundwater resources rehabilitation guidelines that are relevant and appropriate for policy implementation using existing strategies. A summary of policies and strategies that inform groundwater rehabilitation is outlined in **Table 4** below.

Table 4: Polies and strategies informing groundwater rehabilitation.

Legal Framework	Context
Policy and Strategy for Groundwater Quality Management in South Africa (2000)	Policy and Strategy for Groundwater Quality Management (2000) emphasises groundwater remediation which is not sufficiently covered in the NWA. It draws on the experience of countries that already have guidelines for known contaminants. It further suggests a site-specific, needs-based approach to remediation of degraded groundwater.
Artificial Recharge Strategy (ARS) (DWA, 2010)	The DWA developed the Artificial Recharge Strategy (ARS) aimed to use natural sub-surface storage as part of Integrated Water Resource Management (IWRM) wherever technologically, economically, environmentally, and socially feasible. The ARS into relevant planning documents is informed by relevant planning document such as the: • National Water Resource Strategy; and • Groundwater Strategy

Artificial Groundwater Recharge: Recent Initiatives in Southern Africa (DWA, 2010)	The booklet provides an overview of the status of artificial recharge in Southern Africa and lists resources that are easily accessible to anyone considering this water storage, treatment, and conservation measure.
Second and Third Editions of the National Water Resource Strategy (NWRS II, 2013); (NWRS III, 2023)	The NWRS II (2013) notes that much still needs to be done in the areas of implementation of water resource protection programmes and monitoring of ecosystem health to proactively minimize degradation of the resource, focus on rehabilitation efforts and ensure compliance with sustainability. The NWRS III (2023) calls for the development of government policies and strategies for proactive measures to mitigate water resource quality degradation and address legacy deterioration; while maintaining healthy water ecosystems (*i.e.,* groundwater) to ensure their continued provision of ecosystem services.
National Groundwater Strategy, 2nd Edition (NGS, 2016)	The NGS (2016) notes that the mining sector is faced with legacy issues of past pollution, for example, acid mine drainage. It further stipulates that the development of new mines in water-scarce areas and pristine environments requires planning to decide for the transfer of water and development of new sources, and appropriate attention to waste processing and remediation.
Integrated Water Quality Management Strategy (IWQMS, 2017)	Principle 10 of the IWQMS dwells on the promotion of green/ecological infrastructure restoration and rehabilitation and restoration of degraded catchments. However, the IWQMS also notes that the costs associated with rehabilitation of degraded water resources, or of emergency responses to pollution incidents can be extremely high.
Department of Water Affairs: Environmental Rehabilitation Policy (DWA, 2014)	The discussion document highlights the need for an environmental rehabilitation policy linked to water resources. The policy is envisioned to lay the foundation and clarify the approach for DWS to implement, regulate and facilitate environmental rehabilitation within its mandate as custodian authority over water resources.
National Water and Sanitation Master Plan (NW&SMP, 2018)	The NW&SMP (2018) states that implementation of the waste discharge strategy is of critical importance to increase the funding available for the management and rehabilitation of polluted catchments, but also to incentivize the reduction of pollution.
DWS Best Practice Guidelines (BPGs) for Water Resource Protection in South Africa Mining Industry (DWAF, 2006, 2007, 2008).	The DWS developed a series of Best Practice Guidelines (BPGs) for mines dealing with pollution prevention and water management strategies and tools. Below is a list of the available BPGs: • BPG A1. Small-Scale Mining (Standard Format). • BPG A1.1 Small-Scale Mining (User Format). • BPG A2. Water Management for Mine Residue Deposits. • BPG A3. Water Management in Hydrometallurgical Plants. • BPG A4. Pollution Control Dams. • BPG A5. Water Management for Surface Mines. • BPG A6. Water Management for Underground Mines. • BPG G1. Storm Water Management. • BPG G2. Water and Salt Balances. • BPG G3. Water Monitoring Systems. • BPG G4. Impact Prediction. • BPG. G5 Water Management Aspects for Mine Closure. • BPG. H1. Integrated Mine Water Management. • BPG. H2. Pollution Prevention and Minimization of Impacts. • BPG. H3. Water Reuse and Reclamation. • BPG. H4. H4 - Water Treatment.

3. GROUNDWATER IMPACTS

Global availability of sufficient good quality groundwater is important in meeting agricultural, domestic, industrial developments and environmental requirements to ensure sustainable food security for all (Cole *et al*. 2018; Masindi and Abiye 2018; Gomez *et al*., 2019). Groundwater is now considered a viable alternative source of water supply. However, recurring population growth, land-use changes, and anthropogenic activities threaten the water resource systems reliability and resilience (Elmhagen *et al*., 2015; Dlamini *et al*., 2019; Morris 2019). **Figure 8** below represents three main categories of impacts causing groundwater resources degradation.

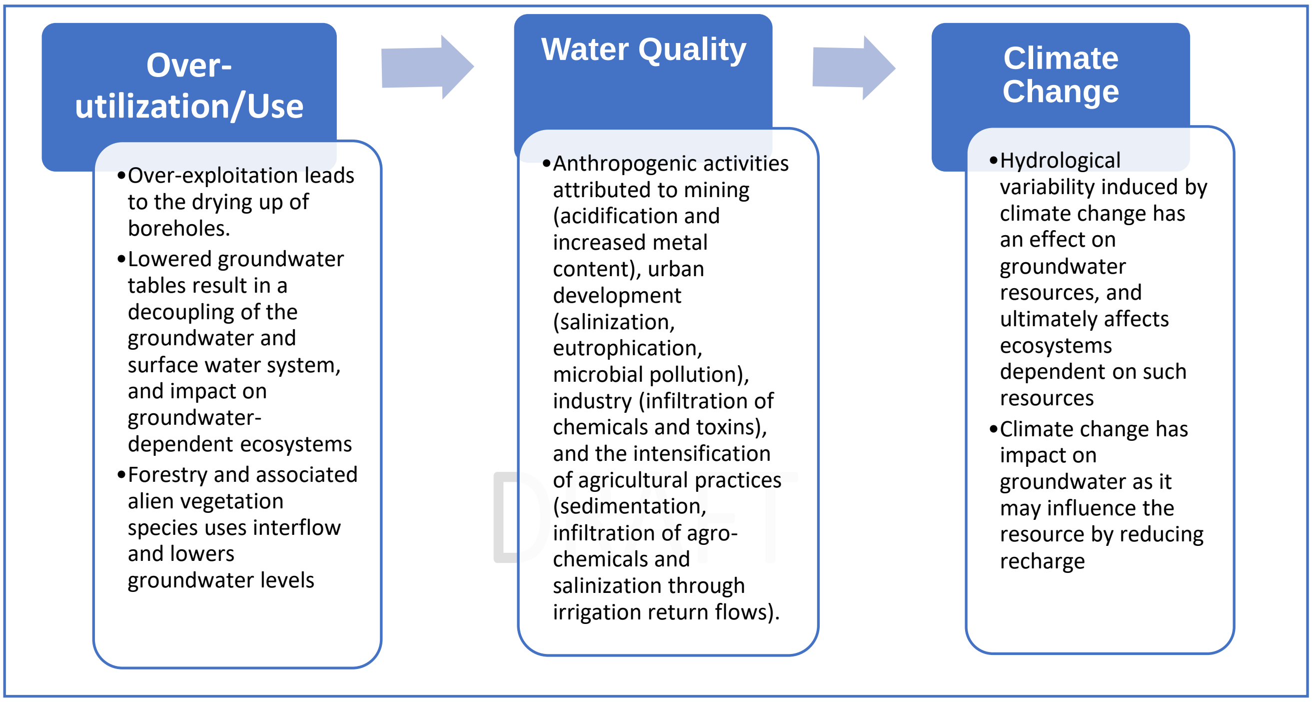

Figure 8: Three main categories of impacts causing degradation of water resources.

4. REHABILITATION MANAGEMENT GUIDELINES FOR GROUNDWATER

4.1 DOMESTIC

4.1.1 Description

Groundwater is an essential water resource that is critical in contributing to the country's water security and universal access to water and sanitation. Over 280 cities and towns (~66% of SA), are solely or partially dependent on groundwater for domestic needs (Knuppe, 2011), while over 74% of the rural population in SA is entirely dependent on groundwater (UN Water, 2006).

Domestic waste has a profound effect on the underlying groundwater quality, especially in the areas surrounding domestic Wastewater Treatment Works (WWTWs) and septic systems. Improperly designed, located, constructed, or maintained septic systems can leak bacteria, viruses, household chemicals, and other contaminants into shallow groundwater systems causing serious problems (Hubbard *et al.,* 2016). The possibility of extended survival of various sources of microbial contamination indicates the need to properly monitor groundwater contamination to identify the presence of microbial contaminants. (Kim and Kim, 2012).

4.1.2 Types of Impacts

Over-abstraction

Over-abstraction of groundwater resources is caused by mismanagement of the resource which influences frequent aquifer failure, which in turn leads to the drying up of boreholes. In addition, over-abstraction also leads to salt intrusion into the aquifer, especially at the coastal areas and when the salty geology of the area is disturbed. The consequences of over-abstraction of groundwater in the long-term are well articulated in Knüppe, (2011) as follows:

- Lowered groundwater tables result in decoupling of the groundwater and surface water system, including water exchange between rivers, wetlands, and springs;
- Drying up of boreholes;
- Reduction of water in surface water bodies such as rivers and wetlands;
- Deterioration of water quality;
- Increased pumping costs; and
- Land subsidence.

Groundwater over-abstraction does not only result in aquifer depletion and water-quality degradation but also impacts the ecological integrity of streams and wetlands and results in significant losses of habitat and biodiversity.

Sewage and pit latrine contamination

Biological contaminants in groundwater resources include algae and microbial organisms, such as bacteria, viruses, and protozoa. Drinking water contaminated by microbial contaminants can result in many serious human diseases, including typhoid, diarrhea and cholera (Li *et al.*, 2021). The COVID-19 virus which is primarily transmitted from person-to person through respiratory droplets has resulted in a pandemic affecting every corner of the world. (Bhowmick *et al.*, 2019). Interestingly, Lokhandwala and Gautam (2020) noted that water contaminated by this virus can also threaten human health.

Feedlot contamination

Groundwater is vulnerable to pollution from feedlots or cattle kraals and stock watering points in areas with high rainfall and shallow water tables. Groundwater vulnerability is potentially significant in environments with high permeability, such as sandy and gravelly soils, or where fractured bedrock lies close to the ground surface (DWAF, 2004).

Livestock watering points rely on groundwater, therefore the distance of a borehole to a watering point either increases or decreases the risk of contaminated water gaining access to groundwater via a borehole. The closer the distance of the watering point to the borehole, the greater the risk of contamination.

The main pollution source is animal faecal contamination, which is characterised by a high, rapidly bio-degradable organic content, a high concentration of nutrients, and numerous potential disease-causing organisms (pathogens). Pathogens and nitrates are the main contaminants of concern for groundwater used for drinking purposes in rural areas (DWAF, 2004).

4.1.3 Rehabilitation Management Guidelines

Scenario 1: *Rehabilitation of human-induced effluent from sewage and pit latrines*

Although groundwater is perceived least as susceptible to contamination by indicator bacteria or human pathogens compared to surface water, groundwater pollution is known to be imminent in most developing countries owing to increased anthropogenic activities apart from possible natural pollutants (Clemens *et al*., 2020). Pollution of groundwater can occur due to either point source such as municipal sewage treatment plant or as a result of non-point sources characterised by the diffusion of pollutants. While groundwater rehabilitation from point source pollution is easy to undertake, rehabilitation for non-point sources is difficult due to the extent of spread (Talabi and Kayode, 2019). Hence, the infiltration of untreated wastewater into aquifers highly endangers the availability of fresh water for human consumption, especially in semi-arid areas (Clemens *et al*., 2020).

PHASE 1: Diagnostic Phase:

The diagnostic phase of the project involves the collection of information that would give a general overview of the status of groundwater pollution within the target area.

Step 1: Conduct an environmental audit periodically (at least biannual).
Step 2: Undertake a review of historical groundwater quality data.
Step 3: Review incident reports supplied by various organizations involved in potential pollution activities and annual reports on the monitoring of WWTWs. (*e.g.,* Green Drop annual reports).
Step 4: Ascertain and summarize the types of groundwater contaminants based on reviewed data and literature.

PHASE 2: Planning and Assessment

Step 1: Undertake a site visit and assessment for ground truthing.
Step 2: Establish the location of boreholes and springs in relation to their proximity to pit latrines or WWTW.
Step 3: Identify potential sources of groundwater pollution such as WWTW in urban areas, and septic tanks or pit latrines in the case of informal settlements and rural areas.
Step 4: Establish and summarize the extent of groundwater pollution in the area.

PHASE 3: Identify and Define the Rehabilitation Objectives

Establish clear goals or objectives of the rehabilitation informed by the data collated in Phase **1** and **2.**

The objective of undertaking groundwater rehabilitation for domestic is to reduce microbiological pollution down to acceptable levels as stipulated in the water quality guidelines for domestic water use.

PHASE 4: Execution

Step 1: Apply the ex-situ[2] treatment technology such as the Pump and Treat technique.
Step 2: Apply a filtration system to remove particulate matter from the pumped groundwater.
Step 3: Apply ultraviolet (UV) light irradiation for effective removal of bacteria, viruses, and protozoa.

[2] *Extraction of groundwater through pumping from aquifer, treatment on surface, and returning of the treated water back into the aquifer. Ex-situ techniques are mainly characterised by Pump and Treat approach.*

Step 4: Apply chlorine disinfection which is a common form of disinfection that is effective against harmful bacteria and virus.

Step 5: Establish a protection zone to protect a borehole from contact with pathogenic micro-organisms (*e.g.,* bacteria and viruses) which can emanate from a source (*e.g.,* septic system) located close to the borehole.

PHASE 5: Monitoring, Evaluation and Reporting

Monitoring must be undertaken to determine the following:

- Changes in the concentrations of microbiological contaminates over time – trend analysis;
- Pump and Treat: monitor water quality in terms of chemical reactions, before injecting it back to the aquifer. Monitoring should be undertaken periodically and concurrent to the pumping activities.
  Note: *After pumping water from underground to the surface, chemical reactions when exposed to oxygen and other gases may change the chemical content or pollute water.*
- Pollution migration in relation to groundwater flow direction; and
- If the quality is improving or deteriorating further, for improved management of the resource.

Evaluation

- Evaluate the effectiveness of interventions against the achievement of rehabilitation objectives and outcomes; and
- Determine maintenance objectives.

Reporting

A Rehabilitation Report should be compiled and be accompanied by supporting information such as:

- A map of disturbed and rehabilitated areas;
- Before and after photos of rehabilitation including a significant landmark for comparison purposes, with a brief description including location, and date; and
- Overall status of the rehabilitated area in relation to the rehabilitation objectives.

Scenario 2: *Control and Management of groundwater over-abstraction activities for domestic uses*

Section 26 of the NWA limits the purpose, manner, or extent of water use, and requires that the use of groundwater be monitored, measured, recorded, and be registered with the responsible authority. The below scenario will focus on providing practical guidance on how to control and manage hydrogeological impact of **(A)** proposed or **(B)** existing groundwater abstraction activities.

(A) Proposed Groundwater Abstraction Activities

PHASE 1: Diagnostic Phase

No diagnostic steps should be undertaken for new groundwater water abstraction activities proposed, because there are no existing impacts. However, it must be noted that there is a requirement for the development of a conceptual groundwater model for the identification and prediction of potential impacts and supporting recommended mitigation measures (**Figures 10** and **11**).

The person(s) applying for the abstraction activities must at this stage compile a technical motivational report to DWS detailing the following key information:

- Property description in terms of size and quaternary catchment where abstraction activities will take place;
- Proposed abstraction point(s); and
- Water use requirements *i.e., groundwater abstraction from **X** number of boreholes at **X** volume.*

PHASE 2: Planning and Assessment

Step 1: Based on the information collated in the technical motivational report, the person(s) intending to undertake abstraction activities must indicate the type of authorization needed for the proposed new water use. **Figure 9** below presents available authorization processes for groundwater within the DWS.

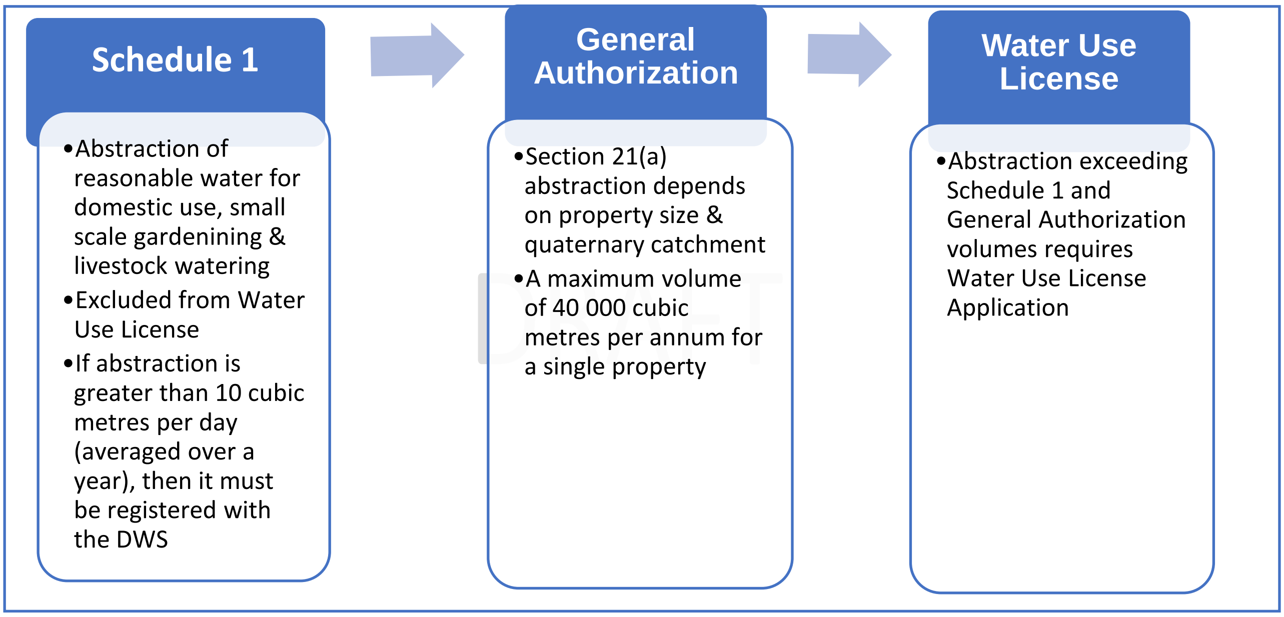

Figure 9: DWS Water Use Authorization Processes for Groundwater

Step 2: Consider the following exclusions pertaining to Schedule 1 and General Authorization:

<u>Schedule 1:</u>

- Small-scale gardening excludes abstraction of groundwater for domestic garden irrigation or subsistence farming; and
- Livestock watering excludes feedlots.

<u>General Authorization (GA):</u>

Basic Equation for General Authorization[3]:

Volume for a property (in m^3/a) = GA of the quaternary catchment (in $m^3/ha/a$) x property size (in ha)

Example:

[3] General Authorization in terms of Section 39 of the National Water Act, 1998 (Act No. 36 of 1998) for water uses as defined in Section 21(a), Published in Government Notice 536 of 2016

- A property of 120 ha size in the greater Cape Town area (quaternary catchments G22A to G22K, which have a GA of 400 m^3/ha/a) would result in a Section 21(a) GA groundwater abstraction volume for the property of 48 000 m^3/a (*i.e* 400 m^3/ha/a x 120 ha)
- However, this would be reduced to 40 000 m^3/a, because of the maximum GA groundwater abstraction volume of 40 000 m^3/a for any single property. Any groundwater abstraction above 40 000 m^3/a would therefore require a Water Use License (WUL), whereas any groundwater abstraction below 40 000 m^3/a would require a less intensive groundwater use registration under the GA.
- Using a smaller sized property of say 5 ha in the Cape Town area would result in a Section 21(a) groundwater abstraction volume of 2 000 m^3/a for the property (*i.e.,* 400 m^3/ha/a x 5 ha), therefore in this case any groundwater abstraction above 2 000 m^3/a would require a WUL. This example is generally why industrial and commercial groundwater users in the greater Cape Town area almost always require a Section 21(a) WUL, due to the generally small property size of <5 ha resulting in any planned groundwater use in excess of 2 000 m^3/a requiring a WUL.

PHASE 3: Identify and define the Rehabilitation Objectives

The objectives of groundwater abstraction activities must be clear from the onset. These objectives must be informed by the information and data collated in **Phase 1 and 2** above. In general, some of the common aims and objectives of controlling and managing groundwater abstraction are as follows:

- **To prevent the groundwater resource (aquifer) from being over-utilised**. If an aquifer is over-pumped a long-term depletion of the groundwater resource can result throughout the entire aquifer. This over-abstraction can negatively affect all users of the aquifer, including aquifer dependent ecosystems;
- **To optimise individual borehole pumping rates**. If individual borehole pumping rates are too high, a localized depletion of groundwater results;
- **To prevent poor quality groundwater from entering the aquifer.** If abstraction from the aquifer is too high, poor-quality groundwater can be drawn into the aquifer; and
- **To minimize groundwater contamination from surface sources** such as pit latrines, animal kraals, fertilizers, and dipping tanks.

For very large abstraction volumes (in the order of millions of cubic meters per annum) with multiple boreholes (*i.e.,* a wellfield), numerical groundwater modelling showing the sustainability of the proposed abstraction volume and/or potential abstraction impacts might also be required.

PHASE 4: Execution

The person responsible for control and management of groundwater over-abstraction activities should appoint a relevant specialist to undertake a study that should include amongst others, desktop geological/hydrogeological assessment, field hydrocensus, drilling and test-pumping of the boreholes(s), recommended yield analysis and operational pumping regime of the borehole(s), groundwater quality analysis and the development of a groundwater model with supporting management recommendations. The key components of the hydrogeological study are described in detail in the steps presented in **Figures 10** and **11** below.

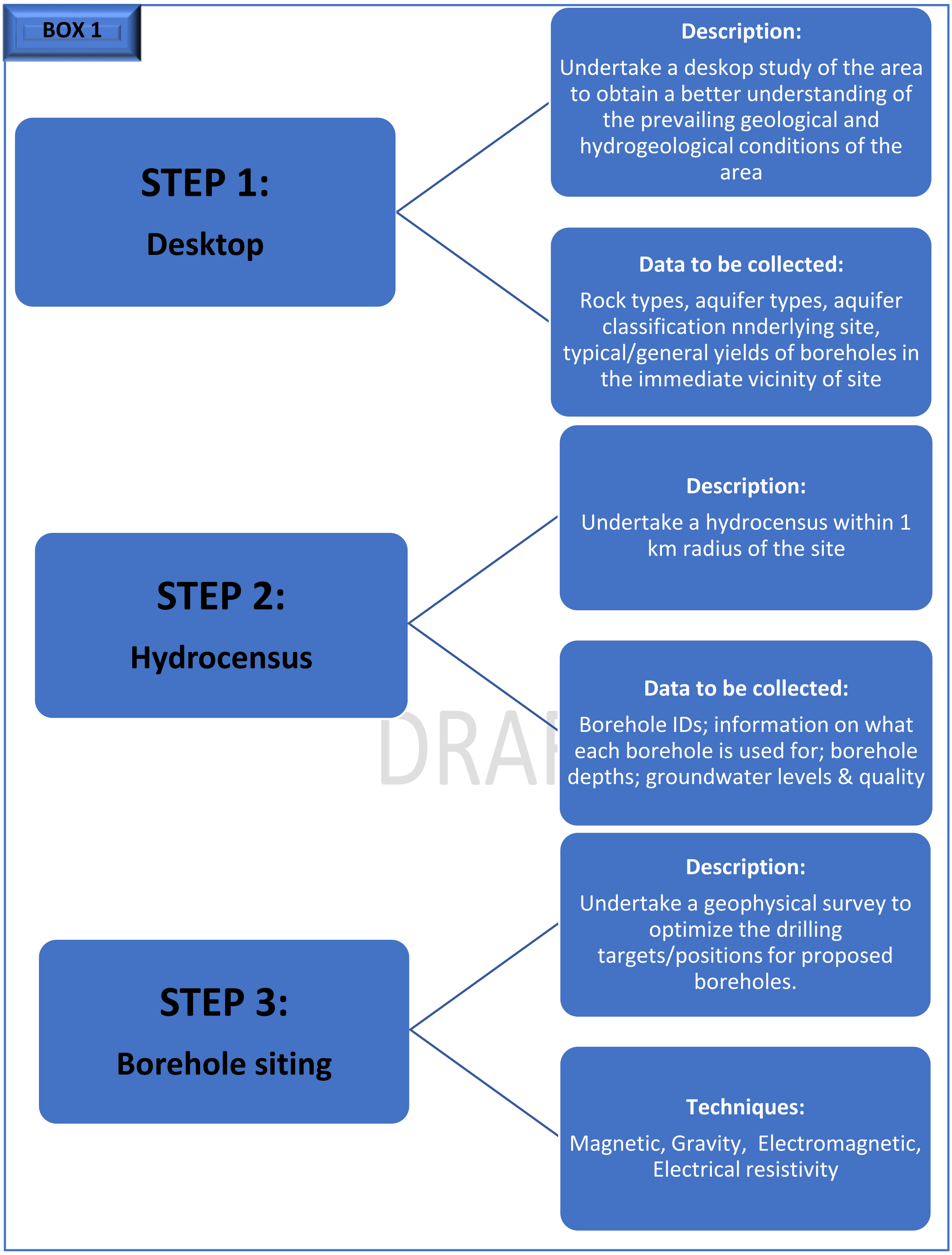

Figure 10: Components (desktop, hydrocensus and borehole siting) of the hydrogeological study.

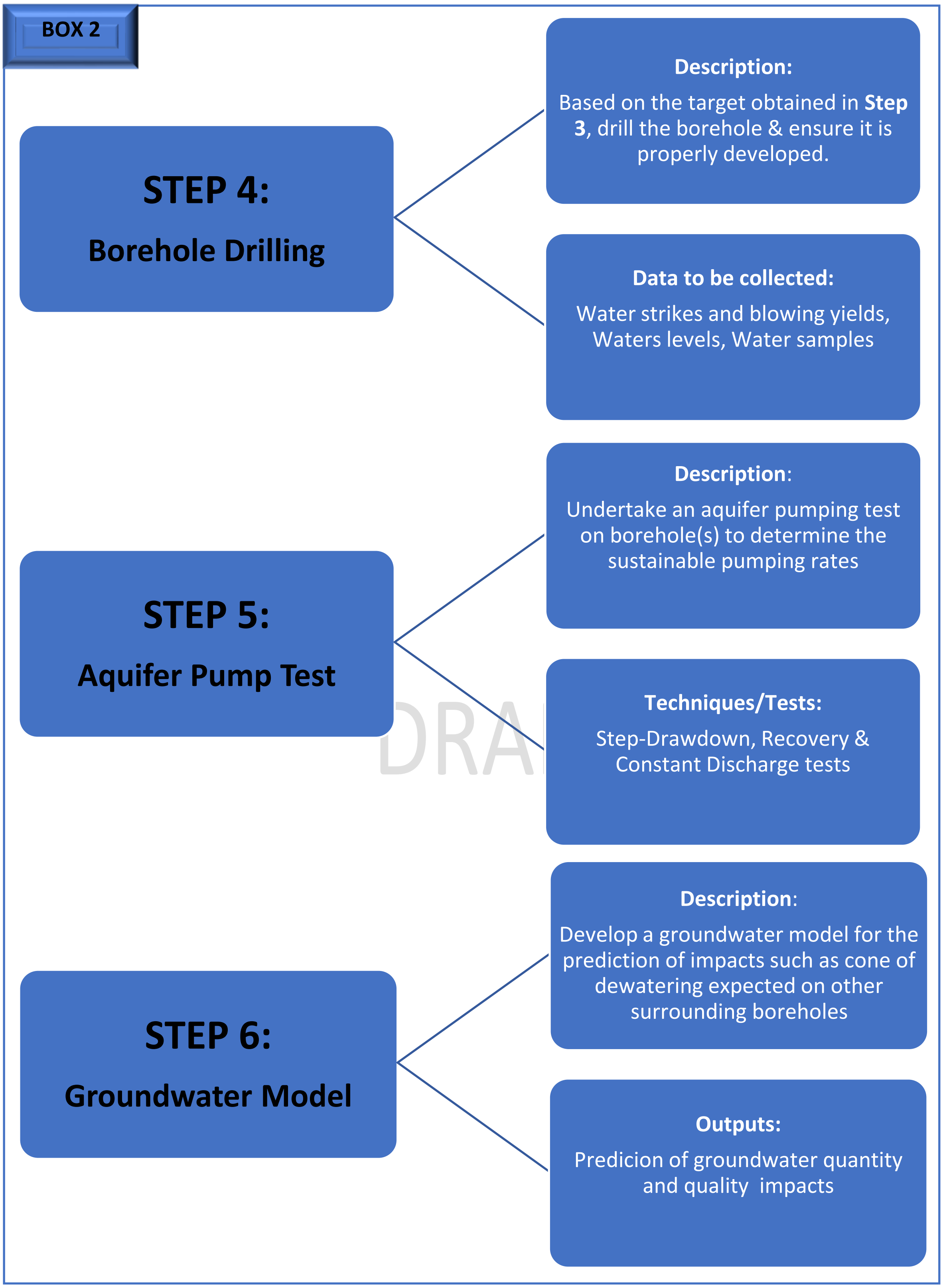

Figure 11: Components (drilling, pump testing and groundwater model) of the hydrogeological study.

PHASE 5: Monitoring, Evaluation and Reporting

Groundwater abstraction activities should be managed and monitored in terms of quantity and quality. This will ensure that the resource is used efficiently, and to its potential, and minimise the risk of deteriorating quality or availability. Besides the basic borehole information such as location, depth, and diameter, **Figure 12** below illustrates water levels, abstraction rates, and water quality that should be monitored and recorded on a regular basis.

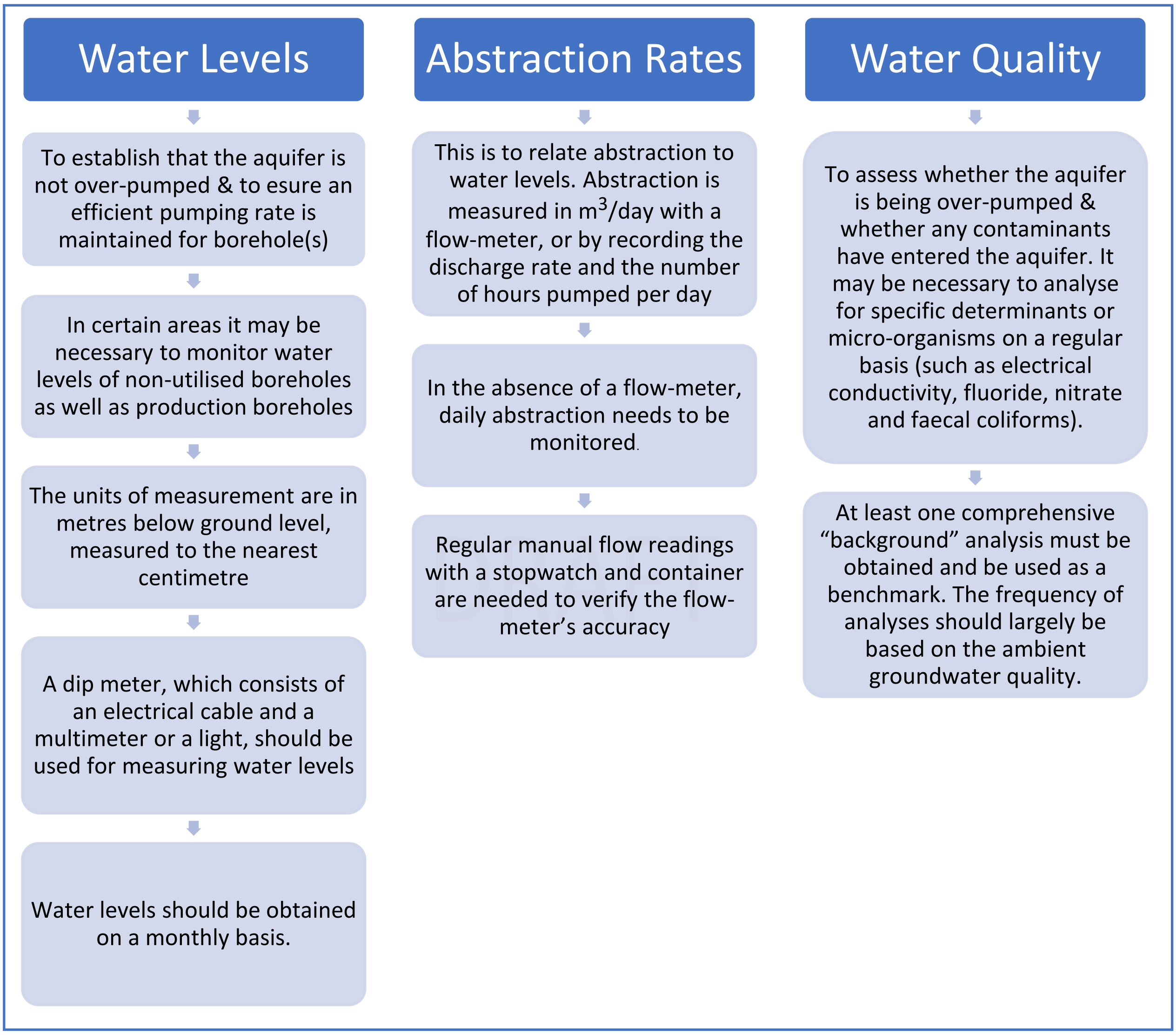

Figure 12: Groundwater Monitoring Components

Evaluation

- Evaluate the effectiveness of interventions against the achievement of rehabilitation objectives and outcomes; and
- Determine maintenance objectives.

Reporting

A Rehabilitation Report should be compiled and be accompanied by supporting information such as:

- A map of disturbed and rehabilitated areas;

- Before and after photos of rehabilitation including a significant landmark for comparison purposes, with a brief description including location, and date; and
- Overall status of the rehabilitated area in relation to the rehabilitation objectives.

<u>(B) Existing Groundwater Abstraction Activities.</u>

This scenario is directly linked to the one presented in the previous section *i.e.,* ***(A) Proposed Groundwater Abstraction Activities*** with a slight difference being that the current scenario *i.e.,* ***(B) Existing Groundwater Abstraction Activities*** becomes applicable after **Phase 1 to 5 in the previous section are completed and the abstraction activities are operational.** Presuming the abstraction activities are in place, all cases of over-abstraction will be deduced from the monitoring reports of the data that is collected, captured, analysed, and interpreted as illustrated in **Figure 13** below.

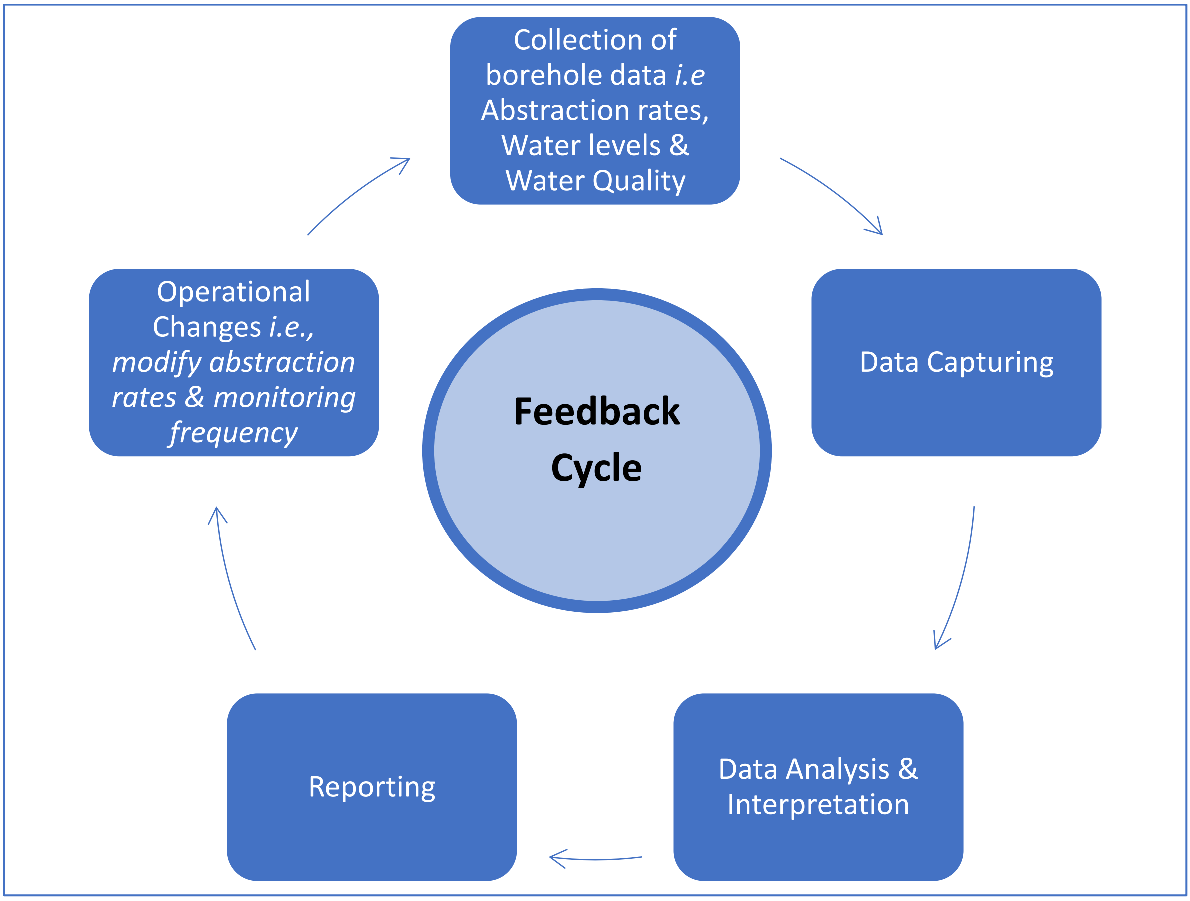

Figure 13: Groundwater monitoring feedback cycle

If over-abstraction is detected in certain boreholes, the following steps should be implemented:

Step 1: Undertake a **diagnostic assessment** of the borehole(s) to identify issues relating to over-abstraction and water quality.

Step 2: Based on the results obtained from the assessment in **Step 1**, the person(s) in charge of the borehole(s) should implement **operational and management amendments** in terms of modifying abstraction rates and monitoring frequency. Depending on the severity of the impacts, additional aquifer pumping tests should be undertaken to prevent any further groundwater level decline and potential impacts on the surrounding groundwater users.

Note: Refer to Section 4.6.3 for details on the Rehabilitation of over-abstraction of groundwater caused by SFR activities.

4.2 MINING

4.2.1 Description

Mining activities have an impact on water quality and quantity. Acid mine drainage (AMD) is one of the most serious and potentially enduring environmental problems for the mining industry. Mining, in its nature, has a major water quality issue as it adversely impacts the environment and water resources. AMD causes a reduction in water resource pH, which increases the availability of dissolved metals for uptake by organisms and fish.

4.2.2 Types of impacts

AMD occurs when sulphide minerals, such as pyrite (FeS_2), are exposed to air and water and undergo oxidation. This occurs primarily in coal and gold mines. After air contact in the presence of sulphide (mostly pyrite) the water is often acidic due to the production of sulphuric acid. The production of AMD depends on the rate of pyrite/sulphide oxidation and the influence of carbonate minerals in the host rock. AMD is characterised by an increase in acidity (low pH), increased metal concentrations, increased sulphate concentrations, and/or increased suspended solids. Known impacts of AMD on water resources include decant into rivers and streams and impact on aquatic ecosystems; corrosion of metal equipment and appliances; coloured water in streams and water unsuitable for use without treatment.

Acidic water has been associated with many mine wastes including underground flows, mine decant and mine residue deposits. The generation, release, mobility, and attenuation of AMD are complex processes governed by a combination of physical, chemical, and biological factors. **Figure 14** illustrates examples of sources, pathways, and receptors of AMD.

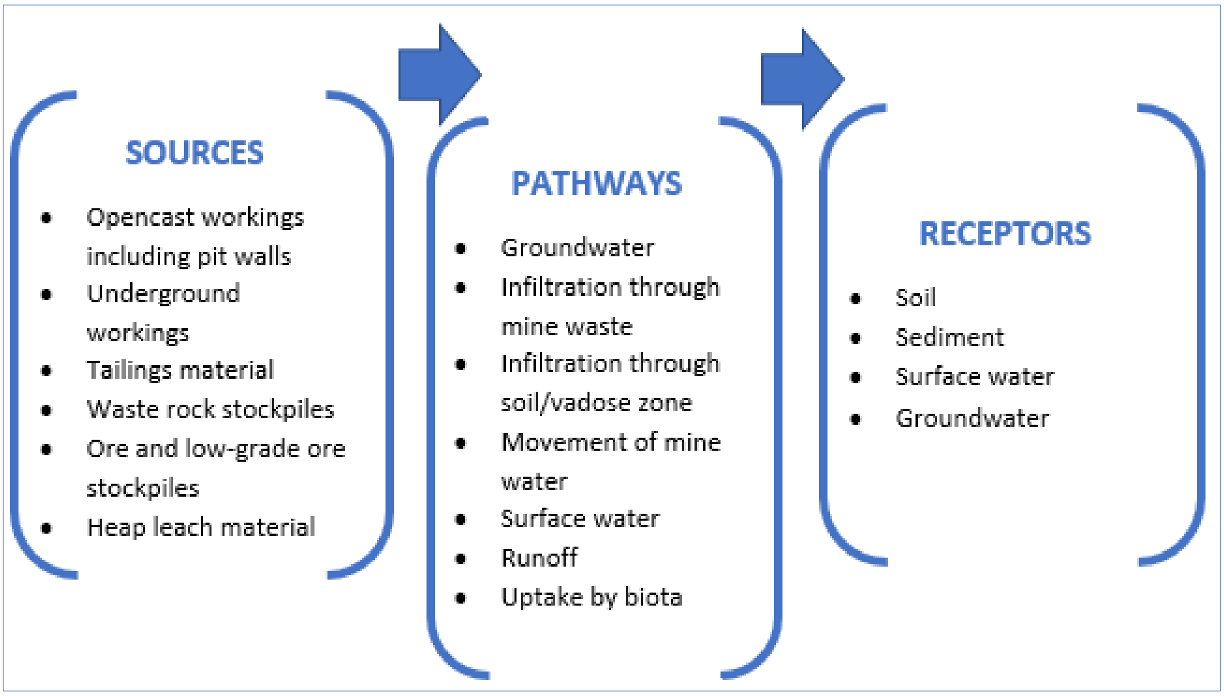

Figure 14: Sources, pathways and receiving environment for AMD.

4.2.3 Rehabilitation Management Guidelines

Scenario 1: *Rehabilitation of opencast and underground operations and improvement of quality of AMD polluted water.*

Undertake the steps illustrated in **Figure 15** below to diagnose the issues relating to AMD.

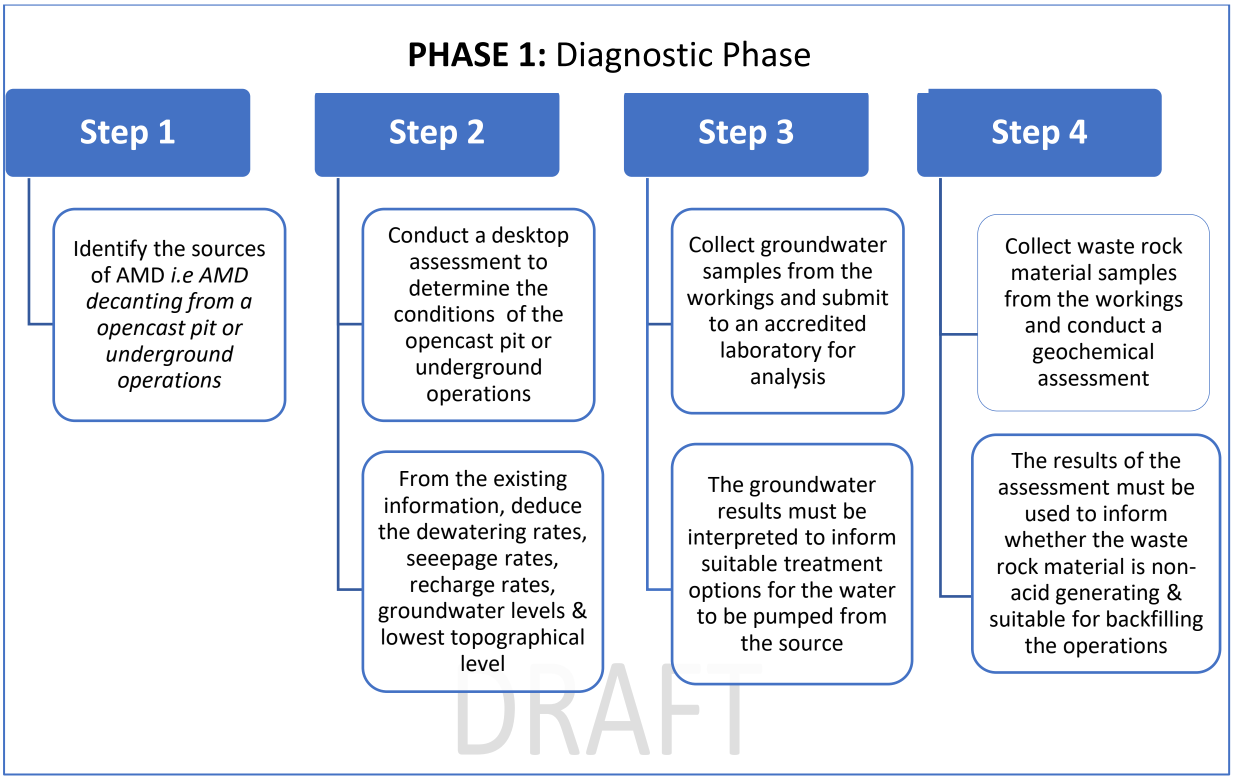

Figure 15: Steps to be followed during the Diagnostic Phase.

The rehabilitation of AMD emanating from the opencast and underground operations triggers Section 21 water uses as illustrated in **Figure 16** below.

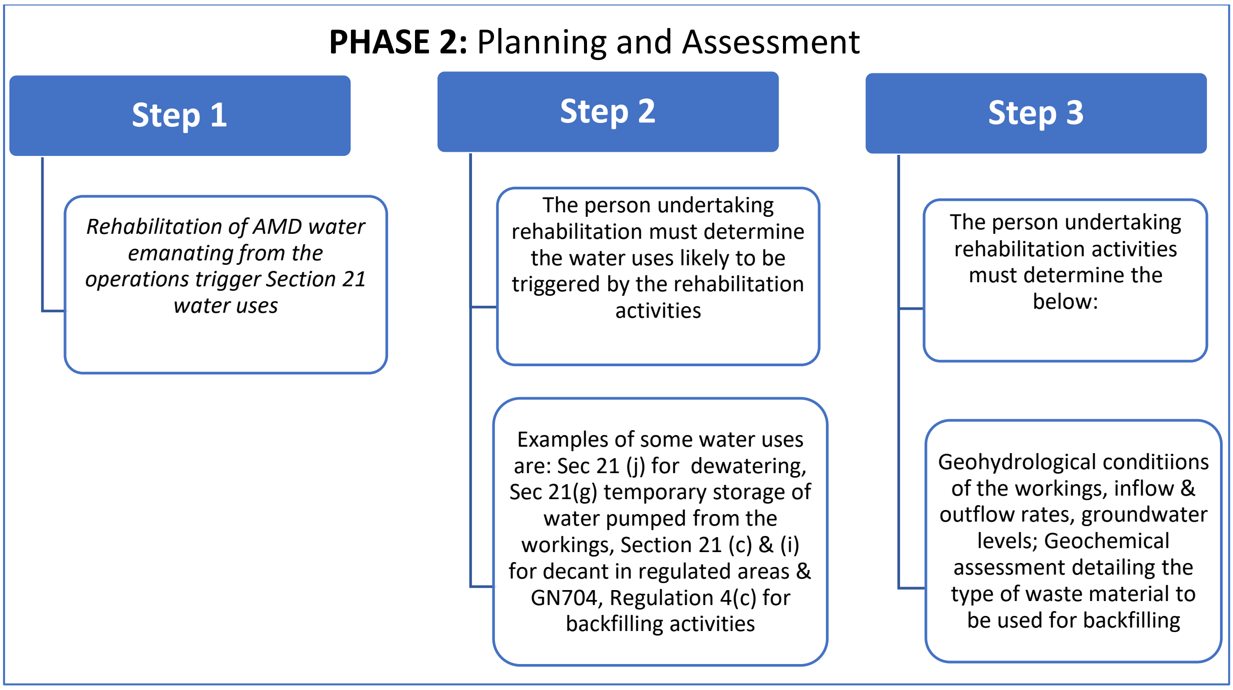

Figure 16: Steps to be followed during the Planning and Assessment Phase

Rehabilitation objectives must be set based on information gathered in **Phase 1** and **2**. **Figure 17** represents some of the common aims and objectives of the rehabilitation of AMD water decanting from opencast and underground operations.

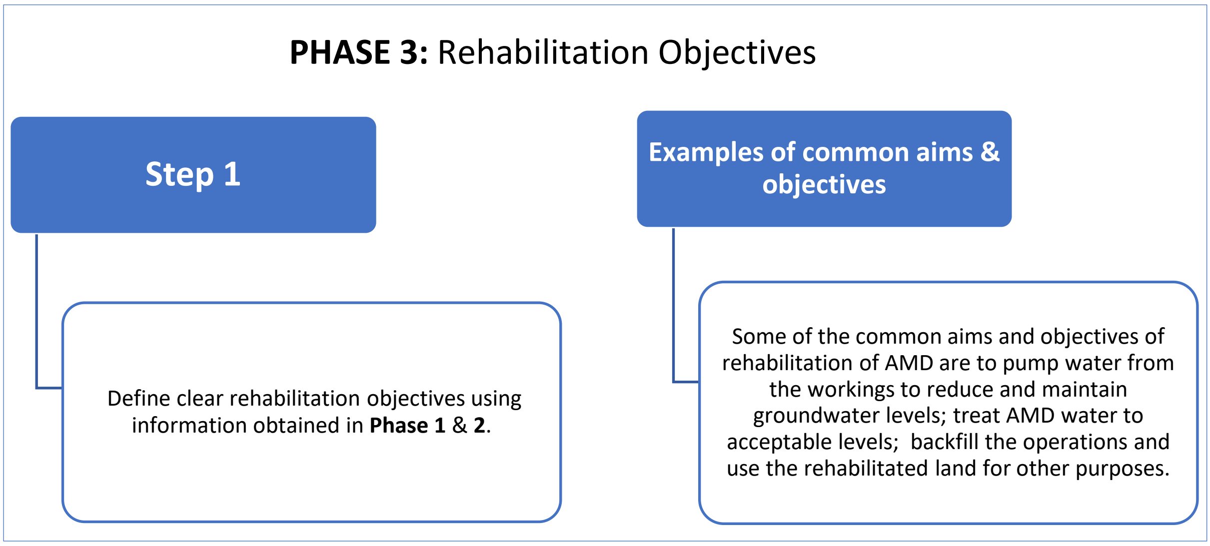

Figure 17: Aims and objectives of the rehabilitation of AMD water decanting from opencast and underground operations.

Figure 18 represents passive methods that can be employed for the rehabilitation of AMD water decanting from opencast and underground operations.

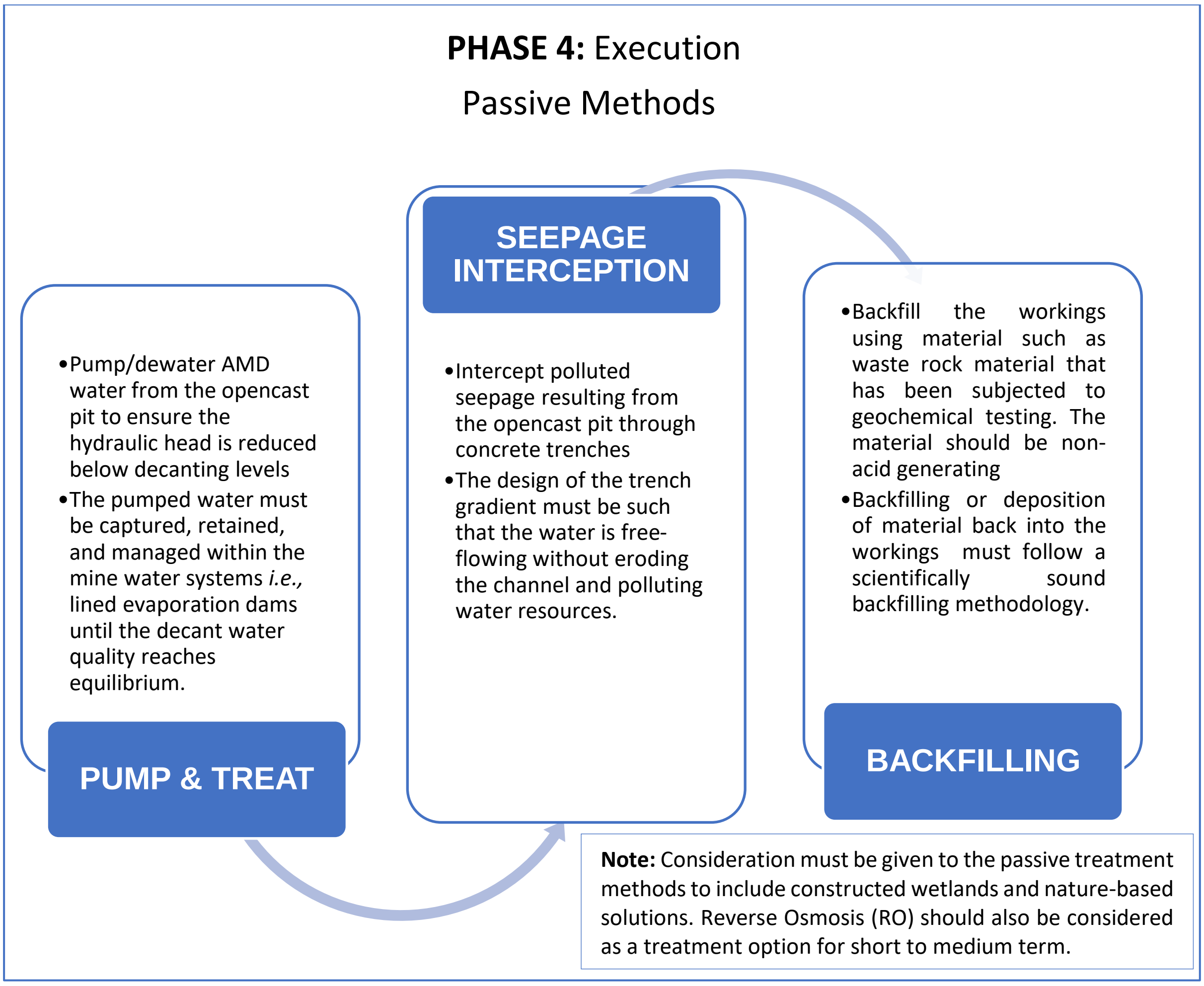

Figure 18: Passive Treatment Methods

Box 3 below presents key considerations when undertaking backfilling activities for opencast operations.

BOX 3

Considerations:

Other considerations when backfilling opencast operations:

- Once backfilling is completed, use a clay final layer below the topsoil cover – this must be compacted to reduce and minimize rainfall recharge into the rehabilitated opencast;
- The final rehabilitated opencast topography must be capped, sloped, and engineered such that runoff is directed away from the rehabilitated area; and
- Ensure the rehabilitated footprint is minimized, vegetated, and sloped to reduce rainfall recharge.

A stormwater management plan[4] comprising ~~of~~ berms and cut-off trenches must be implemented to ensure surface runoff is diverted around the rehabilitated area to drain back into the natural drainage lines and the natural environment.

Figures 19 represents ~~of~~ passive and active methods that can be employed for the rehabilitation of AMD water decanting from opencast and underground operations.

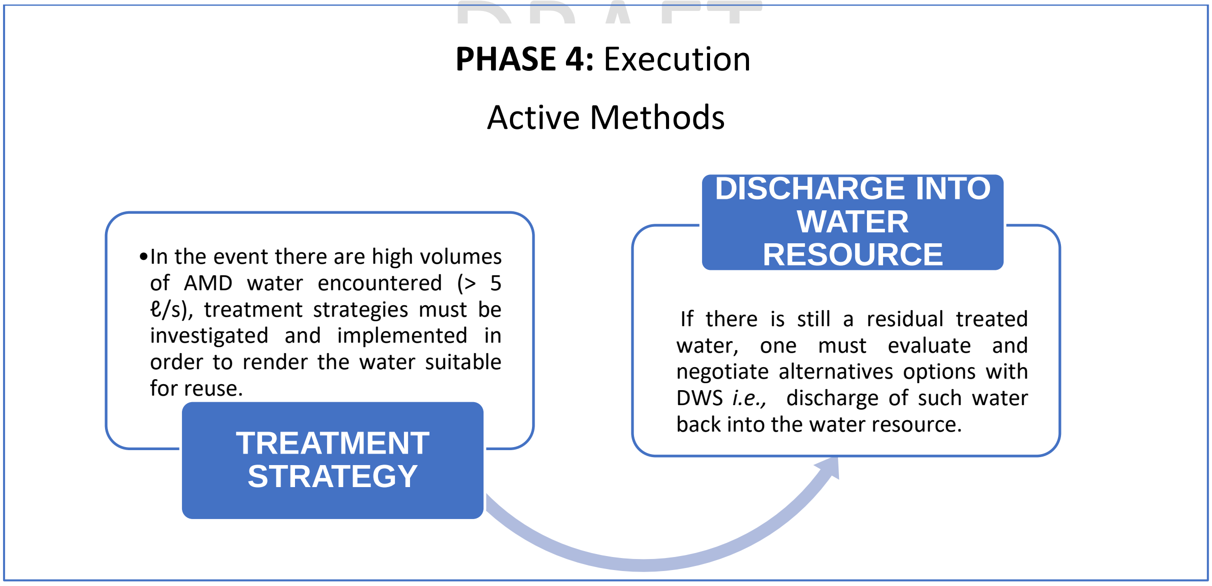

Figure 19: Active Treatment Methods

PHASE 5: Monitoring, Evaluation and Reporting

Figure 20 illustrates monitoring procedures for pump and treat, seepage interception, and backfilled areas.

[4] *The user of the RMGs should consult the DWS Best Practice Guidelines - G1. Storm Water Management for the compilation of the said stormwater management plan.*

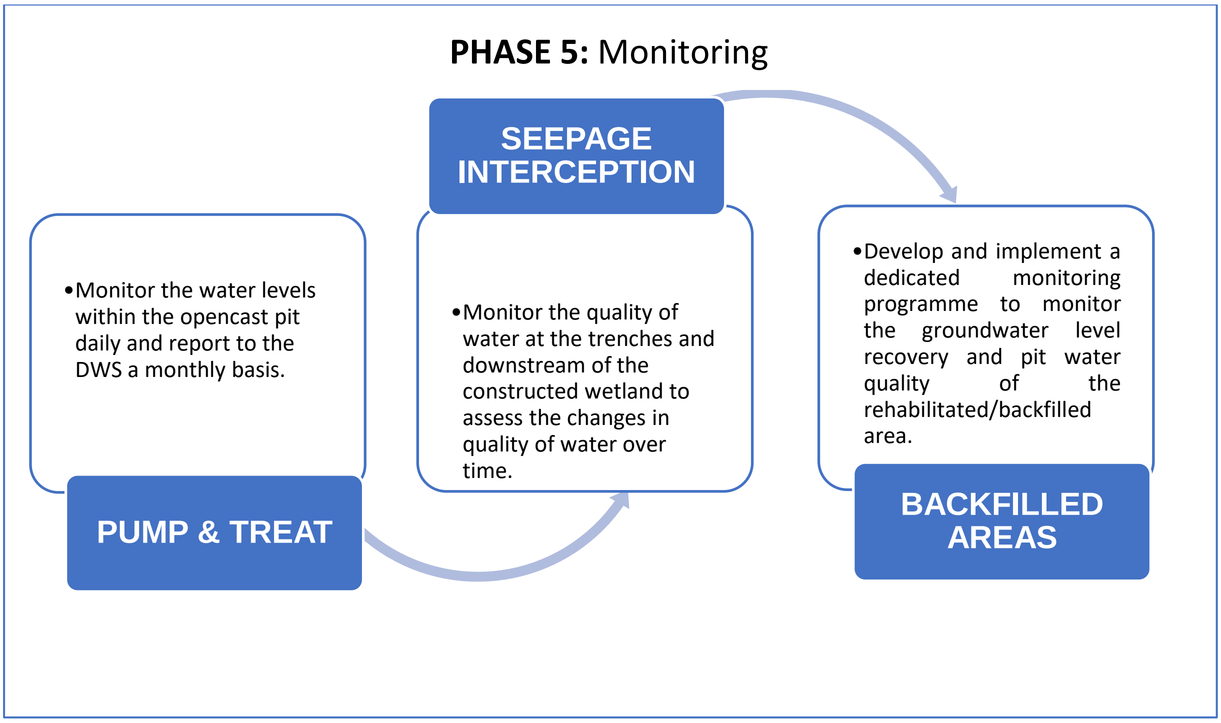

Figure 20: Monitoring procedure to be followed for monitoring of employed rehabilitation methods.

Evaluation

- Evaluate the effectiveness of interventions against the achievement of rehabilitation objectives and outcomes; and
- Determine maintenance objectives.

Reporting

A Rehabilitation Report should be compiled and be accompanied by supporting information such as:

- A map of disturbed and rehabilitated areas;
- Before and after photos of rehabilitation including a significant landmark for comparison purposes, with a brief description including location, and date; and
- Overall status of the rehabilitated area in relation to the rehabilitation objectives.

***Note:** In undertaking the above recommended rehabilitation interventions, the users of the guidelines should also consult the below DWS series of Best Practice Guidelines (BPGs) for mines dealing with pollution prevention and water management strategies and tools:*

- BPG A1. Small-Scale Mining (Standard Format).
- BPG A1.1 Small-Scale Mining (User Format).
- BPG A2. Water Management for Mine Residue Deposits.
- BPG A3. Water Management in Hydrometallurgical Plants.
- BPG A4. Pollution Control Dams.
- BPG A5. Water Management for Surface Mines.
- BPG A6. Water Management for Underground Mines.
- BPG G1. Storm Water Management.
- BPG G2. Water and Salt Balances.
- BPG G3. Water Monitoring Systems.

- BPG G4. Impact Prediction.
- BPG. G5 Water Management Aspects for Mine Closure.
- BPG. H1. Integrated Mine Water Management.
- BPG. H2. Pollution Prevention and Minimization of Impacts.
- BPG. H3. Water Reuse and Reclamation.
- BPG. H4. H4 - Water Treatment.

4.3 INDUSTRIAL

4.3.1 Description

Industrial effluents are discharges from various industries, and various organic pollutants have been found in different water resources. They belong to various sources such as pesticides, fertilizers, hydrocarbons, phenols, plasticizers, biphenyls, detergents, oils, greases, pharmaceuticals, etc. Industrial effluent poses a risk to both groundwater and surface water quality. Besides, contamination of groundwater not only worsens the soil and crop quality, but also affects human, animal, and aquatic lives.

4.3.2 Types of Impacts

The composition of the industrial effluent wastewater depends heavily on the industry from which it originates. Typical contaminants would fall into one or more of the following categories: dissolved organics, suspended solids, priority pollutants (*e.g.,* phenols), heavy metals, colour, nutrients (nitrogen and phosphorus), microbial contamination, oil and grease, refractory compounds, and volatiles. These contaminants, if untreated, have the potential to percolate into groundwater resources.

4.3.3 Rehabilitation Management Guidelines

Scenario 1: *Rehabilitation of industrial effluent ingressing into groundwater*

PHASE 1: Diagnostic Phase

Step 1: Identify the type of industry and the source of effluent.
Step 2: On a desktop level and from existing information, assess the conditions of the site within which the industry is located.
Step 3: Collect groundwater samples from the source effluent in question and submit them to an accredited lab for groundwater quality analysis. The results from the analysis will inform the treatment methods/options to be employed.
Step 4: Identify current potential groundwater use around the area and the likelihood of migration of pollution from the source.

PHASE 2: Planning and Assessment

Step 1: Undertake a site visit to determine and obtain general site information. The data to be collected is critical and will assist in identifying potentially affected sensitive receptors (schools, homes, water bodies), and significant exposure pathways.
Step 2: Based on the information collected, determine whether pollution pathways exist and the possibility of humans or ecological receptors to be affected.
Step 3: Determine aquifer status in terms of vulnerability to pollution.

PHASE 3: Identify and define the Rehabilitation Objectives

Establish clear goals or objectives of the rehabilitation (using data collected in **Phase 1** and **2**) in relation to the types of contaminants emanating from industries. Examples of contaminants are dissolved organics, suspended solids, priority pollutants (e.g., phenols), heavy metals, nutrients (nitrogen and phosphorus), microbial contamination, oil and grease, refractory compounds, and volatiles.

Common aims and objectives of undertaking groundwater rehabilitation for industrial effluent would be:

- To prevent all contaminants from ingressing into polluting groundwater; and
- To prevent contaminants from migrating offsite into the nearby sensitive receptors.

PHASE 4: Execution

Depending on the type of pollutant, the treatment process should be selected accordingly, and a certain effluent may require a combination of unit operations to achieve the correct final effluent quality. The below treatment techniques/methods are available for use:

- **Waste minimisation** - treatment solution can be saved by critically examining the sources of waste within a facility and then trying to minimise their discharge. This can be achieved through improved management of materials and operations.
- **Primary treatment** - removes solids and oils, neutralises excessive acidity or alkalinity and prepares the effluent for either further downstream treatment (biological or chemical) or for final discharge. Unit operations include flow equalisation, acid, or alkali dosing, hydrocyclones, static or rotary screens, flotation, and flocculation/sedimentation.
- **Biological (secondary) treatment** - involves the reaction of the effluent (after primary treatment) with oxygen and microorganisms (bacteria and fungi) to remove oxygen-consuming materials. Examples are aerobic technologies for industrial effluent are the moving bed biofilm reactor (MBBR) and the HYBACS process.
- **Tertiary treatment** - The most common form of tertiary treatment is filtration to remove remaining suspended matter from upstream biological processes or following coagulation in a physical-chemical treatment. Another form of tertiary treatment is the removal of colour and residual refractory pollutants using ozone or other suitable oxidizing agents. Treatment with Granular Activated Carbon (GAC) may also be necessary. In certain cases, electrodialysis is useful to remove various ionic species.

PHASE 5: Monitoring, Evaluation and Reporting.

Monitoring should involve the following:

- Changes in the concentrations of contaminates over time – trend analysis;
- Migration of pollutants in relation to groundwater flow direction; and
- Establish if the treatment technology applied is effective or whether there are any additional interventions required.

Evaluation

- Evaluate the effectiveness of interventions against the achievement of rehabilitation objectives and outcomes; and
- Determine maintenance objectives.

Reporting

A Rehabilitation Report should be compiled and be accompanied by supporting information such as:

- A map of disturbed and rehabilitated areas;
- Before and after photos of rehabilitation including a significant landmark for comparison purposes, with a brief description including location, and date; and
- Overall status of the rehabilitated area in relation to the rehabilitation objectives.

4.4 AGRICULTURAL

4.4.1 Description

Inputs such as fertilisers during irrigation processes may have a negative impact on groundwater quality. Anthropogenic activities such as irrigation may influence the chemistry of groundwater and determine the level of contaminants in groundwater (Napacho and Manyele, 2010; Li *et al*., 2016; Hwang *et al*., 2018; Wu *et al*., 2017). Common contaminants associated with agricultural activities include the elevated concentration of Nitrate (NO3-) as determined by authors such as Lalumbe and Kanyerere (2022a-b), who associated high concentration of NO3- to point source input of Mg2+- NO3- and K+- NO3- fertilisers in arid to semi-arid region of Limpopo Province, South Africa.

4.4.2 Types of Impacts

Groundwater containing NO3- concentration level of above 11 mg/l is considered to be unsuitable for drinking purposes (World Health Organisation - WHO, 2011). This is associated with various water borne diseases associated with infants and sometimes adults. Owing to the parachute type of research discussed by Lalumbe and Kanyerere (2022a), the majority of groundwater users in rural areas utilise contaminated groundwater for drinking purposes, without any form of treatment or knowledge of the quality of groundwater.

4.4.3 Rehabilitation Management Guidelines

To improve the availability and access to clean and safe groundwater, (Verlicchi and Grillini, 2022; Lalumbe and Kanyerere, 2022b) suggested that adequate and reliable groundwater rehabilitation techniques should be applied. Various in-situ and ex-situ techniques have been applied in the rehabilitation of agricultural activities associated with contamination globally. Pump and treat methods are considered cheaper and more sustainable as compared to in-situ methods (Lalumbe *et al*., 2022). Historically, in-situ groundwater rehabilitation techniques were more common until early 2000, when things changed and ex-situ methods were more favourable for groundwater rehabilitation (EPA, 2017). Groundwater does not require immediate use or treatment when pump and treat methods are applied (Favara and Gamlin, 2017)

Scenario 1: *Rehabilitation of nitrate-contaminated groundwater*

PHASE 1: Diagnostic Phase

Step 1: Identify available boreholes and springs within the area.
Step 2: Review historical groundwater quality data.
Step 3: Identify potential sources of contamination – natural (*i.e.,* geogenic) or anthropogenic.
Step 4: Identify the extent of groundwater use in the area.

PHASE 2: Planning and Assessment

Step 1: Conduct a site visit with the relevant specialist.
Step 2: Conduct hydrocensus and determine groundwater flow direction.
Step 3: Collect groundwater samples from the boreholes within the area, including samples from upstream and downstream (within 1-2km radius) of the area.
Step 4: Submit samples to an accredited laboratory for analysis. Data from the analysis should be used to determine the concentration of contaminants. Typical parameters of concern are nitrates, nitrites, ammonia, pH, Total Dissolved Solids, and alkalinity.
Step 5: Map the extent and spatial distribution of contamination.
Step 6: Determine the hydro-geochemical processes influencing groundwater quality to identify the source of contamination.

PHASE 3: Identify and define the Rehabilitation Objectives

These objectives must be determined by the information and data gathered in **Phase 1 and 2** above.

Below is a list of common aims and objectives:

- Rehabilitate groundwater for water supply; and
- Rehabilitate groundwater for the improvement of groundwater quality in the aquifer.

PHASE 4: Execution

Step 1: Apply the ex-situ treatment technology such as the Pump and Treat technique for Groundwater supply
Step 2: Apply in-situ[5] rehabilitation such as such as Managed Aquifer Recharge (MAR) and Permeable Reaction Barriers (PRB) for improvement of groundwater quality in the aquifer.

PHASE 5: Monitoring, Evaluation and Reporting.

Monitoring should include the following:

- Monitor changes in the concentrations of contaminates over time (1-2 years) – trend analysis;
- Pump and Treat: monitor water quality in terms of chemical reactions, before injecting it back to the aquifer.
  Note: *After pumping water from underground to the surface, chemical reactions when exposed to oxygen and other gases may change the chemical content or pollute water.*
- Monitoring of the migration of pollutants in relation to groundwater flow direction; and
- Establish if the treatment technology applied is effective or whether there are any additional interventions required.

Evaluation

- Evaluate the effectiveness of interventions against the achievement of rehabilitation objectives and outcomes; and
- Determine maintenance objectives.

Reporting

A Rehabilitation Report should be compiled and be accompanied by supporting information such as:

[5] *Involves on-site rehabilitation without removal of contaminated groundwater. This technique combines injection of degrading microorganisms and nutrients into the aquifer to stimulate biodegradation.*

- A map of disturbed and rehabilitated areas;
- Before and after photos of rehabilitation including a significant landmark for comparison purposes, with a brief description including location, and date; and
- Overall status of the rehabilitated area in relation to the rehabilitation objectives.

4.5 FORESTRY

4.5.1 Description

Forestry refers to the science or practice of planting and managing forests. Forestry-related activities use interflow and baseflow which impact surface water by lowering surface water levels and to a certain extent lowering groundwater levels because groundwater is an important contributor to baseflow.

Surface water bodies such as rivers, wetlands, and estuaries interact with groundwater (as discussed in **Section 1.3**) and effective water management requires a good understanding of the way in which interaction between groundwater and surface water takes place. The interactions between groundwater and surface water take many forms, which affect both the quantity and the quality of water in both resources. These interactions are often difficult to observe and measure, which creates uncertainty regarding their magnitude, their effect, and the appropriate form of management.

BOX 4

Definitions:

Interflow is the rapid flow of water along the **unsaturated/vadose zone** flow paths and has the potential to infiltrate the subsurface and move both vertically and laterally before discharging into other water bodies (WRC, 2004).

Baseflow is defined as the portion that contributes to the stream by delayed sources and groundwater (Hall 1968), and it is considered the lowest discharge of the stream in the dry season.

4.5.2 Types of Impacts

Groundwater discharge is believed to dominate dry season flows in perennial river systems and to sustain aquatic biodiversity (Le Maitre and Colvin, 2008). Some portion of the flow (to maintain a particular Electrical Conductivity (EC) for river, wetland, or estuary) is derived from surface water (runoff), and some from groundwater via groundwater contribution to baseflow (GWBF). Use of groundwater can reduce GWBF hence impacting on the flow, maintenance of river ecostate, and the degree to which Ecological Water Requirements (EWR) can be sustained by GWBF (DWS, 2017c).

Vegetation affects aquifers by directly extracting groundwater from saturated strata and reducing the proportion of rainfall that is eventually recharged by interfering with the passage of precipitation from the atmosphere to the water table in recharge areas (Le Maitre *et al.,* 1998) Consequently, studies highlighted the importance of incorporating evaporation losses in modelling recharge (Bredenkamp *et al.,* 1995; Le Maitre *et al.,* 1998).

Moreover, afforestation and alien vegetation have impacts on interflow and baseflow which leads to Stream Flow Reduction (SFR). Section 36(2) of the National Water Act (Act No. 36 of 1998) (NWA) states that SFR activity is any activity that is likely to reduce the availability of water in a watercourse to the Reserve, to meet international obligations, or to other water users significantly (DWAF,1999).

Over-abstraction of surface water from a river has a direct impact on interflow which in turn causes streamflow reduction and results in forestry-related impacts. Similarly, these impacts are encountered when there is a relationship between interflow and groundwater - interflow often occurs in the perched shallow water table.

Over-abstraction of groundwater within perched aquifers also impacts interflow. The consequences of over-exploitation are confirmed by Knüppe, (2011) as lowered groundwater tables resulting in a decoupling of the groundwater and surface water systems, including water exchange between these systems. Poor land use management activities such as agricultural, river diversions and developments interrupt flow paths and connectivity between stream channels and groundwater which causes water losses.

Groundwater recharge is affected by forestry, largely due to the greater uptake of soil water by trees and to increased water-holding capacity of forest soils, arising from higher organic contents. Groundwater quality may be affected by enhanced acidification and nitrification under forests.

4.5.3 Rehabilitation Management Guidelines

Scenario 1: *Rehabilitation of over-abstraction of groundwater caused by stream flow reduction activity.*

To sustain the critical role played by groundwater in the sustainability of the ecological ecosystem, especially during dry or fair-weather conditions, groundwater recharge and discharge must be safeguarded. Quantifying the contribution of groundwater to surface water is necessary to safeguard groundwater availability and the ecological needs of the environment. This can be done using various techniques such as direct seepage measurements using seepage meters; hydraulic tests using mini piezometers; chemical analysis; trace tests; hydrograph separation.

PHASE 1: Diagnostic Phase

Step 1: Identify available commercial forestry e.g., pine trees, and gum trees (eucalyptus trees) within the area.
Step 2: Review historical data on stream flow within the area.
Step 3: Identify potential sources of stream flow changes: abstraction for water supply or forestry and vegetation impacts.
Step 4: Identify the extent of groundwater use in the area.

PHASE 2: Planning and Assessment

Step 1: Conduct a site visit with the relevant specialist.
Step 2: Conduct hydrocensus and determine groundwater flow direction.
Step 3: Conduct field assessment on the extent of the receding groundwater and river water levels.
Step 4: Map the extent and spatial distribution of plantations within the area.
Step 5: Establish the extent of forestry impacts on stream flow reduction in the area.

PHASE 3: Identify and define the Rehabilitation Objectives

The objectives of rehabilitation should involve the improvement of groundwater levels and discharge to wetlands, springs, or streams. The objectives must be established based on the information and data gathered in **Phase 1** and **2** above. Below is a list of common aims and objectives:

- To improve groundwater contribution to river baseflow (groundwater discharges into rivers);
- To improve groundwater contribution to wetlands (groundwater discharges into wetlands);
- To improve groundwater contribution to springs (quantification of spring flows) and other groundwater-dependent ecosystems (GDEs).

PHASE 4: Execution

Step 1: Select an appropriate and successful plantation removal approaches for implementation *i.e,* namely, **physical (or mechanical) control, chemical control,** and **biocontrol**.
Step 2: Remove the plantations (using the methods and/or combination of methods in **Step 1)** that interfere with the passage of precipitation to the water table in recharge areas.
Step 3: Prioritize the removal of plantations with a deep root system (tap root) that intercept with groundwater table using the appropriate techniques mentioned in **Step 1.**
Step 4: Apply an appropriate mechanical or chemical method such as stump killer herbicide to prevent roots from sprouting again.
Step 5: Establish a protection zone along a river/stream to protect stream flows as per Dennis *et al.,* 2012.
[L = (T*i)/R
Where L = Distance from a river, T=Transmissivity(m2/d), i=Groundwater, Gradient, R=Recharge(m/d)].
Step 6: Establish a protection zone along a wetland to protect stream flows as per Dennis et al., 2012.
[L=SQRT(T*i*W*π/R)
Where L = Distance from a wetland, T= Transmissivity (square metres/day), i = Groundwater gradient, W = Wetland Perimeter, R = Recharge (metres/day)]

PHASE 5: Monitoring, Evaluation and Reporting.

It is not expected that the system (groundwater recharge, groundwater discharge, and stream flow) would recover immediately after this rehabilitation, therefore periodic (preferably quarterly) monitoring can be performed to establish whether the techniques/methods applied are effective or whether there are any additional interventions required.

Evaluation

- Evaluate the effectiveness of interventions against the achievement of rehabilitation objectives and outcomes;
- Determine maintenance objectives.

Reporting

A Rehabilitation Report should be compiled and be accompanied by supporting information such as:

- A map of disturbed and rehabilitated areas; ~~and~~
- Before and after photos of rehabilitation including a significant landmark for comparison purposes, with a brief description including location, and date; and
- Overall status of the rehabilitated area in relation to the rehabilitation objectives.

4.6 SOLID WASTE

4.6.1 Description

According to Polasi *et al*., (2020) waste management associated with refuse dumps and solid waste disposal has become a major environmental issue in South Africa. Landfills are the places where garbage/solid waste is taken to be buried. Landfills with a significant risk to groundwater resources are supposed to have liners to prevent contaminants from getting into the groundwater. However, if there is no layer or the liner it is cracked or compromised, contaminants from the landfill can make their way down into the groundwater. As reported by Vasanthi *et al*., (2007) leachate produced by municipal solid waste disposal sites contains a significant amount of substances that are likely to contaminate groundwater.

4.6.2 Types of Impacts

Leachate which is a strong reducing liquid produced from landfills percolates through soil into groundwater. Leachate typically contains some of the following examples of metals *i.e.,* Lead (Pb), Cadmium (Cd), Chromium (Cr), and Nickel (Ni), and during its percolation through soil it reacts with Fe, and Mn to reduce them into more soluble species, thus increasing their concentration and/or solubility in groundwater.

4.6.3 Rehabilitation Management Guidelines

Scenario 1: *Rehabilitation of leachate ingressing into groundwater*

The initial stage of groundwater rehabilitation from a landfill site requires a decision on the sensitivity of groundwater resources with respect to a land-based contamination source. Generally, the groundwater pathway is most likely to be impacted by contaminants in soil particularly if the contaminants are easily mobilised by infiltration and leaching processes. If the groundwater conditions on the site of interest are unknown, the groundwater pathway should be considered as a relevant exposure route and in such cases, drinking water quality should be a point of compliance for risk assessment (DEA, 2010).

PHASE 1: Diagnostic Phase:

The diagnostic phase of the project is undertaken to establish a sound conceptual understanding of the relationship between the soil conditions and groundwater-surface water interactions which can be supported wherever possible with information from boreholes and trials.

Step 1: Review historical groundwater quality and levels data.

Step 2: Identify available boreholes and springs in the vicinity of the area.

Step 3: Collect groundwater samples from the source effluent in question and submit them to an accredited lab for groundwater quality analysis. The results from the analysis will inform the treatment methods/options to be employed.

Step 4: Identify current or potential groundwater use/users around the affected area and the likelihood of migration of pollution from the source.

PHASE 2: Planning and Assessment

In this phase, a qualitative risk assessment should be undertaken based on general site assessment information. This data would need to identify obvious environmental impacts (if any), potentially affected sensitive receptors (schools, homes, surface water bodies), and significant exposure pathways (drinking water wells).

Step 1: Undertake site visit and assessment for a ground survey.

Step 2: Establish if pollution pathways exist and the possibility of humans or ecological receptors to be affected.

Step 3: Determine aquifer status in terms of vulnerability to pollution.

PHASE 3: Identify and Define the Rehabilitation Objectives

Establish clear goals or objectives of the rehabilitation (using data collected in Phase 1 and 2) linked to the protection of human health and the environment. Examples of toxic metals are Lead (Pb), Cadmium (Cd), Chromium (Cr), and Nickel (Ni), to acceptable levels.

The objective of undertaking groundwater rehabilitation for landfill sites is to reduce or prevent all identifiable contaminants from polluting groundwater in the vicinity of the site.

PHASE 4: Execution

Step 1: Apply the in-situ treatment technology such as the Barrier and Cap Systems, and/or Phytoremediation techniques.

Step 2: Construct groundwater containment or barrier systems through the injection of reagents within the treatment zone to prevent off-site migration of contaminants.

PHASE 5: Monitoring, Evaluation and Reporting.

Monitoring should involve the following:

- Monitor changes in the concentrations of metal contaminates over time – trend analysis;
- Monitoring of the migration of pollutants in relation to groundwater flow direction; and
- Establish if the treatment technology applied is effective or whether there are any additional interventions required.

Evaluation

- Evaluate the effectiveness of interventions against the achievement of rehabilitation objectives and outcomes; and
- Determine maintenance objectives.

Reporting

A Rehabilitation report should be compiled and be accompanied by supporting information such as:

- A map of disturbed and rehabilitated areas;
- Before and after photos of rehabilitation including a significant landmark for comparison purposes, with a brief description including location, and date; and
- Overall status of the rehabilitated area in relation to the rehabilitation objectives.

5. RECOMMENDATIONS AND WAY FORWARD

The Groundwater Rehabilitation Management Guidelines have been developed to address specific impact types emanating from various sectors through a phased approach. In implementing these guidelines, the below is a summary of recommendations to users:

- The users of the guidelines should consider using readily available information from the DWS to make informed decisions. Examples of this information include~~s~~ 1:500 000 scale hydrogeological map series, Aquifer Classification, Groundwater Quality, Aquifer Vulnerability and Aquifer Susceptibility Maps (https://www.dws.gov.za/Groundwater/Default.aspx).
- The rehabilitation actions should be able to return the final remedies ~~in~~to their maximum beneficial use or to their predefined ambient conditions.
- The target levels for groundwater rehabilitation should be based on the set environmental conditions such as groundwater resource quality objectives to ensure that protection for both human health and ecological ecosystem for current and future generations is realized.
- Rehabilitation activities relating to impacts on groundwater quantity and quality must consider the priority areas which are sensitive and must be protected. These priority areas that must be protected are Strategic Water Source Areas.
- Groundwater rehabilitation timeframes should be reasonable, be aligned to specific goals of rehabilitation, and must be based on the following:
  - Potential threat to human exposure and aquatic ecosystems;
  - The potential for achieving rehabilitation goals;
  - Type and extent of contamination or non-compliance with environmental background conditions;
  - Hydrogeologic characteristics;
  - Choice of rehabilitation technology, and its ability to remove contaminant mass under controlled conditions;
  - Design and capabilities of rehabilitation project to eliminate groundwater pollution to acceptable levels;
  - Public health and safety concerns associated with implementing the technology in or near a study area;
  - Public perception and community preferences;
  - Resources and relative cost of implementation.
- The performance of a groundwater rehabilitation activity should be monitored. Performance monitoring can assess changes in groundwater so that project managers can modify rehabilitation actions to ensure maximum efficiency, protectiveness, and compliance. Performance monitoring can also demonstrate whether the rehabilitation technique applied is performing as expected.
- Upon completion of the groundwater rehabilitation project, control of the source(s) of release must be ensured to reduce or eliminate, to the extent practicable, further releases of hazardous waste or hazardous constituents that may pose a threat to human health and the environment.

REFERENCE LIST

Antonio, M.E., & Price, S.R. 2021. Experiences and interactions with treatment staff: reactions from state prison inmates. Journal of Offender Rehabilitation, 60(7), 423-443. https://doi.org/10.1080/10509674.2021.1966155

Azubuike, C.C., Chikere, C.B., & Okpokwasili, G.C. 2016. Bioremediation techniques–classification based on site of application: principles, advantages, limitations, and prospects. World Journal of Microbiology and Biotechnology, 32(11), 180. https://doi.org/10.1007/s11274-016-2137-x

Bhowmick, G.D., Dhar, D., Nath, D., Ghangrekar, M.M., Banerjee, R., Das, S., & Chatterjee, J. Coronavirus disease 2019 (COVID-19) outbreak: some serious consequences with urban and rural water cycle. NPJ Clean Water,3, 32. https://doi.org/10.1038/s41545-020-0079-1

Bonnechèr, B., & Van Sint Jan, S. 2019. Chapter 39 - Rehabilitation. DHM and Posturography, 541-547. https://doi.org/10.1016/B978-0-12-816713-7.00039-8

Brusseau, M.L. (2019) Chapter 19 - Soil and Groundwater Remediation. Environmental and Pollution Science (Third Edition). 329-354. https://doi.org/10.1016/B978-0-12-814719-1.00019-7

Chapelle, F.H., Widdowson, M.A., Brauner, J.S., Mendez III, E., & Casey, C.C. (2003) Methodology for Estimating Times of Remediation Associated with Monitored Natural Attenuation. U.S. Geological Survey Water-Resources Investigations Report 03-4057. U.S. Geological Survey, Branch of Information Services, Box 25286, Denver Federal Center, Denver, CO 80225-0286, 1-888-ASK-USGS (275-8747)

Clemens, M., Khurelbaatar, G., Merz, R., Siebert, C., Van Afferden, M., & Rödiger, T. (2020) Groundwater protection under water scarcity; from regional risk assessment to local wastewater treatment solutions in Jordan. Science of The Total Environment, 706, 136066. https://doi.org/10.1016/j.scitotenv.2019.136066

Cole, M.J., Bailey, R..M, Cullis, J.D.S., & Mark, G. 2018. Water for sustainable development in the Berg Water Management Area, South Africa. South African Journal of Science, 114(3/4), 2017-20134. http://dx.doi.org/10.17159/sajs.2018/20170134

CGIAR Research Program on Water, Land and Ecosystems (WLE). (2017) Building resilience through sustainable groundwater use. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Research Program on Water, Land and Ecosystems (WLE). 12p. (WLE Towards Sustainable Intensification: Insights and Solutions Brief 1). https://doi.org/10.5337/2017.208

Dennis, I., Witthüsser, K., Vivier, K., Dennis, R, & Mavurayi, A. 2012. Groundwater Resource Directed Measures. WRC Project: K8/891. Water Research Commission. Republic of South Africa.

Department of Environmental Affairs (DEA). 2010) Framework for the Management of Contaminated Land. Private Bag X 447, PRETORIA, 0001. Republic of South Africa.

Department of Water Affairs (DWA). 2014. Environmental Rehabilitation Policy. Directorate Water Abstraction and Instream Use, Sub- Directorate Environment and Rehabilitation. Private Bag x 313, Pretoria, 0001. Republic of South Africa.

Department of Water Affairs and Forestry (DWAF). 1997. National Water Policy (NWP). White paper on a national water policy for South Africa. Private Bag x 313, Pretoria, 0001. Republic of South Africa.

Department of Water Affairs and Forestry (DWAF), 2000. Policy and Strategy for Groundwater Quality Management in South Africa. Number W.1.0: First Edition. Private Bag X313, Pretoria, 0001, Republic of South Africa

Department of Water Affairs and Forestry (DWAF). 2004. Guidelines on Protecting Groundwater from Contamination; produced under: The NORAD-Assisted Programme for the Sustainable

Development of Groundwater Sources under the Community Water and Sanitation Programme in South Africa.

Department of Water and Sanitation (DWS). 2016. National Groundwater Strategy, Water Resource Planning, Private Bag x 313, Pretoria, 0001, Republic of South Africa.

Department of Water and Sanitation (DWS). 2017a. Water Quality Management Policies and Strategies for South Africa. Report No. 3.2. Integrated Water Quality Management (IWQM) Strategy. Water Resource Planning Systems Series, DWS Report No.: 000/00/21715/16. Pretoria, South Africa.

Department of Water and Sanitation (DWS). 2017b. Water Quality Management Policies and Strategies for South Africa. Report No. 4.3. Note on the Monitoring and Evaluation Framework. Water Resource Planning Systems Series, DWS Report No.: 000/00/217115/20. Pretoria, South Africa.

Department of Water and Sanitation (DWS). 2017c. Determination of Water Resources Classes and Resource Quality Objectives in the Breede-Gouritz Water Management Area: Quantification of the Ecological Water Requirements and changes in Ecosystem Goods, Services and Attributes. Water Ecosystems Management, DWS Report No.: RDM/WMA8/00/CON/CLA/0117. Pretoria, South Africa.

Devika, N, & Rastogi, A.K. (2015) Remediation Techniques for BTEX Contamination of Groundwater- A Review. ETWQQM -2014 Conference Proceedings, Special Issue. International Journal of Engineering Research & Technology (IJERT), 3(03), 1-6.

Dlamini, S., Gyedu-Ababio, T. K., & Slaughter, A. 2019. The Loading Capacity of the Elands River: A Case Study of the Waterval Boven Wastewater Treatment Works, Mpumalanga Province, South Africa. Journal of Water Resource and Protection, 11,1049-1063. https://doi.org/10.4236/jwarp.2019.118062.

Dwivedi, M. (2014) Groundwater Contamination and prevention. Available online: https://www.slideshare.net/mohitishere/groundwater-contamination-and-prevention. (Accessed on 12 November 2022).

DWS, 2017d. Integrated Water Quality Management Policies and Strategies for South Africa: Strategy – Edition 2 (Report No. 3.2) (Water Resource Planning Systems Series Report No. 000/00/21715/13, PRETORIA: Department of Water and Sanitation (DWS).

ENI. (2022) Remediation Technologies Handbook. Available online: https://www.eni.com/assets/documents/eng/enirewind/remediation/vademecum-eng.pdf (Accessed on 12 November 2022).

Elmhagen, B., Destouni, G., Angerbjörn, A., Borgström, S., Boyd, E., Cousins. S.A.O., Dalén, L., Ehrlén, J., Ermold, M., Hambäck, P.A., Hedlund, J., Hylander, K., Jaramillo, F., Lagerholm, V.K.W., Lyon, S.W, Moor, H., Nykvist, B., Pasanen-Mortensen,M., Plue, J., Prieto C., Van der Velde, Y., & Lindborg, R. 2015. Interacting effects of change in climate, human population, land use, and water use on biodiversity and ecosystem services. Journal of Ecology and Society, 20(1), 23. http://dx.doi.org/10.5751/ES-07145-200123

Environmental Protection Agency (EPA). (2004) Handbook of Groundwater Protection and Clean-up Policies for RCRA Corrective Action for Facilities Subject to Corrective Action Under Subtitle C of the Resource Conservation and Recovery Act

Environmental Protection Agency (EPA). (2018) Examples of Groundwater Remediation at NPL Sites. EPA 542-R-18-002, https://www.epa.gov/remedytech (Accessed 07 November 2022)

Gomez, M., Perdiguero, J., & Sanz, A. 2019. Socioeconomic Factors Affecting Water Access in Rural Areas of Low- and Middle-Income Countries. MDP Journal of Water, 11(2), 202. http://dx.doi.org/10.3390/w11020202

Hall, F. R. (1968). Base-flow recessions—A review. Water resources research, 4(5), 973-983.

Hubbard, L., Keefe, S.H., Kolpin, D.W., Barber, L.B., Duris, J.W., Hutchinson, K.J., & Bradley, P.M. (2016) Understanding the hydrologic impacts of wastewater treatment plant discharge to shallow groundwater: before and after plant shutdown, Environmental Science: Water Research & Technology, 5(2), 864-874. https://doi.org/10.1039/c6ew00128a

Hyun-su Kim, H., and Kim, K. (2012) Microbial and chemical contamination of groundwater around livestock mortality burial sites in Korea-a review. Journal of Geosciences, 16, 479-489. https://doi.org/10.1007/s12303-012-0036-1

Hubbert, M. K. (1940). The theory of groundwater motion. The Journal of Geology, 48(8, Part 1), 785-944.

International Atomic Energy Agency (IAEA). (1999) Technical options for the remediation of contaminated groundwater. Wagramer Strasse 5, P.O. Box 100, A-1400 Vienna, Austria, E-mail: CHOUSE® IAEA.ORG. URL: http://www.iaea.org/programmes/inis/inis.htm

Kennish, M.J. 2017. Estuaries: Anthropogenic Impacts. In: Finkl C., Makowski C. (eds) Encyclopedia of Coastal Science. Encyclopedia of Earth Sciences Series. Springer, Cham.

Lalumbe, L., Oberholster, P.J., & Kanyerere, T. (2022) Feasibility Assessment of the Application of Groundwater Remediation Techniques in Rural Areas: A Case Study of Rural Areas in the Soutpansberg Region, Limpopo Province, South Africa

Le Maitre, D. C., Scott, D.F., & Colvin, C. A. 1999. A review of information on interactions between vegetation and groundwater. Water SA 25(2), 137-152.

Le Maitre, D. C., & Colvin, C. A. 2008. Assessment of the contribution of groundwater discharges to rivers using monthly flow statistics and flow seasonality. Water SA 34(5), 549-564.

Lokhandwala, S., & Gautam, P. (2020) Indirect impact of COVID-19 on environment: a brief study in Indian context. Journal of Environ Research, 188, 109807. https://doi.org/10.1016/j.envres.2020.109807

Li, P., Karunanidhi, D., Subramani, T., Srinivasamoorthy, K. (2021) Sources and Consequences of Groundwater Contamination. Archives of Environmental Contamination and Toxicology, 80(1): 1-10. https://doi.org/10.1007/s00244-020-00805-z

Masindi, K., & Abiye, T. 2018. Assessment of natural and anthropogenic influences on regional groundwater chemistry in a highly industrialized and urbanized region: a case study of the Vaal River Basin, South Africa. Journal of Environmental Earth Sciences, 77(20), 722-736. https://doi.org/10.1007/s12665-018-7907-3

Masindi, V., & Foteinis, S. 2021. Groundwater contamination in sub-Saharan Africa: Implications for groundwater protection in developing countries. Journal of Cleaner Engineering and Technology, 2, 100038. https://doi.org/10.1016/j.clet.2020.100038

Morris, D. 2019. Developing and exploring indicators of water sustainable development. Journal of Heliyon, 5, e01778. https://doi.org/10.1016/j.heliyon.2019.e01778

National Environmental Management Act (NEMA), (Act No. 107 of 1998). 1998. Republic of South Africa. Government Gazette 19519. Government Printer, Cape Town.

National Groundwater Strategy (NGS). 2016. Department of Water and Sanitation, Water Resources Planning Systems, Private Bag x 313, Pretoria, 0001. Republic of South Africa.

National Water Act (NWA) (Act No. 36 of 1998). 1998. Republic of South Africa. Government Gazette 39299. Government Printer, Cape Town.

National Water Resource Strategy (NWRS), Second Edition, 2013. Department of Water Affairs (DWA), Private Bag x 313, Pretoria, 0001. Republic of South Africa.

National Water and Sanitation Master Plan (NW&SMP), 2018. Ready for the Future and Ahead of the Curve. Volume 1: Call to Action, Version 10.1. Department of Water and Sanitation, Private Bag x 313, Pretoria, 0001. Republic of South Africa.

Nkosi, M., Mathivha, F.I., & Odiyo, J.O. (2021) Impact of Land Management on Water Resources, a South African Context. Journal of Sustainability,13, 701. https://doi.org/10.3390/su13020701

Odiyo, J. & Makungo, R. 2012. Water quality problems and management in rural areas of Limpopo Province, South Africa. Journal of WIT Transactions on Ecology and the Environment, 164, 35-46. https://doi.org/10.2495/WP120121

Pearce, K., Snyman, H., van Heerden, H., Greben, H., & Oellermann, R.A. (1995) Bioremediation technology for the treatment of contaminated soil in South Africa. Water Research Commission, Private Bag X03, Gezina, 0031.

Pi, L., Xie, X., Ma, T., Su, C., Li, J., & Wang, Y. 2020. Arsenic immobilization by in-situ iron coating for managed aquifer rehabilitation. Journal of Water Research, 181, 115859. https://doi.org/10.1016/j.watres.2020.115859

Polasi, T., Matinise, S., & Oelofse, S. (2020) South African Municipal Waste Management Systems: Challenges and Solutions. United Nations Environment Programme (UNEP) International Environmental Technology Centre (IETC. 2-110 Ryokuchikoen, Tsurumi Ward, Osaka, 538-0036, Japan.

Practices in Johannesburg City Townships. 2nd International Conference on Sustainable Materials Processing and Manufacturing (SMPM 2019). Procedia Manufacturing, 35, 1025-1031. https://doi.org/10.1016/j.promfg.2019.06.052

Rasmeni, Z.Z., & Madyira, D.M. (2019) A Review of the Current Municipal Solid Waste Management

Remediation at NPL Sites. EPA 542-R-18-002, https://www.epa.gov/remedytech (Accessed 07 November 2022)

Smith, M., Cross, K., Paden, M., & Laban, P. (eds.) 2016. Spring-Managing groundwater sustainably. International Union for Conservation of Nature and Natural Resources (IUCN), Gland, Switzerland. http://dx.doi.org/10.2305/IUCN.CH.2016.WANI.8.en

Sophocleous, M. (2002). Interactions between groundwater and surface water: the state of the science. Hydrogeology journal, 10(1), 52-67.

Talabi, A.O. & Kayode, T.J. (2019) Groundwater Pollution and Remediation. Journal of Water Resource and Protection, 11, 1-19. https://doi.org/10.4236/jwarp.2019.111001

Tóth, J. (1970). A conceptual model of the groundwater regime and the hydrogeologic environment. Journal of Hydrology, 10(2), 164-176.

Vasanthi, P., Kaliappan, S., & Srinivasaraghavan, R. (2007) Impact of poor solid waste management on ground water. Environmental Monitoring and Assessment, 143(1-3), 227-238.

https://doi.org/10.1007/s10661-007-9971-0

UNESCO. (2022) United Nations World Water Development Report 2022: groundwater: making the invisible visible. https://www.unesco.org/reports/wwdr/2022/en/groundwater-and-industry (Accessed 03 November 2022).

United States- Department of Energy (US-DOE). (1998) Feasibility Study for Remedial Action for the Groundwater Operable Units at the Chemical Plant Area and the Ordnance Works Area at the Weldon Spring Site, Weldon Spring, Missouri. Forrestal Building 1000 Independence Avenue Southwest, Washington, D.C., U.S.

Winter, T.C., Harvey, J.W., Franke, O.L. & Alley, W.M. 1998. Ground water and surface water: a single resource (Vol. 1139). Diane Publishing.

Zhang, H., Xu, Y., & Kanyerere, T. 2020. A review of the managed aquifer recharge: Historical development, current situation, and perspectives. Journal of Physics and Chemistry of the Earth, Parts A/B/C, 118-119, 102887. https://doi.org/10.1016/j.pce.2020.10288

APPENDICES

APPENDIX A: