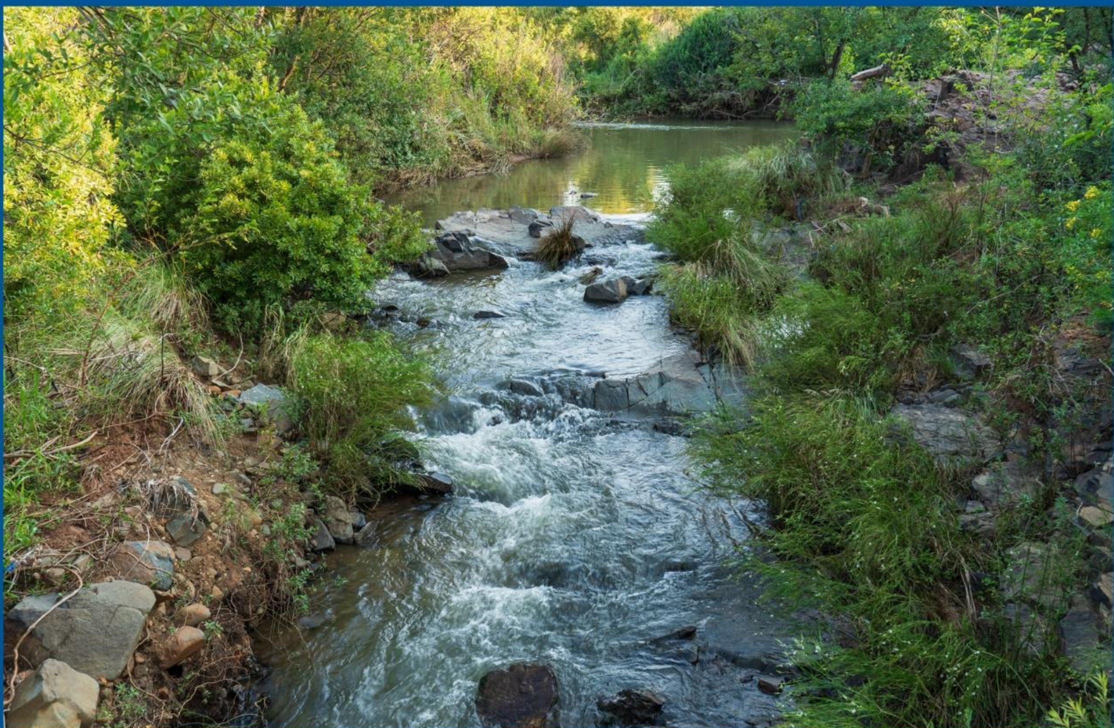
REHABILITATION MANAGEMENT GUIDELINES FOR WATER RESOURCES

VOLUME 1: RIVERS



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Sanitation is Dignity

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AMD	Acid Mine Drainage
AIS	Alien Invasive Species
BEI	Body Exposure Indices
BMGs	Best Management Practices
CARA	Conservation of Agricultural Resources Act
CD: WEM	Chief Directorate: Water Ecosystems Management
CMA	Catchment Management Agency
CECs	Contaminants of Emerging Concern
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
DFFE	Department of Forestry, Fisheries and Environment
DO	Dissolved Oxygen
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
ECA	Environment Conservation Act
EcoRA	Ecological Risk Assessment
EDCs	Endocrine Disrupting Chemicals
EIA	Environmental impact Assessment
EP	Environmental Programme
EPA	Environmental Protection Agency
ELU	Existing Lawful Use
EWRs	Ecological Water Requirements
GBF	Global Biodiversity Framework
GHS	Globally Harmonised System
GIS	Geographic Information System
HCA	Hazardous Chemical Agents
HHPs	Highly Hazardous Pesticides
HAS	Hazardous Substances Act
PES	Present Ecological State
SES	Social-Ecological System
SDS	Directorate: Sources Directed Studies
IPCC	Intergovernmental Panel on Climate Change
IWQM	Integrated Water Quality Management
IWRM	Integrated Water Resource Management
WRC	Water Research Commission
M & E	Monitoring and Evaluation
MPRDA	Mineral and Petroleum Resources Development Act
NEMA	National Environmental Management Act
NEM: BA	National Environmental Management: Biodiversity Act
NEM: WA	National Environmental Management: Waste Act
NEM: PAA	National Environmental Management: Protected Areas Act
NHRA	National Heritage Resources Act
NTAs	Nitrilotriacetic Acids
NWA	National Water Act
NWRS	National Water Resource Strategy
NW&SMP	National Water and Sanitation Master Plan
OEL	Operator Exposure Level
OHS	Occupational Health and Safety
OTC	Over-the-Counter

PAHs	Polycyclic Aromatic Hydrocarbons
PFAS	Per and Polyfluoroalkyl Substances
PPE	Personal Protective Equipment
PES	Present Ecological State
RAM	Risk Assessment Matrix
RQOs	Resource Quality Objectives
RDM	Resource Directed Measures
RWQOs	Resource Water Quality Objectives
SANBI	South African National Biodiversity Institute
SANRAL	South African National Roads Agency SOC Ltd
SWSAs	Strategic Water Source Areas
SFR	Streamflow reduction
SDGs	Sustainable Development Goals
SDCs	Sources Directed Controls
WDCS	Waste Discharge Charge System
WML	Waste Management License
WULA	Water Use License Application
WUL	Water Use License
WWTWs	Wastewater Treatment Works

GLOSSARY OF TERMS

In terms of the definition contained within the National Water Act, 1998 (Act 36 of 1998), a **watercourse** means:

- A **river** or spring;
- A natural channel in which water flows regularly or intermittently;
- A wetland, dam, or lake into which, or from which, water flows; and
- Any collection of water which the Minister may, by notice in the Gazette, declare to be a watercourse; and
- A reference to a watercourse includes, where relevant, its bed and banks.

Catchment in relation to a watercourse or watercourses or part of a watercourse, is defined as the geographical area from which any rainfall will drain into the watercourse or watercourses or part of a watercourse, through surface flow to a common point or common points. This land area from which a river or reservoir is fed is also known as a drainage region, basin, or watershed.

Chlorophyll is a pigment found in plants and some microorganisms (*e.g.,* cyanobacteria) that play an important role in the conversion of solar energy to chemical energy through a process known as photosynthesis. All oxygenic photosynthetic organisms use chlorophyll-α, which contributes to the green colour of most plants and algae, but differ in accessory pigments like chlorophyll-β.

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 Releases pertaining to specific low and high flows for maintaining ecological conditions within a specific ecological category, in the form of assurance rules for each selected EWR site.

Ecological Risk Assessment (EcoRA) involves the assessment of the risks posed by the presence of substances released to the environment by man, in theory, on all living organisms in the variety of ecosystems which make up the environment.

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.

Eutrophic is a state of an aquatic ecosystem rich in minerals and nutrients, very productive in terms of aquatic plant life and exhibiting increasing signs of water quality problems.

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.

Global Biodiversity Framework (GBF) aims to enable urgent and transformative action by Governments, and subnational and local authorities, with the involvement of all of society, to halt and reverse biodiversity loss, to achieve the outcomes it sets out in its Vision, Mission, Goals and Targets (*i.e.,* GBF Goal A target 2 for restoration of ecosystems). Although the DWS focuses mainly on the reporting on the SDG targets, it is recommended that the relevant authorities should use the outputs of the current RMGs for their reporting at the respective platforms.

Hazard class is the nature of a physical, health or environmental hazard under the GHS.

Highly Hazardous Pesticide (HHP's) are pesticides that are acknowledged to present particularly high levels of acute or chronic hazards to health or environment according to internationally accepted classification systems such as WHO or Global Harmonized System (GHS).

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.

Mean annual runoff is the average volume of water that flows in a river per year (annum), expressed as cubic meters per annum.

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."

Occupational exposure limit is the limit value set by the Minister, which represents the airborne concentration of a pesticide, where the exposure standard can be, a) an eight-hour time-weighted average, b) a ceiling limit, c) a short-term exposure limit.

National Freshwater Ecosystem Priority Areas (NFEPAs) form part of a comprehensive approach to sustainable and equitable development of South Africa's scarce water resources. For integrated water resources planning, NFEPA provides guidance on how many rivers, wetlands and estuaries, and which ones, should remain in a natural or near-natural condition to support the water resource protection goals of the National Water Act.

Present Ecological State (PES) is a term used to describe the ecological condition of the resource. The PES of a river is expressed in terms of the drivers (physico-chemical, geomorphology, hydrology) and biological responses (fish, riparian vegetation and aquatic invertebrates).

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.

Reference State is the natural or pre-impacted condition of the system.

Rehabilitation is the process of promoting the recovery of ecosystem functions and values in a degraded system to regain some of the values of the system previously had to society.

Restoration refers to the manipulation of a site to revert the watercourse back to its full range of natural (historic) processes and functions. Restoration attempts to restore habitats back to their natural (historic also known as the Reference State) conditions.

Rehabilitation and **Restoration** both aim for the same outcome, the return of the structure and function of a degraded ecosystem to the closest achievable approximation of its natural (pre-impact) state.

Remediation refers to the improvement of the ecological condition of the ecosystem, while not aiming for an outcome which resembles its original condition.

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.

Resource Water Quality Objective (RQOs) are the water quality component of the Resource Quality Objective. Are numeric and/or descriptive objectives, which address the physical, chemical and/or microbiological properties of waterbodies that should be met in receiving water resources to ensure that the water quality requirements of the recognised water users and the aquatic ecosystem are sufficiently protected. Resource Water Quality Objectives are not gazetted, per se.

River Eco-status Monitoring Programme (REMP) is a programme for monitoring the ecological conditions of the river ecosystems based on the drivers and responses in the river. REMP is aimed to establish the reference condition (usually a natural or close to natural condition) of the river or reach that will used to assess the temporal conditions of that river or reach with the consideration of both the biotic (instream and riparian biota) and abiotic (hydrology, geomorphology, and physico-chemical conditions) factors of that river.

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.

Social-Ecological System (SES) are linked systems of people and nature, emphasising that humans must be seen as a part of, not apart from, nature (Berkes and Folke, 1998).

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.

Sustainable Development Goals (SDGs) are aimed ensuring the availability and sustainable management of water and sanitation for all by 2030. Every year, an annual SDG Progress Report should be produced based on the global indicator framework and data produced by national statistical systems and information collected at the regional level.

Strategic Water Source Areas (SWSAs) are formally defined as natural source areas for water that supply disproportionately large volumes of water per unit area and that are considered of strategic significance for water security from a national planning perspective. Water from SWSAs feeds major dams and can be considered ecological infrastructure that works hand in hand with built infrastructure for delivering water.

Trophic status refers to the degree of nutrient enrichment of surface water resources and the associated amount of primary productivity that can be sustained.

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

Water quality - the biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial water use.

Weirs, also known as low-head dams, are small overflow-type dams commonly used to raise the level of a river or stream. Water flows over the top of a weir, although some weirs have sluice gates, which release water at a level below the top of the weir.

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EXECUTIVE SUMMARY

There has been an increase in river rehabilitation interest and research efforts over the last two decades in South Africa by the Water Research Commission (WRC). To date, the WRC have developed and produced comprehensive River Rehabilitation Guidelines and manuals that are readily available for providing locally appropriate rehabilitation interventions which enable effective protection and management of our rivers systems.

In 2020, the Department of Water and Sanitation (DWS) Directorate: Sources Directed Studies (SDS) initiated an in-house project for the development of the Rehabilitation Management Guidelines (RMGs) for Water Resources in South Africa. The project responds to one of the objectives of the Chief Directorate: Water Ecosystem Management to conduct sources directed studies. In the interest of efficiency, the DWS acknowledges all river rehabilitation work completed to date and is not duplicating efforts; however, the project aims to address the fragmentation of efforts across different projects, programmes, and initiatives due to separate mandates and various institutions responsible for this work. Most of the river programmes do not address all characteristics of watercourses. It is for this reason that the DWS is developing River RMGs to address characteristics of watercourses, namely surface flow, interflow, groundwater flows, geomorphology, water quality, habitat, and biota through following a phased approach *viz,* diagnostic, planning, and assessment, setting of the rehabilitation objectives, execution, and monitoring phases. The following are key aspects covered to address the shortcomings of each characteristic of watercourses:

- Description of the specific characteristics of watercourses;
- Types of impacts for each characteristic of watercourse – a brief overview and description of the impacts that give rise to the degradation of the watercourses to better understand the problem and subsequently develop effective rehabilitation guidelines;
- Legal Considerations - applicable legislation to be considered for undertaking site-specific rehabilitation activities on a particular characteristic of a watercourse; and
- Step-by-step guidelines on rehabilitation measures/interventions for executing rehabilitation - planning, design, implementation, and monitoring.

Afforestation activities and Alien Invasive Species (AIS) vegetation clearing are the main impacts on interflow. Over-abstraction of groundwater within perched aquifers also impacts interflow, including the lowering of groundwater tables resulting in decoupling of the groundwater and surface water systems. Agriculture and associated agricultural pesticides, as well as river diversions are some of the other poor land management activities contributing to impacts on interflow. Rehabilitation Management Guidelines for hydrology – surface flow and interflow have been developed with a focus on rehabilitation of afforestation activities and AIS vegetation clearing.

Human interventions influence the modification of river systems. Activities such as scouring the channel bed deepens the channel. Other activities such as channel engineering, deforestation, AIS vegetation clearing, agriculture, and mining affect the flow of water and the production of sediment. Rehabilitation Management Guidelines for geomorphology were developed and focused on rehabilitating improperly designed culverts and incised river channels.

Water quality is affected by both point-source and non-point source pollution. Point source pollution emanates mainly from industries and Wastewater Treatment Works (WWTWs). Inadequately treated effluent from WWTWs poses a health risk to humans and the environment. Many chemicals and pesticides, transformation products, metabolites and residues are not included in the list of pollutants to be treated in WWTW effluent, but what is becoming an increasing concern is that Contaminants of Emerging Concern (CECs) such as Endocrine Disrupting Chemicals (EDCs) and Per and Polyfluoroalkyl Substances (PFAS). Non-point source pollution is caused by activities such as irrigation, mining, agriculture, and urban development. Acid mine drainage (AMD) is one of the mining industry's most severe and possibly enduring environmental issues. Rehabilitation Management Guidelines have been developed to address point and non-point source pollution affecting water resources.

Anthropogenic activities have the potential to change river channel morphology by altering channel dimensions, and the discharge magnitude and frequency. These activities also affect bedload and can change channel gradient. Channelization is another factor that can directly alter effective channel gradients. Rehabilitation Management Guidelines have been developed for habitats with a focus on the rehabilitation of disturbed river channels.

The existing instream barriers to migration in rivers/dams (weirs) is a major factor responsible for the reduction in numbers and range of many migratory fish and invertebrate species throughout South Africa. Most indigenous fish species undergo annual migrations within river systems to optimise feeding, promote dispersal, avoid unfavourable conditions and enhance reproductive success (WRC, 2007). Rehabilitation Management Guidelines have been developed for biota with specific reference to re-establishing species migratory routes.

1. INTRODUCTION

1.1 BACKGROUND

South Africa is a water-scarce country with a significant demand for its limited water resources. Key socio-economic sectors such as agricultural, industrial, mining, and land-based activities heavily depend on this scarce resource. Despite its role in these sectors, river ecosystem conditions declined by 11% between 1999 and 2011 thus limiting freshwater availability (SANBI, 2018). Of the 222 river ecosystem types assessed, 64% were found to be threatened (43% critically endangered, 19% endangered and 2% vulnerable) (SANBI, 2018). River ecosystem types are also poorly protected with only 13% considered well protected and 42% not protected (SANBI, 2018). Driver *et al.,* (2004) also argued that impacts on rivers are not only a result of anthropogenic activities upstream and along riverbanks, but also due to the management issues related to land and water throughout the river catchment.

To address the impacts of anthropogenic activities on South African river systems, the Directorate Sources Directed Studies (SDS) within the DWS initiated an in-house project for the development of Rehabilitation Management Guidelines for Water Resources (*i.e.,* rivers). The project responds to one of the objectives of the Chief Directorate Water Ecosystems Management (CD: WEM), which is to conduct sources-directed studies to promote water resource protection.

In the Situation Assessment Phase of the project, it was found that a great deal of research has been conducted in South Africa to understand the discipline of river rehabilitation and to provide locally and site-specific rehabilitation interventions. Below is a list of the main findings from the review conducted:

- ***The Comprehensive Manual for River Rehabilitation (WRC, 2016a) and Buffer Zone Guidelines for Rivers, Wetlands and Estuaries (WRC, 2017)*** are river rehabilitation guidelines currently in place to provide technical methods for undertaking rehabilitation activities. These guidelines provide overarching legislative framework to consider in the planning, designing, implementation and monitoring phases of rehabilitation interventions.
- The Buffer Zone Guidelines do not take into consideration the hydrological functions of a river, which has a direct impact on rehabilitation.
- Some several programmes and initiatives are currently in place to ensure natural river rehabilitation improvement and management. The impacts on rivers were also clearly identified and contextualised for each of the studies reviewed. A range of management options have been implemented to address the various impacts identified.

The Situation Assessment Phase concluded that the existing guidelines, manuals, or best practices suffice in the protection and management of rivers, with the main gaps identified below.

- Most of the river programmes do not address all characteristics of watercourses namely surface flow, interflow, groundwater flow, geomorphology, water quality, habitat, and biota.
- Efforts across different departments, projects, programmes, and initiatives are fragmented due to separate mandates and various institutions conducting rehabilitation work.
- Rehabilitation initiatives were conducted, and challenges were experienced with the interpretation of the legislation and compliance and enforcement, which are inconsistent within the various branches of the authorising agencies. It is not always possible to obtain consistent opinion from the relevant departments on what needs to be complied with and by

when. This presents a considerable risk for water users, especially landowners given the significant fines associated with contravention of the Acts or associated regulations. Non-compliance issues are related to rehabilitation and/or duty of care.

1.2 REHABILITATION CONCEPTS AND DEFINITIONS

The concept of rehabilitation has been studied, explored, and defined by many authors around the globe. Various descriptions and definitions have been documented in several studies.

Rutherfurd *et al.* (2000) defined **rehabilitation** as the process of restoration/return/recovery to natural or former state/conditions in which part of the original ecosystem elements have not been recovered.

WRC (2016a) defined **rehabilitation** as the process of promoting the recovery of ecosystem functions and values in a degraded system to regain some of the values of the system previously had to society.

The two most commonly used concepts for the rehabilitation of water resources are **rehabilitation** and **restoration**. In most literature, both are aiming for the same outcome, the return of the structure and function of a degraded ecosystem to the closest achievable approximation of its natural (pre-impact) state (WRC, 2003a). Several authors have since defined restoration of the components of an ecosystem as rehabilitation (NRC, 2002; Roni *et al.,* 2008; Åberg and Tapsell, 2013). The main difference between rehabilitation and restoration is the perceived endpoint (WRC, 2016a).

Restoration is different from **rehabilitation** and refers to the manipulation of a site to revert the watercourse back to its full range of natural (historic) processes and functions. Restoration attempts to restore habitats back to their natural (historic also known as the Reference State) conditions. In the South African context, this means restoring rivers to a Reference State whilst rehabilitation, by comparison, only aims to improve aspects of the degraded state such as some of the identified assets and processes of a system (WRC, 2016a).

Rutherfurd *et al.* (2000) argued that to achieve true restoration, the natural range of water quality functioning, natural sediment and flow regime, natural channel geometry and stability, natural riparian communities and native aquatic plants and animals would have to be fulfilled.

There is no consensus on the strict definitions of the descriptions and distinctions between river **restoration, rehabilitation**, and **remediation** internationally (WRC, 2016a). All these terms indicate activities undertaken to improve or enhance river ecosystems in some way or the other. **Figure 1** below illustrates the different concepts as generally understood in the South African rehabilitation perspective.

The term **remediation** is appropriate in cases where it is not possible to rehabilitate due to ecosystems being irretrievably degraded or where a system has been fundamentally altered in character but has, over time, adjusted and achieved a state of dynamic equilibrium. Remediation aims to improve the ecological condition of the ecosystem, while not aiming for an outcome which resembles its original condition (WRC, 2004).

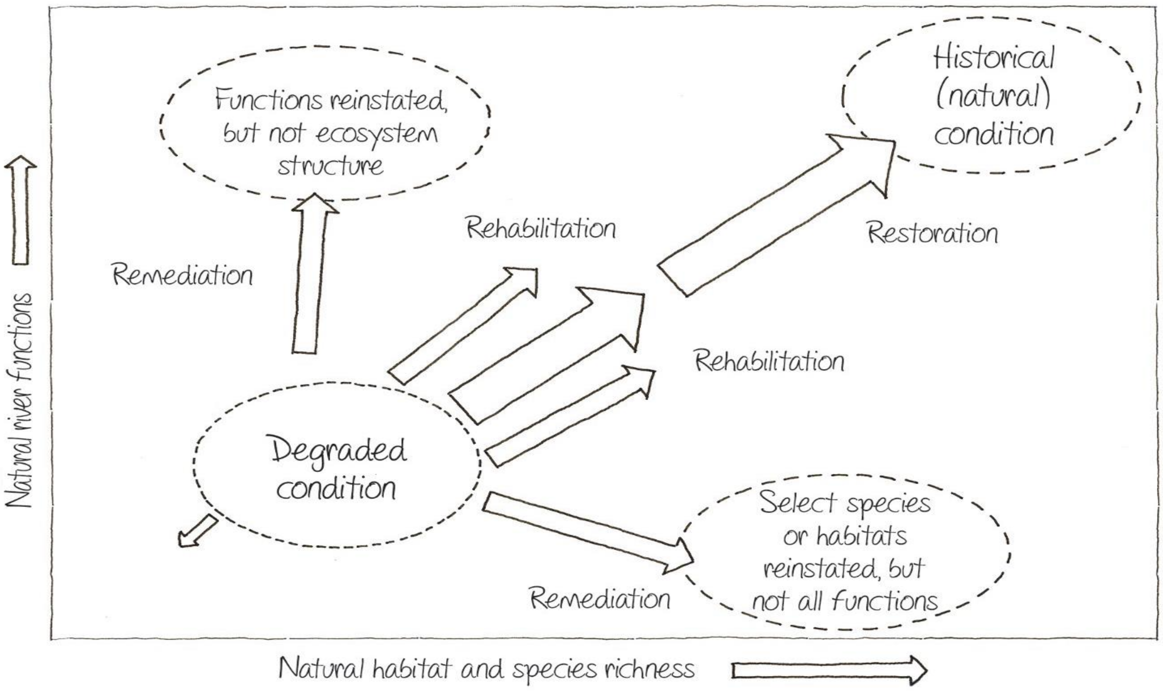


Figure 1: The distinction between rehabilitation (towards natural), restoration (the achievement of the natural or historical condition) and remediation (select mitigation of degradation)
Source: WRC, 2016a

Other concepts, such as enhancement, improvement, mitigation, ecological reclamation, and habitat creation, are part of restoring an ecosystem to its natural condition (Roni *et al.,* 2002). When these activities do not entirely restore an ecosystem, they are referred to as rehabilitation (Stanford *et al.,* 1996; Roni *et al.,* 2005).

In this River Rehabilitation Guidelines document, the term rehabilitation has been adopted, with the goal of rehabilitation being the process of improvement of essential aspects of the ecosystem, with the aim to regain some of the value the system previously had. This resonates with the DWS goal of promoting sustainable usage of water resources.

1.3 PURPOSE FOR DEVELOPMENT OF THE REHABILITATION MANAGEMENT GUIDELINES FOR RIVERS

The primary objectives of the guidelines are to:

- Develop Rehabilitation Management Guidelines (RMGs) for Rivers in terms of their interactions with characteristics of watercourses, namely; hydrology (surface flow and interflow), geomorphology, water quality, habitat, biota, and groundwater flows; and
- Integrate, align, and harmonize river rehabilitation work across various disciplines and institutions.

Note:

The DWS is not in any position duplicating existing rehabilitation guidelines, manuals or best practices that are currently available. Instead, it is integrating existing work and efforts across various disciplines, government, and non-government departments as well as institutions to ensure the harmonization and centralisation of the existing work to date.

1.4 DEFINITION OF WATERCOURSES

In terms of the definition contained within the National Water Act, 1998 (Act 36 of 1998), a watercourse means:

- A **river** or spring;
- A natural channel in which water flows regularly or intermittently;
- A wetland, dam, or lake into which, or from which, water flows; and
- Any collection of water which the Minister may, by notice in the Gazette, declare to be a watercourse; and
- A reference to a watercourse includes, where relevant, its bed and banks.

Note: *The link between water resources and characteristics of watercourses is contained in the definition above as well as in Section* ***3.1*** *and* ***3.2*** *of the report.*

1.5 GUIDING PRINCIPLES AND APPROACH FOR DEVELOPMENT OF THE GUIDELINES

The current RMGs was developed for characteristics of watercourses, namely; **hydrology (surface flow and interflow), geomorphology, water quality, habitat, biota** and **groundwater flows**.

The following aspects were covered under each characteristic of the watercourse:

- Description of the specific characteristics of watercourses;
- Types of impacts for each characteristic of the watercourse – a brief overview and description of the impacts that gives rise to the degradation of the watercourses to better understand the problem and subsequently develop effective rehabilitation guidelines;
- Legal considerations – applicable legislation to be considered for undertaking site-specific rehabilitation activities on a particular characteristic of a watercourse~~;~~ and
- Development of Rehabilitation Guidelines – step-by-step guidelines on rehabilitation measures/interventions for executing rehabilitation planning, design, implementation, and monitoring.

1.5.1 Guiding Principles

According to Rountree *et al.* (2007), guidance for rehabilitation planning can be applied to the river rehabilitation context derived from the South African National Working for Wetlands Programme. Some important aspects of guidance are provided in **Figure 2** below.

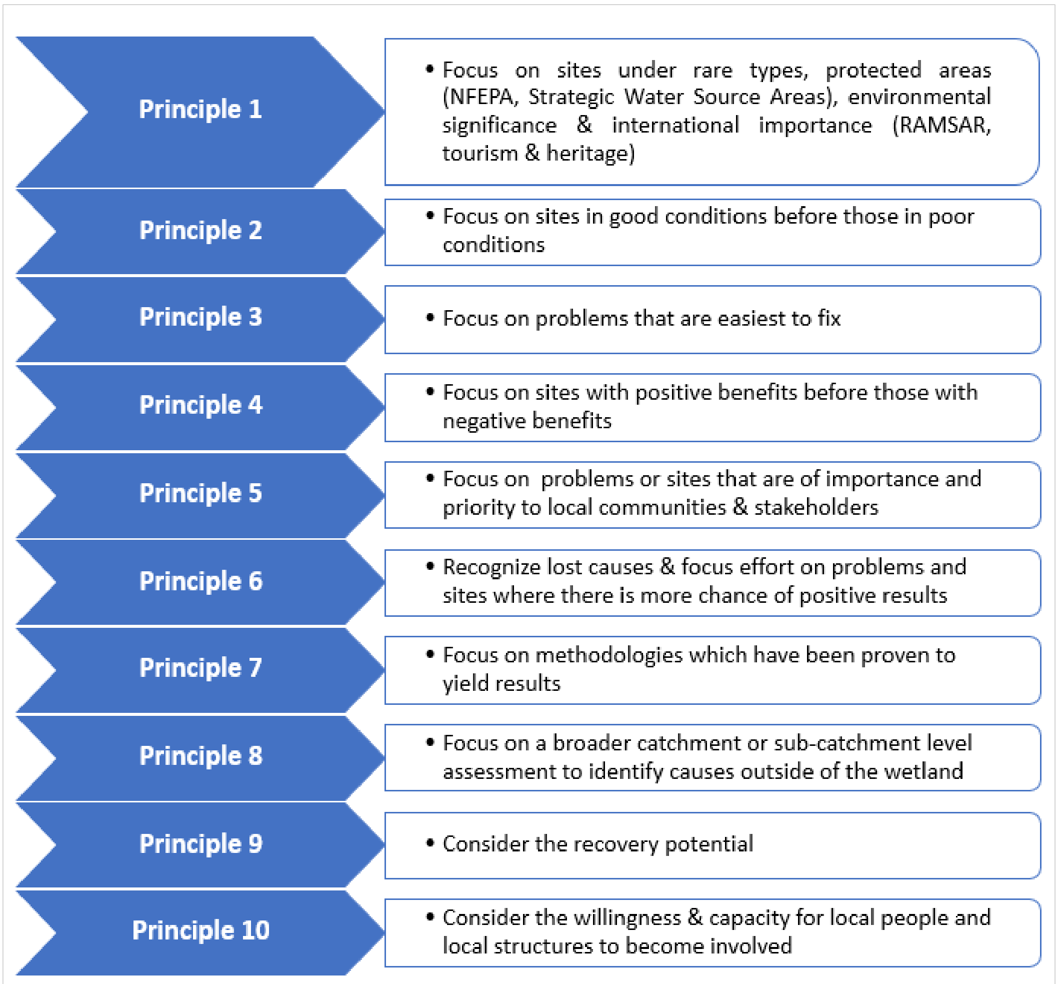


Figure 2: Guiding Rehabilitation Steps

Source: Adapted from Rountree and Batchelor, 2008

The need for rehabilitation arises from degradation and pollution input from various sources such as compounding toxic agricultural chemicals and industrial/mining pollutants. Although interventions may not be able to reinstate water resources to a natural state, a functional state must be the aim of ecosystem recovery initiatives. King *et al.* (2003) and WRC (2016) recommended the following key principles for rehabilitation:

- Defining rehabilitation objectives;
- The objectives for rehabilitation should be clear, and explicit;
- Rehabilitation must direct the system back towards a more natural state, and work in harmony with the significant abiotic drivers of the ecosystem[1];
- Undertaking rehabilitation should be seen as an interdisciplinary activity, recognising that rehabilitation may be necessary over a range of spatial and temporal scales;
- Rehabilitation should aim at treating causes rather than symptoms;
- Given that ecosystems are dynamic and can naturally exist in alternative metastable states, it should be remembered that it is easier to cross a degradation threshold than to return over it; and
- Monitoring should be an essential component of rehabilitation.

[1] *Recognising that toxic environmental pollutants and contaminants will always be a factor and the flow into the aquatic systems will not stop.*

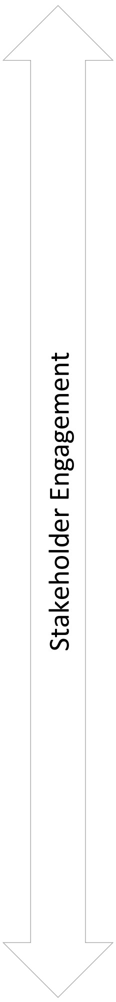
Below is a list of some key importance and applicability of the above-mentioned principles:

- Ecosystem-based approach;
- Re-instating natural processes;
- Enhancing biodiversity and habitat diversity;
- Improving water quality;
- Flood mitigation and erosion control;
- Stakeholder engagement and community involvement; and
- Long-term sustainability.

1.5.2 Approach

The development guidelines are the core of this report. The River RMGs aim to guide the water users on step-by-step measures/interventions to be followed for executing rehabilitation with specific attention to and consideration to planning, design, implementation, and monitoring for the identified impacts. **Table 1** below depicts the approach for the development of the RMGs.

Table 1: Approach for the development of Rehabilitation Guidelines for Rivers including the associated characteristics of watercourses.



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 that will be recommended to reinstate the conditions of the drivers. • Determine the conditions and the type, size, and 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 the water 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 Report.

1.6 INTENDED USERS OF THE GUIDELINES

The RMGs for rivers is a set of tools developed to ensure that clear and practical steps are provided on a wide range of rehabilitation measures/interventions related to characteristics of watercourses which take cognisance of legal, social, economic, and ecological 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 scale/level.

1.7 STRUCTURE OF THE GUIDELINES

The guideline is divided into six 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 river rehabilitation.
- **Section 3** describes the characteristics of watercourses and their linkage to water resources.
- **Section 4** provides the overarching impacts of water resources and the impacts related to the characteristics of watercourses.
- **Section 5** provides step by step Technical Rehabilitation Guidelines for characteristics of watercourses.
- **Section 6** provides recommendations and a way forward.
- The last section presents the bibliography and list of appendices.

2. LEGAL FRAMEWORK

2.1 OVERARCHING LEGAL FRAMEWORK

Section 24 of the Constitution of the Republic of South Africa (Act 108 of 1996) makes provision for the right to an environment that is not harmful to the health or well-being of everyone; and an environment that is protected for the benefit of present and future generations, through reasonable legislative and other measures that (i) prevent pollution and ecological degradation; (ii) promote conservation; and (iii) secure ecologically sustainability. A variety of legal tools (*i.e.,* acts, gazettes, regulations) need to be considered when undertaking river rehabilitation activities. The main pieces of overarching legislation in South Africa are the National Water Act (NWA) (Act 36 of 1998), National Environmental Management Act (NEMA) (Act 107 of 1998), National Environmental Management: Biodiversity Act (NEMA:BA) (Act 10 of 2004) and National Environmental Management: Waste Act (NEM: WA) Act 59 of 2008). These legislative tools, in some instances, give provision for some small-scale rehabilitation activities to be undertaken without prior authorization (NEMA) or are eligible for General Authorization (GA) (under the NWA). Medium-to-large-scale rehabilitation activities may require different approvals before commencement. These may include licenses, environmental authorizations, permits or rights. The various types of environmental approvals are discussed below **(Table 2)**. There are other related environmental legislations that can apply to river rehabilitation activities depending on the cause for rehabilitation and steps that may need to be carried out. The overarching pieces of legislation applicable to river rehabilitation are as follows:

- Constitution of the Republic of South Africa, Act 108 of 1996;
- National Water Act, 1998 (Act 36 of 1998) (NWA);
- National Environmental Management Act, 1998 (Act 107 of 1998) (NEMA);
- National Heritage Resources Act, Act 25 of 1999 (NHRA);
- National Environmental Management: Waste Act, 2008 (Act 59 of 2008) (NEM: WA);
- National Environmental Management: Biodiversity Act, 2004 (Act 10 of 2004) (NEM: BA) and its related AIS Regulations (GG No.R 1020, 25 September 2020) and associated AIS lists (GG No.R 1003, 18, September 2020);
- National Environmental Management: Protected Areas Act, 2003 (Act 57 of 2003) (NEM: PAA);
- Fertilizer, farm Feeds, Agricultural Remedies and Stock Remedies Act, 1947 (Act 36 of 1947) and Regulations relating to Agricultural Remedies (GG No. R. 3812, 25 August 2023); Hazardous Substances Act, (Act 15 of 1973) (HSA);
- Occupational Health and Safety Act, 1993 (Act No. 85 of 1993): Hazardous Chemical Agent *Regulations, 2021, (published as Government Notice No. R280 of 29 March 2021) (HCA)*;
- Conservation of Agricultural Resources Act, 1993 (Act 43 of 1983) (CARA); and
- Mineral and Petroleum Resources Development Act, 2002 (Act 28 of 2002) (MPRDA).
- Municipal by-laws.

Table 2: Legislative Tools Applicable for River Rehabilitation.

Institution	Legislative Tool	Sections	Process
DWS	National Water Act, 1998 (Act 36 of 1998)	21, 36, 40, 41, 43, 19	Water Use License Application (WULA), Waste Discharge Charge System (WDCS), General Authorization (GA).
	Government Notice (GN. 704)	21 (j), (g), Reg 4(c)	GN.704 Exemption Application for backfilling activities.
	GN 509	21(c) and (i)	GN509 allows water users to apply for Section 21(c) & (i) under a General Authorisation (GA), as opposed to a full WULA. These water uses may include general construction, maintenance and/or emergency work, river and stormwater management activities and undertaking river rehabilitation works within the regulated area of a watercourse. For a water use (or potential) to qualify for a GA under GN 509, the proposed water use/activity must be subject to analysis by a suitably qualified natural scientist who is professionally registered with the South Africa Council for Natural Scientific Professions (SACNASP) using the DWS **Risk Assessment Matrix (RAM).** ***Note: GN509 does not exempt the water user from compliance with any other provision of the Act or from any other applicable legislation, regulation, ordinance, or by-law.***

Institution	Legislative Tool	Sections	Process
	GN 1198	21(c) and (i)	GN1198 relieves a water user from the need to apply for a license for impeding or diverting the flow of water in a watercourse in terms of section 21(c) or altering of the bed, banks, characteristics of watercourses in terms of section 21 (i) of the NWA for the purpose of rehabilitation, provided that the use is within the provision set out in the Notice. ***Note: GN1198 does not exempt the water user from compliance with any other provision of the Act or from any other applicable legislation, regulation, ordinance, or by-law.*** *GA 1198 authorizes the Working for Wetlands Program, and as a result, the DFFE makes its submission in terms of that to DWS. This is the current approach DFFE uses to obtain authorization.*
DALRRD	Conservation of Agricultural Resources Act, 1983 (Act 43 of 1983)	6, 7, 12, 15D	Application for consent Section 12 Demarcation of biocontrol reserve- 15D
	Fertilisers, Farm Feeds, Agricultural Remedies and Stock Remedies Act, 1947 (Act 36 of 1947) and its Regulations relating to Agricultural Remedy (GN 3812, 25 August 2023)	Section 3(1)(2)(3), Section 7	Deals with all pesticides registered in the country to control AIS, and the amended regulations highlight the new registration criteria indicating that pesticides have to comply with GHS labelling practises and HHP's will not be registered from June 2024 in the categories stipulated in Annexure A. The act provides for the registration of fertilisers, farm feeds, agricultural remedies, stock remedies, sterilising plants, and pest control operators with the aim of regulating or prohibiting the importation, sale, acquisition, disposal or use of fertilisers, farm feeds, agricultural remedies, and stock remedies. Furthermore, it governs the use of antimicrobials for growth promotion and prophylaxis/metaphylaxis and the purchase of over-the-counter (OTC) antimicrobials by the lay public (chiefly farmers).
	Regulations relating to Agricultural Remedies (GG No. R. 3812)	8(1)(b), 8(6)(a), 34(1), 38, Annexure A	Unreasonable adverse effects on the environment, risks from exposure, waste management and disposal (contamination risks), categorization criteria.
DFFE	Mountain Catchment Areas Act, 1970 (Act 63 of 1970)	2, 3, 4(1), 11, 14	-
	Environment Conservation Act, 1989 (Act 73 of 1989)	26	Scoping

Institution	Legislative Tool	Sections	Process
	National Environmental Management: Biodiversity Act, 2004 (Act 10 of 2004)	38, 41, 43, 52, 53, 56, 57, 65, 66, 67, 69, 70, 71, 73, 75, 76, 88, 89, 90, 91, 92, 93	The act deals with the requirements to control Invasive Alien and Invasive Species and the requirements for Alien and Invasive Species Monitoring, Control and Eradication Plans if found on your property. National Biodiversity Framework & bioregional plans, Biodiversity management Plans, Environmental Impact Assessment (EIA) (2(bA)(iii), Basic Assessment Report (BAR)
	• Alien and Invasive Species Regulations (GG no. R 1020) • Guidelines for Monitoring, Control and Eradication Plans for species listed as invasive in terms of section 70 of Act no. 10 of 2004 (NEM: BA) and as required by section 76 of this act.	70 (1)(a), 75(1), (2), (3), 6, 21, 76 • Plans must be submitted to the Competent Authority in terms of Section (10)(2)(b)	AIS listed, Species Management Plans, restricted activities, permitting. The conveying, moving/removing or otherwise translocating any specimen of a listed invasive species as PROHIBITED for category 1a and 1b species.
	National Environmental Management Act, 1998 (Act 107 of 1998)	Section 28, Regulation 386, Activity 1 (m) gazetted in terms of Section 24	EIA, BAR, Environmental Management Plan/Programme (EMP)
	National Environmental Management: Waste Act, 2008 (Act 59 of 2008)	5, 7,12(1)(b)(iii), (iv), 16(3), 19, 27(2), 45, 69(d), (f), 81	Waste Management Strategy, Control/modify/monitor environmental pollution, Detrimental waste management activities, Water Management License (WML), Licence in terms of section 45, Regulations for compliance monitoring, duty of care, transitional provisions
South Africa Heritage Resources Agency (SAHRA)	National Heritage Resources Act, 1999 (Act 25 of 1999)	34(1), 35, 36, 38, 45, 28,	Permit in terms of section 48
Department of Minerals Resources and Energy (DMRE)	Mineral and Petroleum Resources Development Act, 2002 (Act 28 of 2002)	5A, 22, 23, 27, 38A, 98, 99, 106	Permit in terms of section 27 or right in terms of section 23
Municipalities	By-laws	Sanitation, Land use Management, Waste Management, Stormwater Management, Diffuse Water Quality Management by-laws	Applicable (per area) municipal by-laws need to be considered by every person(s) undertaking rehabilitation.
Department of Employment and Labour.	Occupational Health and Safety Act, 1993 (Act no. 85 of 1993) and Regulations for Hazardous Chemical	-	The act deals with exposure to hazardous chemical agents (pesticides) and protection of operators. It provides GHS hazard classes in relation to physical hazards, health hazards and environmental hazards as well prohibited HCA's. Operator exposure limits

Institution	Legislative Tool	Sections	Process
	Agents (HCA), 2021 (GN 280, 29 March, 2021).		(OEL) and body exposure indices (BEI) are given to assist in developing safety limits for controlling AIS.

Note: *The DWS GA 509 of August 2016 was revised and updated with GA 4167 of December 2023. The GA makes provision for rehabilitation work in general that will enhance the Present Ecological State (PES) of watercourses/ water resources. In general, the RMGs do not only concentrate on water use authorisations for new applications but also on historic activities that were undertaken without proper authorization.*

Note:

- *The DWS does not authorize rehabilitation, but it authorizes the impeding, diverting, or changing of bed/banks of characteristics of watercourse. If any of those activities in terms of rehabilitation constitute those water uses, they need to get authorized accordingly.*
- *The RMGs guide other external persons (i.e., private) for any rehabilitation activities that may impede, divert, and change the bed/banks of characteristics of watercourses; if these other person(s) are impeding, diverting, and changing the bed/banks, then they should apply for authorization for which there is a provision for within the DWS.*

2.2 ALIGNMENT WITH POLICIES, STRATEGIES AND PRINCIPLES

Various policies, strategies and principles inform River Rehabilitation Management in South Africa, and these include, but are not limited, to the items:

Policies and Strategies

- National Development Plan (NDP).
- The National Water Resource Strategy (NWRS III) (2023).
- The National Water and Sanitation Master Plan (NW&SMP) (2018).
- The Draft Environmental Rehabilitation Policy (2014).
- National Biodiversity Strategy and Action Plan.
- National Biodiversity Assessment.
- National Freshwater Ecosystem Priority Areas (NFEPA).
  The NFEPA maps and supporting information form part of a comprehensive approach to sustainable and equitable development of South Africa's scarce water resources. For integrated water resources planning, NFEPA guides how many rivers, wetlands and estuaries, and which ones, should remain in a natural or near-natural condition to support the water resource protection goals of the National Water Act (Act 36 of 1998) and for biodiversity resilience and persistence (WRC,2011).
- The Integrated Water Quality Management (IWQM) Policies (2016) and Strategies for South Africa (2017).
- Eutrophication Management Strategy for South Africa – Second Edition (2023).
- The implementation of Gazetted Resource Directed Measures (RDM), particularly the Reserve, Water Resource Classification, Resource Quality Objectives (RQOs), and Sources Directed Controls (SDCs).
- The Catchment Management Strategy is informed by the National Water Policy and promotes

the sustainable balance between the utilisation and protection of water resources in a catchment.

- Policy principles and guidelines for control of developments affecting natural forests (2010) aimed to ensure the effective protection and sustainability of natural forests through proper control over development and land use change affecting forests in South Africa.
- National Waste Management Strategy.
- National Species Monitoring, Control and Eradication Plans.
- National Biodiversity Framework and Bioregional Plans.

Key Water Resource Management Principles and Concepts

- Integrated Water Resource Management (IWRM) - a process for co-ordinated planning and management of water, land, and environmental resources. It considers the amount of available water (surface and groundwater), water use, water quality, and environmental and social issues as an integrated (combined) whole to ensure sustainable, equitable and efficient use.
- Sustainable Development Goals (SDGs) - are aimed at ensuring the availability and sustainable management of water and sanitation for all by 2030. Every year, an annual SDG Progress Report should be produced based on the global indicator framework, data produced by national statistical systems, and information collected at the regional level.
- Global Biodiversity Framework (GBF) - aims to enable urgent and transformative action by Governments, and subnational and local authorities, with the involvement of all of society, to halt and reverse biodiversity loss to achieve the outcomes it sets out in its Vision, Mission, Goals and Targets. Although the DWS focuses mainly on reporting on the SDG targets, it is recommended that the relevant authorities should use the outputs of the current RMGs for their reporting at the respective platforms.
- Social-Ecological Systems (SES) – are linked systems of people and nature, emphasising that humans must be seen as a part of, not apart from, nature (Berkes and Folke, 1998).

3. CHARACTERISTICS OF WATERCOURSES

3.1 INTRODUCTION TO CHARACTERISTICS OF WATERCOURSES

A comprehensive process of water resources rehabilitation requires the consideration to characteristics of watercourses, namely **hydrology** (**surface flow and interflow), geomorphology, water quality, habitat, biota, and groundwater flows.**

For all the characteristics mentioned above, rehabilitation of watercourses is limited. Generally, rehabilitation concerning shaping, re-vegetation, and AIS eradication is limited under the NWA. Rehabilitation interventions and practices that prioritise and include water quality issues such as pollution from WWTWs and from non-point sources are also limited. There are multiple concerns around issues of rehabilitation and the main contributing factors are mines, industries, agriculture, WWTWs as well as poor compliance and implementation of legislation in terms of buffers to watercourses. Therefore, the need for the development of the rehabilitation guidelines with a focus on the characteristics of watercourses is essential.

To this end, it is to consider factors (drivers and responses) that underpin water ecosystem condition and functionality, including the interactions between the physical patterns, products (*e.g.,* ecosystem services) and materials (*e.g.,* aquatic ecosystems). **Figure 3** below depicts the Ecological Water Requirements (EWRs) components for ecosystems. This figure demonstrates that water flow, water quality, and geomorphology are the main drivers of EWRs, whilst habitat (vegetation) and biota (fauna) *i.e.,* animals and flora (*i.e.,* plants), are the responses. These drivers and responses are inherently interlinked.

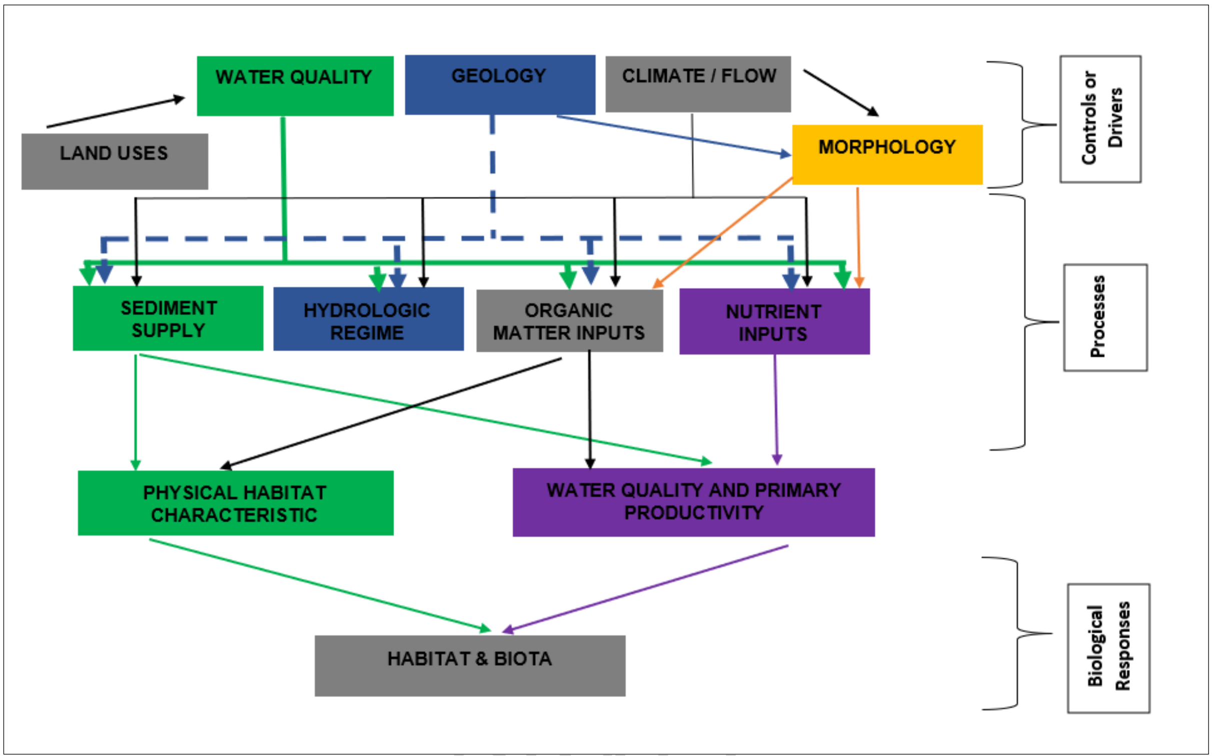


Figure 3: The Ecological Water Requirements of the Reserve including drivers and responses
Source: Beechie and Bolton, 1999

3.2 LINK BETWEEN WATER RESOURCES AND CHARACTERISTICS OF WATERCOURSES

The rehabilitation of water resources is directly linked to that of the characteristics of watercourses (drivers and responses) because impacts on water resources may be as equally prevalent on all these characteristics of watercourses. A point in case is that instream dams are considered water resources as well as part and parcel of the watercourses because all characteristics of watercourses come into play when dealing with a dam *e.g.,* surface flow, interflow, water quality, geomorphology, habitat, and biota. The other reason is that dams share the same characteristics as lakes and/or rivers in terms of hydrological and geomorphological connectivity, whilst habitat, and buffers around them are as equally important. In terms of the implementation of the management actions, rivers require Ecological Flow requirements**. Figure 4** below illustrates the link between water resources and characteristics of watercourses.

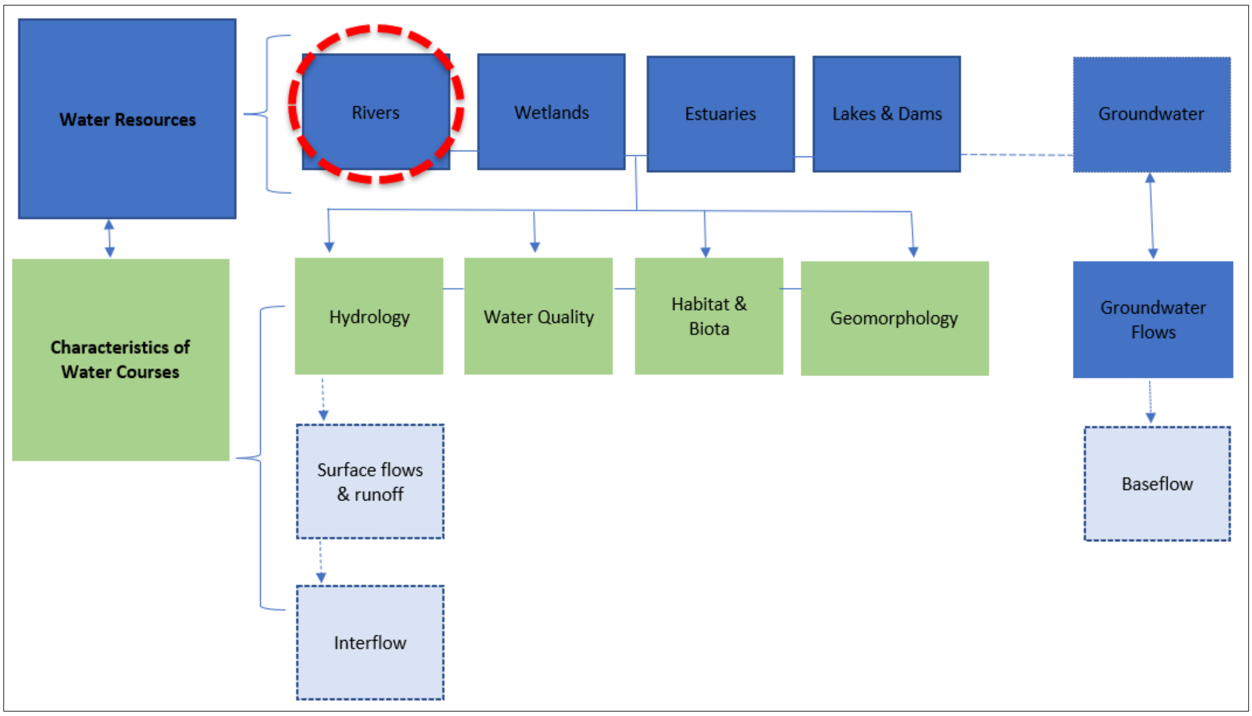


Figure 4: Diagram depicting the link between water resources and characteristics of watercourses.

4. WATER RESOURCE IMPACTS

4.1 RIVER ECOSYSTEM STATUS AND DEGRADATION IMPACTS

Generally, river ecosystems are mainly threatened and impacted by flow and physico-chemical alterations which are regarded as a significant impact on river ecosystems. Flow and physico-chemical alteration is driven by activities such as unlawful damming, irrigation, excessive abstractions and poor catchment management; continuous and excessive amounts of pollutants from domestic, agricultural, and industrial sources upstream; and infestation and encroachment of alien and invasive plants.

Figure 5 below provides a schematic illustration of the three main broad categories of impacts on river systems in South Africa as reported by WRC (2003b), namely **physical disturbance** associated with AIS and land use either within the broader catchment or the river channel itself; **hydrological manipulations** due to agricultural and afforestation activities; and **chemical disturbances** which relate to the variation of water quality in rivers due to irrigation return flows, discharge of effluent and pesticide and associated compounds loading and decanting AMD water.

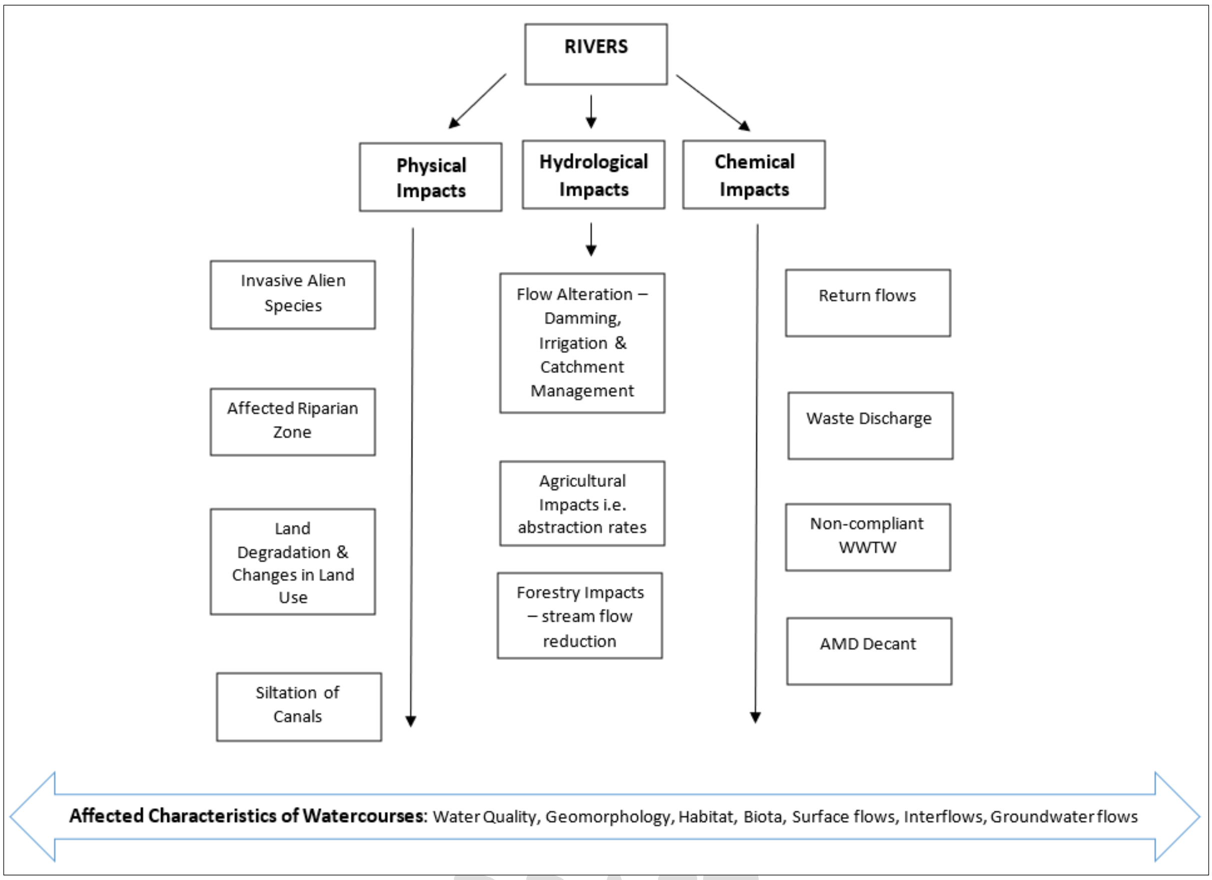


Figure 5: Schematic illustration of the three main broad categories of impacts on river systems

5. GUIDELINES FOR RIVERS AND ASSOCIATED CHARACTERISTICS OF WATERCOURSES

5.1 HYDROLOGY

The hydrological cycle is the circulation of water within the earth's hydrosphere, involving changes in the physical state of water between liquid, solid, and gas phases and the exchange of water between atmosphere, land, surface, and subsurface waters. **Figure 6** below illustrates the interaction between different components of the hydrological system and water movement and storage.

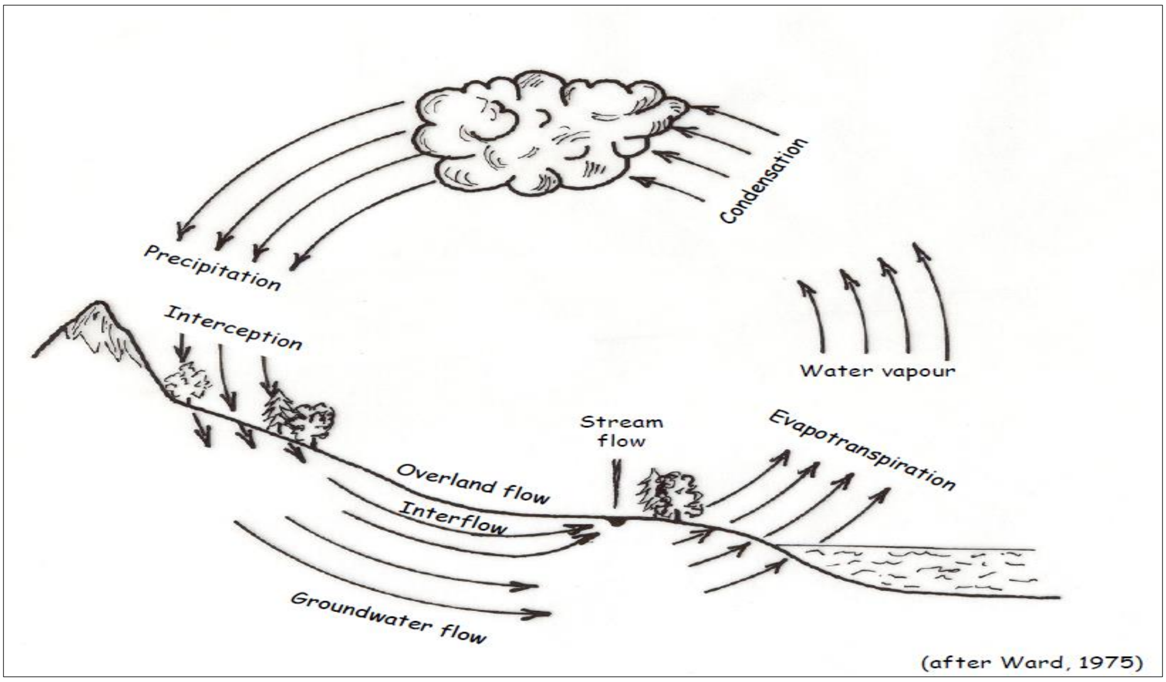


Figure 6: Illustration of the Hydrological cycle
Source: WRC, 2004

5.1.1 Components of the Hydrological Cycle

The hydrological cycle consists of various components as illustrated in **Figure 7** form an essential part of the development of the guidelines.

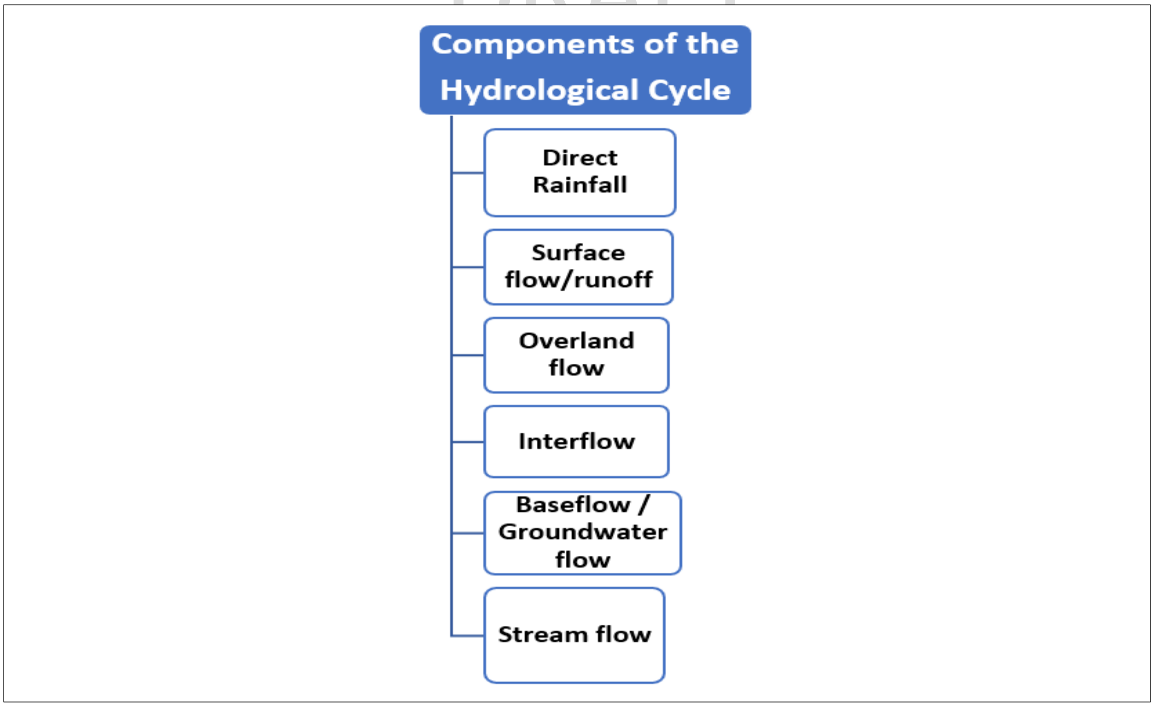


Figure 7: Components of the Hydrological Cycle
Source: adapted from WRC, 2004

Two components of the hydrological cycle will be the focus of the guidelines and are described as follows:

- **Surface flow/surface runoff** - all surface and subsurface flow from a catchment, which in practice refers to the flow into a river, *i.e.,* excludes groundwater not discharged into a river (WRC, 2004)
- **Interflow** - 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).

5.1.2 Surface Flow/Runoff Impacts

Access to free-flowing water of good quality is a basic human need, yet anthropogenic activities are persistently altering and degrading rivers which directly impacts on water availability for various ecosystem needs such as ecosystem functioning and human livelihood. As a result, there is a global growing concern about extensive ecological degradation and loss of biological diversity due to river exploitations. Flow alteration (by construction of dams, weirs, abstractions, diversions etc.) is one of the key impacts humans have on freshwater ecosystems leading to biological impairment of the ecosystem services they provide. Flow alteration (**Figure 8**) refers to the modification of flow characteristics or natural conditions, which may change biotic community composition. Flow alterations are closely linked to temporal variability and regional flow characteristics such as the variance in rainfall patterns, vegetation, development, geology, and other catchment characteristics**.**

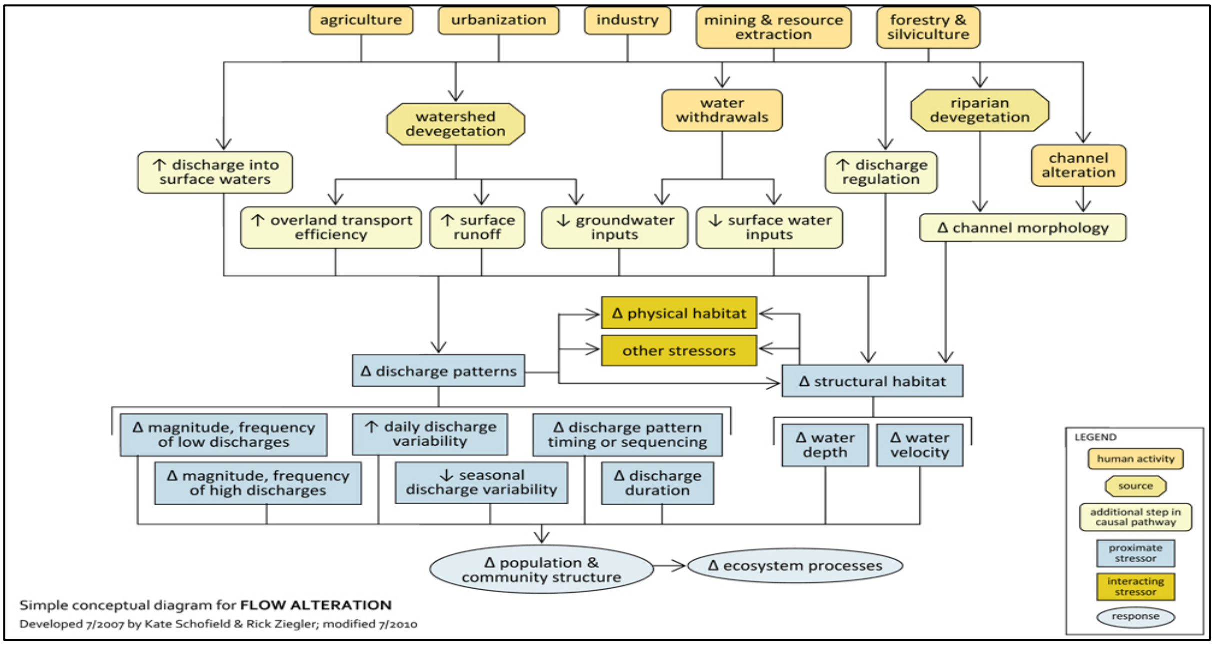


Figure 8: Conceptual diagram for flow alteration
Source; US EPA, 2021

According to Rolls and Bond (2017), flow regime change is evident in terms of altered baseflows, reduced flooding magnitude and frequency, reduced floodplain inundation, and altered flow variability; however, the extent to which these hydrological components are modified depends on the river hydrological change. It is, therefore, crucial to understand that characteristics of ecological responses differ in response to change across hydrological components and are strongly determined by local factors such as hydroclimatic region, biological traits of organisms, and how flow regime change manifests in terms of stream hydraulics. In general, the main factors affecting the runoff from a catchment area are:

- Precipitation characteristics (type of precipitation, rainfall intensity, rainfall amount and duration);
- Shape and size of catchment;
- Topography;
- Geologic characteristics;
- Meteorological characteristics; and
- Storage characteristics of a catchment linked to geology and land cover/use.

5.1.3 Interflow Impacts

Afforestation[2] and alien vegetation impacts[3]:

Afforestation and **alien** and **invasive vegetation** impact runoff, *i.e.,* interflow and/or stream flow. Alien vegetation impacts are notably linked to water quality and geomorphological impacts. Section 36(2) of the National Water Act (Act No. 36 of 1998) (NWA) states that a stream flow reduction 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). Afforestation has been declared as a streamflow reduction activity, the only activity declared thus far by the DWS.

Stream flow reduction (SFR) activities produce less runoff (or outflow) than they would have produced if it were a natural area (WRC, 2011). These activities are, in general, easily visualised as wooded areas within a catchment, but it may also be alien and invasive vegetation or an afforestation area (*e.g.*, commercial and eucalyptus plantation). As such, there may be many different stream flow reduction activities within a catchment, each with their own characteristics.

Afforestation plants are usually listed as AIS per the NEM: BA AIS Lists of (GG No.R 1003, 18 September 2020). Species, clones, and hybrids from Eucalyptus, Pinus and Acacia genera are usually planted for commercial purposes. However, because they are deep rooted, evergreen, have higher evapotranspiration, and are highly invasive, they have to be closely managed and their spread controlled.

Over-abstraction and water loss impacts:

Over-abstraction of surface water from a river has a direct impact on interflow. Similarly, these impacts are encountered when there is a relationship between interflow and groundwater - interflow often occurs in the perched shallow water table. A perched water table occurs when the groundwater level is located above the main water table in the unsaturated zone formed as a result of a discontinuous impermeable layer**. Figure 9** depicts perched water bodies (aquifers) and water tables.

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[2] *The intergovernmental Panel on Climate Change (IPCC) Guidelines define afforestation as the "planting of new forests on lands which, historically, have not contained forests, Duan & Abduwadi (2021)". This then means that if the area is a commercial forestry plantation, but the AIS are forestry species that has 'escaped', then it is not considered under afforestation.*

[3] *Cullis et al., (2007) highlighted the impact of up-land AIS on catchments and riparian areas to amount to approximately 172 million m^3/annum while Eucalyptus species in ideal conditions can account for at least 35% of that volume.*

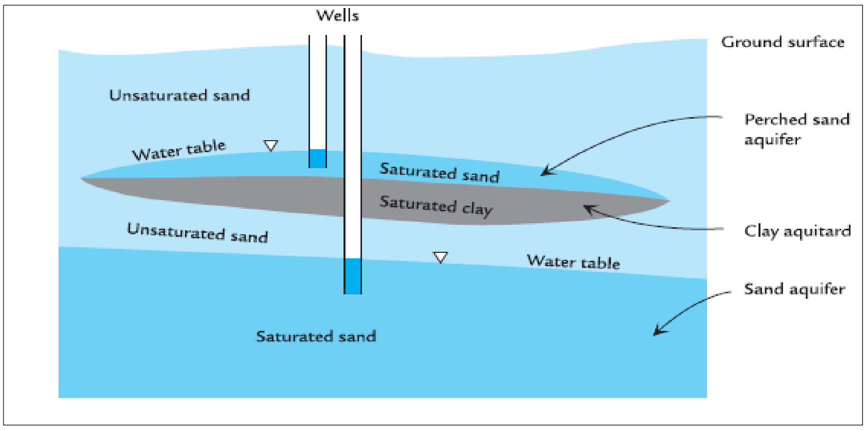

Figure 9: Illustration of a Perched Aquifer and water table
Source: Fitts, 2002

Over-abstraction of groundwater within perched aquifers also impacts interflow. The consequences of overexploitation are confirmed by Knüppe (2011) as lowered groundwater tables resulting in a decoupling of the groundwater and surface water systems, including water exchange between rivers, wetlands, and springs. Poor land use management activities such as agriculture, river diversions, and developments interrupt flow paths and connectivity between stream channels and groundwater, which causes water losses. The excessive use of pesticides adversely affects the state of groundwater as pesticides, their transformation products, metabolites, and residues are not broken down due to the absence of microbes and bacteria, resulting in an increasing concentration in the groundwater and exponential risk to the environment and communities who subsist on groundwater.

Below is a list of impacts of poor land use management on interflow.

- **Forestry impacts –** forestry utilises interflow and impacts surface water and groundwater resources by lowering both surface and groundwater levels. Pesticides used in forestry practices enter surface waters through run-off and drift while entering interflow and groundwater through percolation and leaching.
- **Agricultural impacts -** changes in soil properties due to changing land use include ploughing (loosening), compaction (densification), imported material (variable properties), cut-and-fill (interruption of flow paths), and change processes and the associated movement of ions and fines (WRC, 2014). The above changes in soil properties impact interflow negatively since it occurs in shallow soils. Agricultural pesticides are available in a variety of formulations and applications, but those that have high mobility rates (Kd & Koc = high), high soil sorption (Koc / Kfoc) factors, persistence in soil (DT50 = high), GUS leaching potential indices, the potential for particle-bound transport indices, and potential for loss via drain flow, will negatively impact interflow (Pesticide Properties Database - PPDB, 2023).
- **River diversion and developments -** connectivity between stream channels and groundwater may be lost due to interruption of the continuous water supply or through canalisation Downstream ecosystems are inevitably influenced, and groundwater recharge may be significantly decreased due to increased evaporation from sealed surfaces and the removal of water through stormwater systems.
- **Poorly sited graves –** interflow can be impacted from a quality perspective due to gravesites that are poorly located in areas dominated by shallow groundwater levels. WRC (2014) confirmed that interaction and interflow are possible between proximate graves, and/ or contaminated water may enter the vadose zone below the grave.

5.1.4 Groundwater Flows

Groundwater is an important contributor to baseflow. Baseflow is defined as the portion of water 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. Below are some of the factors/impacts that affect the contribution of groundwater flows to rivers and streams.

Groundwater Impacts:

According to Tóth (1970) and Sophocleous (2002), groundwater flows are influenced by three main hydrogeological factors described in **Table 3**, 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 3: Factors and Impacts affecting groundwater flow

Source: Tóth, 1970; Sophocleous, 2002

Factors/Impacts	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:

Groundwater and surface water interaction occurs when groundwater contributes to surface water or the river recharges groundwater. The flow of water between the groundwater in aquifers and surface water is largely controlled by 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 10** is an illustrative diagram depicting the interaction between groundwater and streams/rivers.

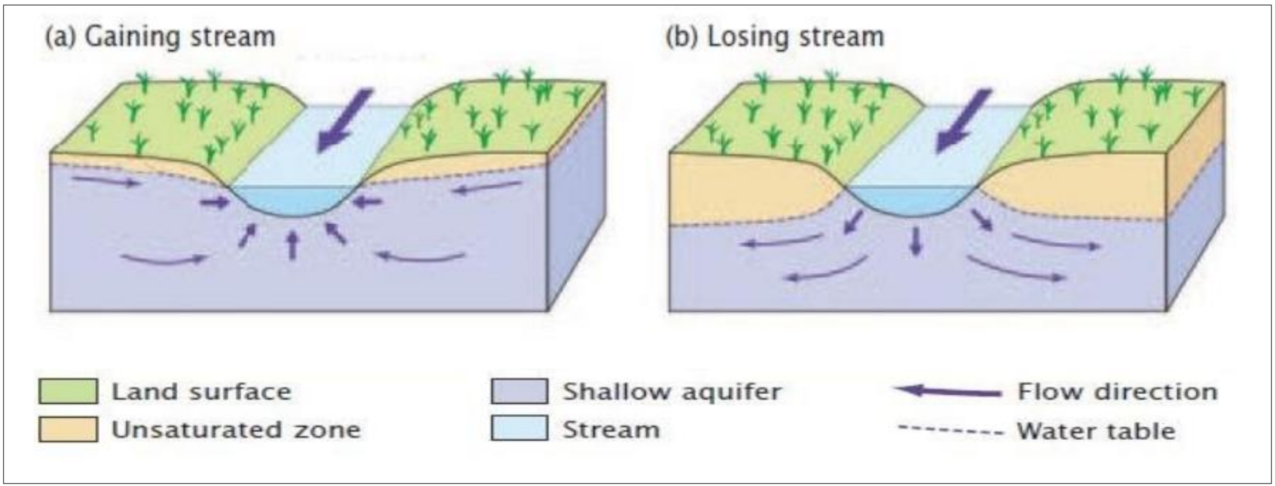

Figure 10: Illustrative diagram depicting stream/river-aquifer interactions – (a) connected gaining stream (b) connected losing stream
Source: Winter *et al.,* 1998

Anthropogenic activities in the catchment affect groundwater contribution to baseflow. **Abstraction** of groundwater for various purposes, reduces—river-aquifer water exchange fluxes, **reduces connectivity** between groundwater and surface water, and **organic** and **inorganic contamination**. Contamination emanating from the river-aquifer must be investigated and suitable mitigation measures be implemented.

Pesticides contaminating groundwater also contaminate surface water as well through the interactions between the two – creating a cyclic effect of pesticides, transformation products, metabolites, and residues between the river-aquifer, then added to the compounding effect when more CECs are added, which exponentially increases the exposure and risks. Heavy metals, particulate contaminants (nanomaterials, microplastics) and organic compounds (such as Polycyclic Aromatic Hydrocarbons (PAH's) and Alkylphenols and Alkylphenol Ethoxylates are extremely toxic and persistent and proven to be Endocrine Disrupting Chemicals (EDC's) (Olujimi *et al.,* 2011). Wee and Aris, (2023) indicated that Per- and Polyfluoroalkyl substances (PFAS) - known as the 'forever chemicals' have caused a global crisis as PFAS contamination increased globally by 13.6% between 2018 and 2019, in both river and groundwater and Cserbik *et al.,* (2023) has proven that PFAS has been associated with endocrine disruption, developmental and reproductive toxicity, carcinogenicity, genotoxicity, immunotoxicity, cytotoxicity, neurotoxicity, and hepatotoxicity , and is supported by Wee and Aris, (2023) and Cordner *et al.,* (2019).

Numerous methods and techniques have been used to quantify and detect groundwater and surface water interaction in South Africa and on a global scale. These methods and techniques are well established in literature, and the most commonly used methods include the following:

- Hydrochemistry;
- Hydrochemical analysis;
- Environmental tracers (isotopes);
- Hydrograph separation of the baseflow;
- Direct seepage measurements using seepage meters; and
- Hydraulic tests using mini-piezometers.

Quantifying groundwater and surface water mechanisms is critical in groundwater resource-directed measures. The above methods and techniques will be explored in more detail in the upcoming *Rehabilitation Management Guidelines for Groundwater in the current RMG project.*

5.1.5 Rehabilitation Management Guidelines for Interflow

Scenario 1: Rehabilitation and Management of stream flow reductives activities i.e., afforestation

PHASE 1: Diagnostic Phase:

Step 1: Identify areas where there are afforestation species, for example, Eucalyptus species that need to be removed. Either due to being:
- Unlawful plantations;
- Areas where plantation species have spread or dispersed to (invaded), or
- Sensitive and vulnerable areas (like riparian areas and wetlands) with established plantations where the implementation of buffers is required.

Step 2: Initiate communications with the responsible authorities (*i.e.,* local and district municipalities as well as DWS Regional Office) responsible for the catchment in which the affected resource is located.

Step 3: Utilize tools such as Google Earth/ Pro /Google Earth Engine/Sentinel, ensuring high spatial resolution (<10 m) satellite imagery, GIS, and remote sensing is used to map out the targeted areas and their extent.

Step 4: Utilize tools such as Google Earth/ Pro /Google Earth Engine/Sentinel, ensuring the use of high spatial resolution (<10 m) satellite imagery, GIS, remote sensing, and other available information; describe in detail the area identified, proximity to water resources, natural vegetation type, soil type that produces less runoff/inflow (or outflow) than it would have produced if it were a natural area. Consider including the following in the descriptions:
- **Step 4.1:** Visual description of the SFR areas, *i.e.,* wood vegetated area, a swath of vegetation, or dense sugar cane or AIS infestation.
- **Step 4.2:** Indicate whether the affected area is at a catchment, sub-catchment, or quaternary scale?
- **Step 4.3:** Describe the extent or type of the infestation of the affected area, *i.e.,* patchy or dense.
- **Step 4.4:** Describe the conditions upstream, downstream, and in the vicinity of the affected area which will depend on the scale in **Step 4.2.**
- **Step 4.5:** Assess platforms such as the CEC Knowledge Hub for data on possible contaminants in the river in question and source of the contamination.

PHASE 2: Planning and Assessment:

Step 1: Conduct a ground-truthing survey (*e.g.*, use drones) to identify and ascertain area(s) accurately affected by Afforestation.

Step 2: Based on all the above information obtained in **Step 1** above, identify the type of afforestation. Afforestation, in this case, forestry species that are also AIS and can be included in one of the following three priority genera, namely:
- *Pinus* species (pines)

- *Eucalyptus* species (eucalypts)[4] and
- *Acacia* species (wattles).

Step 3: Map and delineate the area indicating the category and extent of the area(s) affected
This step must also consider the upstream and downstream conditions of the area(s) affected.

Step 4: Existing maps (topographic and/or orthophoto) must also be considered and used to ascertain the following:

- Existing afforestation activities – this must also be inclusive of site-specific area(s) and specie(s) type(s).
- Proposed afforestation activities - this must include site-specific area(s) and specie(s) type(s).
- Existing surrounding land use activities indicating site-specific area(s) and specie(s).
- Existing surrounding land use activities indicating types of pesticides used, volume (in kg's or tons /litres) of pesticides, and hazard criteria of pesticide class (indicating potential environmental contamination and human health risks).
- Existing and proposed infrastructure – this may include but is not limited to roads and dams.
- Existing natural landscape features, such as rivers.

PHASE 3: Identify and define the Rehabilitation Objectives:

The rehabilitation objectives of SFR activities must be clear from the onset. These objectives must be informed by the information and data collated in **Phases 1 and 2** above. In general, some of the common aims and objectives of rehabilitating SFR activities which must be defined and highlighted are:

- To improve dry season streamflow by managing streamflow reduction activities on small river systems that are often stressed during the dry season.
- To improve access to the flow of water (during both low and high flow seasons) to rivers and allow the natural infiltration process. Soil profiles for chronic contamination of residues, transformations products etc. must be taken into account before rehabilitation commences as it has the potential to impact how one rehabilitates (soil microbes, Nitrilotriacetic Acids (NTA's) etc.)
- To mitigate and/or reduce ground water contamination by managing pollution inputs into rivers. Groundwater contamination must also be taken into account with regards to CECs.

PHASE 4: Execution

Afforestation plants are usually also declared AIS as per the NEMBA AIS list of 2020. Therefore, below is a list of available methods of control:

- **Manual control** such as uprooting, felling, cutting, or burning;
- **Chemical** control with a registered herbicide under Act 36 of 1947, using the registered method and dosage for the species according to the label;
- **Biological control** carried out in accordance with the stipulations of the Agricultural Pests Act, 1983 (Act 36 of 1983), the Environment Conservation Act, 1989 (Act 73 of 1989) and any other applicable legislation.

Box 1 contains information to be considered for the application of the manual, chemical and biological methods for control for AIS.

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[4] *Dzitziki et al., (2016) gives an example of 490 000 ha of Eucalyptus species that were planted in the Berg River catchment for commercial purposes, however, studies showed an annual streamflow reduction of 217 million m3 directly linked to the Eucalyptus and Pinus species in the catchment, Sibanda (2023).*

Box 1

Summary:

- A combination of one or more methods recommended in the execution phase must be employed.
- AIS Monitoring, Control and Eradication Plans must be developed in terms of Sections (75(4) and (76) and submitted to the competent Authority in compliance with Section (10)(2)(b).
- Progress in weed control should be documented or photographed and reported to the competent authority in line with Section 10(3) of the AIS Monitoring, Control and Eradication Plans.
- Do not disturb biological control agents when they are effective with other control methods to the extent that the agents are destroyed or become ineffective. Biocontrol reserves should be demarcated and protected under CARA Section (15D) of 1983.
- Control options should form part of an ecological risk assessment[5].

PHASE 5: Monitoring, Evaluation and Reporting

Monitoring

Monitoring of areas must be undertaken to:

- Ensure that treatment methods are adequate and effective to ensure that no additional measures are required and comply with the conditions stipulated in the AIS Monitoring, Control and Eradication Plans Section (76).
- Allow learning from past practices, so that ongoing initiatives are constantly improving and are in accordance with applicable legislation.

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, location, and date.

Scenario 2: Control and Clearing of Alien Invasive Vegetation

PHASE 1: Diagnostic Phase

Step 1: Identify the areas infested by alien and invasive vegetation.

Step 2: Initiate communications with the responsible authorities (*i.e.,* local and district municipalities as well as DWS Regional Office) responsible for the catchment in which the affected resource is located.

Step 3: Utilize tools such as Google Earth/ Pro /Google Earth Engine/Sentinel, ensuring the use of high spatial resolution (<10 m) satellite imagery, GIS, and remote sensing to identify the areas affected.

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[5] *Ecological Risk Assessment (EcoRA) involves the assessment of the risks posed by the presence of substances released to the environment by man, in theory, on all living organisms in the variety of ecosystems which make up the environment.*

Step 4: Using information obtained from Google Earth satellite images and Remote Sensing, describe in detail areas identified that produce less runoff/inflow (or outflow). Consider including the following in the description:

- **Step 4.1:** Visual description of the areas affected, and a ground assessment of the areas affected.
- **Step 4.2:** Is the affected area at a catchment, sub-catchment, or quaternary scale?
- **Step 4.3:** Is the area affected at a localized non-localized scale?
- **Step 4.4:** Describe the extent of the infestation of the affected area.
- **Step 4.5:** Describe the conditions upstream or downstream of the affected area, including the CEC's.

Step 5: Based on all the above information acquired, make an informed decision in terms of the type and habitat types of AIS vegetation affecting your area of concern. Two habitat types of alien vegetation are dealt with, namely:

- Riparian and/or aquatic; and
- Landscape/terrestrial.

Other examples of known aquatic invasive species include floating macrophytes such as *Pontederia crassipes* (water hyacinth), *Pistia stratoites* (water Lettuce), and the newly emerging species, *Salvinia minima* (common salvinia) amongst others, and submerged species such as *Myriophyllum spicatum* (spiked water milfoil), *Egeria densa* (dense water weed) and *Vallisneria spiralis* (tapeweed) amongst others.

Landscape/Terrestrial invasive plants can further be categorized into the following growth forms, namely:

- Sprouting trees
- Non-sprouting trees
- Shrubs
- Cacti
- Herbaceous
- Grass
- Creepers
- Aquatic weeds

Terrestrial species that are priority aggressive alien invasive invaders include the following, *Prosopis vellutina* (honey mesquite), *Grevillea robusta* (silky oak), *Lantana camara* (lantana), *Opuntia stricta* (Australian pest pear), *Parthenium histerophorus (*fevwerfew), *Arundo donax* (giant Spanish reed), and *Andera baselloides* (madeira vine) amongst others.

PHASE 2: Planning and Assessment

Below is a summarised list of steps to be followed during the planning and assessment phase of alien and invasive vegetation clearing[6,7]:

- Identify priority alien and invasive plant species for control.
- Identify sensitive indigenous vegetation that should be protected during alien and invasive plant clearing operations.

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[6] *Water Research Commission (WRC). 2016. The Development of a Comprehensive Manual for River Rehabilitation in South Africa.*
[7] *DFFE: EP.2021. Environmental Programmes Pesticide Policy and Pesticides Toolkit.*

- Mark individual trees or stands of vegetation to guide workers on-site during alien and invasive plant clearing and prevent accidental environmental contamination. Danger tape or paint markings can be used for marking or utilising mapping tools such as ArcGIS for mapping and monitoring.
- Identify areas that should be protected from disturbance activities (e.g., fynbos renosterveld and biocontrol reserves)
- Identify the most appropriate clearing method or combination of methods hat take account of the species requiring control, the specific conditions of the site, ecotoxicity, environmental fate, and human health impacts of the herbicide, and the circumstances of the landowner. Consult the DFFE: Environmental Programme (EP) Pesticide Policy and toolkit.
- Identify and obtain the necessary field and personal protective equipment (PPE) for the selected clearing method(s) according to the mode of action of the herbicide and exposure risk utilising the appropriate PPE matrix, including the most appropriate herbicides. (DFFE, 2022),
- Identify training needs for clearing workers and supervisors (e.g., herbicide application, use of chain saws, etc.)
- Identify approaches and areas for the disposal of cleared plant material, dependent on the hazardous waste classification of the material.
- Consult the DFFE EP Pesticide Policy and Pesticide Toolkit for the decision support tool to ensure environmental contamination and chronic human health exposure and risks are mitigated or at the least, lessened.
- Prepare an accurate estimate of the financial costs of clearing and ensure that there are sufficient funds to achieve a successful outcome.

PHASE 3: Identify and define the Rehabilitation Objectives

The objectives of rehabilitation of alien and invasive vegetation must be defined and be clear at the start. These objectives must be informed by the information and data collated in **Phases 1 and 2** above. Below is a list of common aims and objectives[8]:

- To create space in which to address bank erosion by managing eroding banks and sites and reaches where down-cutting or incising occurs in compliance with 11(1)(n)(ii) of NEM: BA.
- To increase space for flood alleviation by clearing alien and invasive vegetation to improve the conveyance or the natural flow of water, noting restricted activities compliance with Section (65)(1) and environmental authorisations under Section (24) of NEMA.
- To rehabilitate a more natural river flow regime by releasing trapped sediments and allowing erosion processes to restore natural river levels.
- To prevent erosion as a result of channel confinement and bank undercutting.
- To improve biodiversity by allowing the establishment/generation of natural indigenous riverine flora.
- To revitalise the natural disturbance regime of a river and allow natural erosion of sediments that would otherwise accumulate against encroaching alien and invasive plants.

PHASE 4: Execution:

Alien and invasive vegetation control methods are divided into three main categories; control options, namely manual (or mechanical) control, chemical control, and biocontrol, as illustrated in **Figure 11**. Integrated control methods or integrated plant species management (IPM) is the most effective method in various combinations, depending on the AIS, landscape, and bioregion. The DFFE Pesticide

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[8] *WRC. 2016. The Development of a Comprehensive Manual for River Rehabilitation in South Africa.*

Policy and associated EP species and pesticide list, 2021[9], with the pesticide toolkit and decision support tool, provides all the information needed, from the species, control methods, and herbicides to ecotoxicity, environmental fate, human health exposure and risks, hazard criteria and acute and chronic toxicities. These three methods have been prescribed and comprehensively covered in the River Rehabilitation Guidelines/Manual developed by WRC[10] and adapted to align with the methods under NEM: BA and the EP Pesticides Policy. These methods must be supported by a Plant Species Plan developed by a landscape architect or botanist.

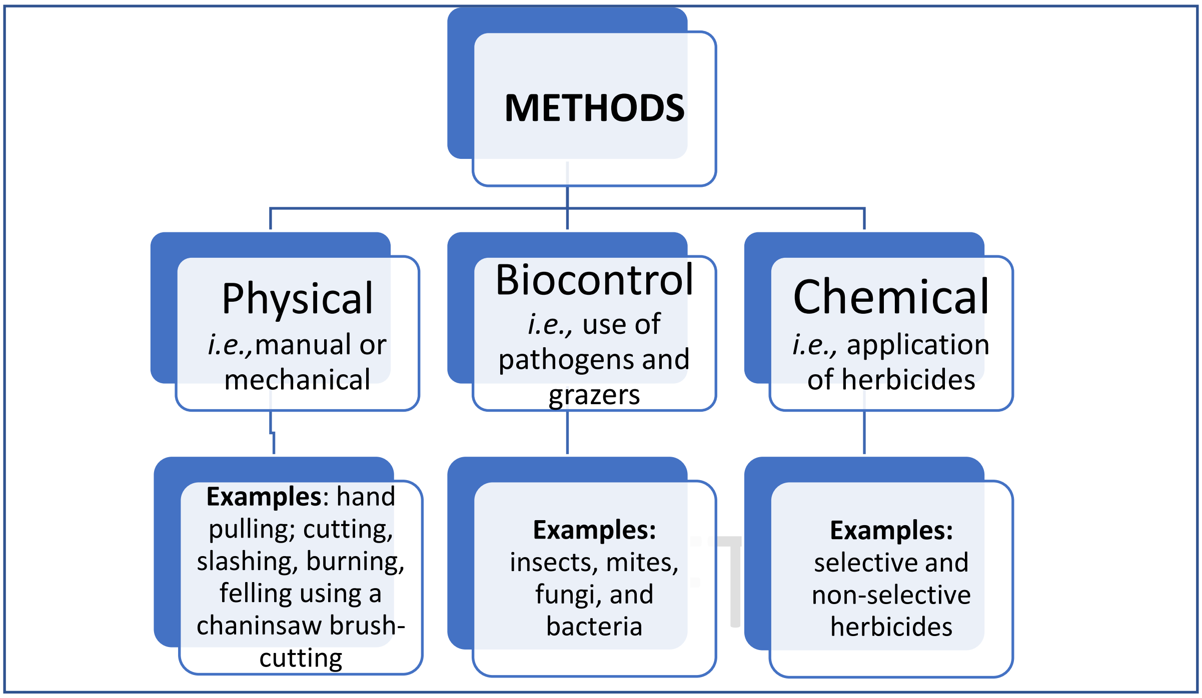

Figure 11: Alien vegetation clearing and control methods adapted to align to NEM: BA and the EP Pesticides Policy

Sources: WRC, 2016; DFFE, 2021

Note:

The chemical control method, which entails the application of herbicides, should be carried out in accordance with the stipulations of the Fertilisers, Farm Feeds, Agricultural Remedies and Stock Remedies Act, 1947 (Act 36 of 1947).

Box 2 contains information on other known methods that should be considered for the clearing and control of alien vegetation.

[9] *DFFE: EP, 2021. Environmental Programmes Pesticide Policy for the Control of AIS and associated documents.*
[10] *WRC. 2016. The Development of a Comprehensive Manual for River Rehabilitation in South Africa.*

Box 2

Cultural Control Methods focus on altering the environmental conditions to discourage the growth and spread of invasive plants, *i.e.,* altering water levels, modifying soil conditions, implementing proper land management practices, or promoting the growth of native plant species to outcompete invasives.

Preventive Measures include early detection and rapid response to new infestations, implementing strict biosecurity measures to prevent the introduction and spread of invasive plants, and promoting awareness and education about the risks associated with invasive species.

PHASE 5: Monitoring, Evaluation and Reporting

Monitoring

Monitoring of rehabilitated areas must be undertaken to:

- Ensure that treatment methods are adequate and effective to ensure that no additional measures are required.
- Allow learning from past practices so that ongoing alien and invasive plant-clearing initiatives are constantly improving and are in accordance with seasonal changes.

The following monitoring suggestions are recommended by WRC[11]:

- A fixed-point photographic record should be compiled, showing the river in its affected reaches before, during and at regular time periods after initial alien and invasive clearing has taken place. The internals will depend on the herbicide's mode of action, the time taken to control the AIS and the time taken for regrowth to appear.
- Historical Google Earth images should be used over time to provide a spatial record of the extent and effects of alien and invasive clearing.
- Records should be kept of the time and costs required for each alien and invasive clearing intervention, and the approximate volume and life stage (*e.g.,* seedling or mature plant) of the bulk of material removed on each occasion. Restricted activities as defined by NEM: BA includes 'The conveying, moving/removing or otherwise translocating any specimen of a listed invasive species' as PROHIBITED for category 1a and 1b species'. This information will allow quantifying of the costs of alien and invasive control, show landscape changes resulting from alien and invasive removal and potentially inform decisions that are required around changes in clearing frequency, area, or approach.
- The use of remote sensing and GIS as tools for monitoring the effectiveness of the treatment methods employed.

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

[11] *WRC. 2016. The Development of a Comprehensive Manual for River Rehabilitation in South Africa.*

- Before and after photos of rehabilitation including a significant landmark for comparison purposes, with a brief description including location, and date.

5.1.6 Special considerations to be applied for Rehabilitation of areas affected by Alien and Invasive Vegetation

Alien and invasive vegetation must be replaced with the appropriate indigenous vegetation to enable ecological functionality and reinstate ecosystem services. Rehabilitation and revegetation of the area in question must be done in the most appropriate way using best management practices (BMPs) according to Section 75(1) of the AIS Monitoring, Control and Eradication Plans. Furthermore, alien management must be implemented in a phased approach to include both eradication and revegetation. Bantol *et al.* (2020) emphasised that consideration must be given to soil contamination remediation, especially where chronic toxicity herbicides were used that are persistent and residual in soil, and these pesticides can migrate into water and have serious impacts on vulnerable communities such as children, immunodeficient individuals and the elderly.

5.2 GEOMORPHOLOGY

5.2.1 Description

Geomorphology is a science focused on understanding earth surface processes and landscape evolution (Keller *et.al.,* 2020*)*. Geomorphological understanding is central to environmental flows because it is the interaction between flow, form, and substrate that influences habitat type, condition, availability and biotic use across space and time (Meitzen *et. al.,* 2013). The sub-discipline of geomorphology that specifically deals with landforms related to processes of erosion and deposition by flowing water is called fluvial geomorphology. It focuses on river channels and their associated riparian zones, as well as the catchment that generates the runoff, sediment and other materials transported by the river (WRC, 2013).

According to Guano (2021), fluvial geomorphology is one of the principal landscapes of the world, and its processes greatly influence landscape modification. The long-term geomorphological evolution of rivers is strictly controlled by the interplay of tectonic activity and climate changes, and close to coastal zones, sea-level oscillations also contribute to modifying this natural system, as well as anthropogenic activities, which also contribute to the modification of river ecosystems (**Figure 12**).

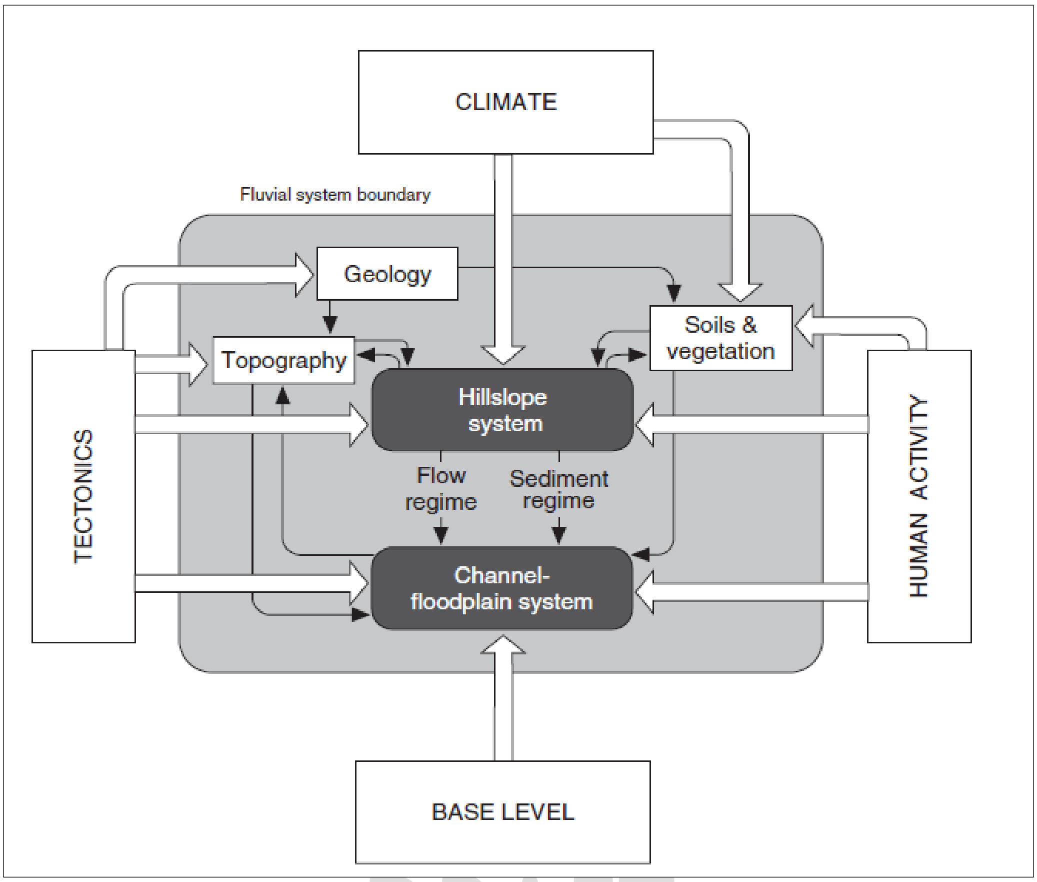

Figure 12: Simplified representation of the fluvial system and human interference
Source: Charlton, 2008

Where moderate to rapid flow predominates, rivers erode, deposit silt and organic particles in areas of slow current, and their channel features are constantly altering in relation to discharge, width, depth, substrata, and sediment transport (Wetzel, 2001). It is, therefore, very important to note that fluvial geomorphology is a critical aspect that needs to be considered when doing river rehabilitation. It is important to note that the areas of sediment loading, and deposition will have higher concentrations of contact pesticides, transformation products and metabolites while the hydrophobic pesticides, transformation products and metabolites, will be in the water column (Gilliom *et al.,* 2007). **Table 4** provides some of the common geomorphological characteristics of rivers.

Table 4: Geomorphological Characteristics of Rivers
Source: adapted from Wetzel, 2001

Properties	Characteristics
Drainage basins	Many small tributaries coalesce into trunk stream; and drainage area are high in relation to surface area
Shape	Long, meandering, and linear river elongate as drainage basins increase in size
Mean depth	Shallow in headwaters and increases to mouth
Depth gradient	Increases from headwaters to mouth
Shoreline erosion and substrata distribution	Extensive, induced by water currents and gravity driven
Shoreline development	Great and astatic
Sediment loading	High with large drainage basin area
Deposition of sediments	Determined by water current; and highly variable with precipitation events
Sediment suspended in water	High and variable

5.2.2 Factors Influencing Fluvial Geomorphology

Scale is an important consideration in fluvial geomorphology, with process-form interactions occurring over a huge range of space (spatial scale) and time (temporal scale) (Charlton, 2008). Therefore, it is important to note that the change along a river channel and river system does not happen at once. As such, rivers and streams continuously shape and reform their channel through erosion of their bed and banks. Riverbed and bank erosion are a major environmental problem that is associated with fluvial geomorphology. Such that, once the topsoil has been removed, the lower soil layers are exposed. These layers have poor structure and are low in organic matter and nutrients, as a result they are less permeable leading to increased overland flows which increases the sedimentation supplied to rivers (Freeman and Rowntree, 2005). Sediment depositions reduce the depth and lead to the formation of channel bars.

Human interventions on the other hand have had an influence on modification of river systems for many years. Anthropogenic activities can lead to events such as scouring or channel bed incision. Activities such as scouring of the channel bed deepens the channel, therefore channel engineering, deforestation, alien and invasive vegetation clearing, agriculture, and mining activities affects the flow of water and pesticide transformation products accumulate in bed-sediment (Gilliom *et al.,* 2007) and affect the production of sediment. See the note below for consideration in terms of sediment management for ecological function improvement.

Note: *Instream dam construction on rivers intercepts sediments and causes reduced sediment supply/discharge into rivers.*

The watercourses are interrelated and therefore a systems approach is followed in the development of the scenario for management of sedimentation in rivers.

5.2.3 Rehabilitation Management Guidelines for Geomorphology

Scenario 1: Rehabilitation of deteriorated culverts to manage upstream floods and promote free flows.

Culvert rehabilitation can be described as the practice of extending or restoring the service life of a culvert without the removal of the existing culvert. The culvert rehabilitation process involves a number of steps starting with problem identification (**diagnostic**), causes of deterioration, impacts, and evaluation of stream conditions (**assessment**) and ending with maintenance (**monitoring**) after rehabilitation. Culvert deterioration results from many causes, such as improperly designed (loading exceeding the design capacity) or poorly maintained culverts (leading to increased soil elevation), which poses a serious threat to fish by disrupting their habitat and endangering spawning success and may be problematic for migratory species, which may lead to fragmentation of resident populations, as well as lead to flash floods due to clogged culverts.

The following steps can be used to rehabilitate deteriorated culverts and should be complemented by other available nature-based solutions to reinstate ecological functions:

Phase 1: Diagnostic Phase

Step 1: The first and most important step is to develop a vision and realistic goal for rehabilitating that specific river before setting specific/precise objectives and undertaking any planning or assessment work. This must be done in consultation with all the affected parties such as local and district municipalities.

For example, a vision may be developed as follows: to restore river x to its pre-impact dynamic equilibrium state, or to rehabilitate all the poorly designed culverts as well as to maintain all culverts along river x to allow water to flow unobstructed and to prevent flooding. Whereas a goal may be set as follows: To improve the instream and riparian biodiversity within the stream corridor and to make it a safe, attractive, and indigenous recreational green belt[12].
It is also important before starting out to determine what the ecological condition of the water is and coupled with human and natural systems status quo assessment to ensure that the rehabilitation measures planned do not negatively impact the ecological condition.

Step 2: Initiate communications with the responsible authorities (*i.e.,* local and district municipalities as well as DWS Regional Office) responsible for the catchment in which the resource affected is located.

Step 3: Choose a site that has more than one poorly designed or maintained culvert using tools such as Google Earth, existing maps, and ground truthing.

Phase 2: Planning and Assessment

Step 1: Map all culverts identified along the channel. A Specialist with an understanding of geomorphology needs to be present to describe the natural (or pre-impact) state. The estimated water velocity needs to be included as part of the description. Makris *et. al.* (2012) in their study applied Manning's formula (Equation 1) to estimate the water velocity.

$$V = \left(\frac{1}{n}\right) R^{2/3} S^{1/2} \qquad \textbf{(1)}$$[13]

Step 2: Channel classification - channel classification is important as it assists with understanding the connection between the individual characteristics and the common features of different rivers. One of the recommended tools for classifying channels is the Geomorphology Driver Index Assessment (GAI), developed by WRC, 2013. The GAI is a rule-based model used to assess geomorphic Ecological Category (EC).

Step 3: Describe the river conditions including the features that have not changed from the natural conditions, and assess all impacts and problems associated with degradation. This exercise informs areas that needs to be prioritised (Focus Areas) in the river. Once problems have been identified, the next step is to categorise them according to their priorities. Priorities can be categorised into classes from low priority (such as nuisance problems which have a minor effect on the biotic community) to high priority (such as damages to low water bridges due to blocked culverts and fatal problems which may include removing of fauna and flora from a reach).

Phase 3: Identify and define the Rehabilitation Objectives

The objectives of rehabilitation must be informed by the vision and goal, as well as data collected during the assessment phase. This process must include conditions and prioritisation of

[12] *WRC. 2004. A River Rehabilitation Planning Pilot Trial: The Ihlanza River, East London, South Africa. Based on the Australian River Rehabilitation Guidelines*

[13] *Where, V is the average discharge velocity (m/s); n is the roughness coefficient of the culvert material; R is the average of the hydraulic radius [cross-sectional area of flow divided by a wetted parameter (m)]; S is the channel bed slope (m/m) and the outlet perch was the elevation of the culvert outlet minus the elevation downstream.*

areas/segments of the river as identified in the assessment phase. The most common objectives may include: the prevention of degradation, improvement of waterways/environment, or/and fixing the present problems (as identified in the assessment phase). Each prioritized area may have its distinct objective, based on any of these categories: Ecological, Infrastructural, social, or recreational.

The identified objectives must be checked to determine if they are feasible and affordable, and a reasonable timeframe must be set to allow the river to respond to the rehabilitation actions. For instance, WRC (2004) adopted Rutherfurd *et. al*.'s (2000) method of setting a timeframe: a short-term objective for the completion of the rehabilitation output and a long-term objective for evaluation of the effect of the work.

Phase 4: Execution

This step involves providing detailed designs for the structure to be built or actions to be taken. It is important to determine the level of deterioration the culvert has sustained. Thereafter, decide whether to repair, rehabilitate or replace the culvert taking into consideration the cost involved and level of problems to be addressed. **Figure 13** presents some of the standard methods to use when undertaking the rehabilitation of culverts.

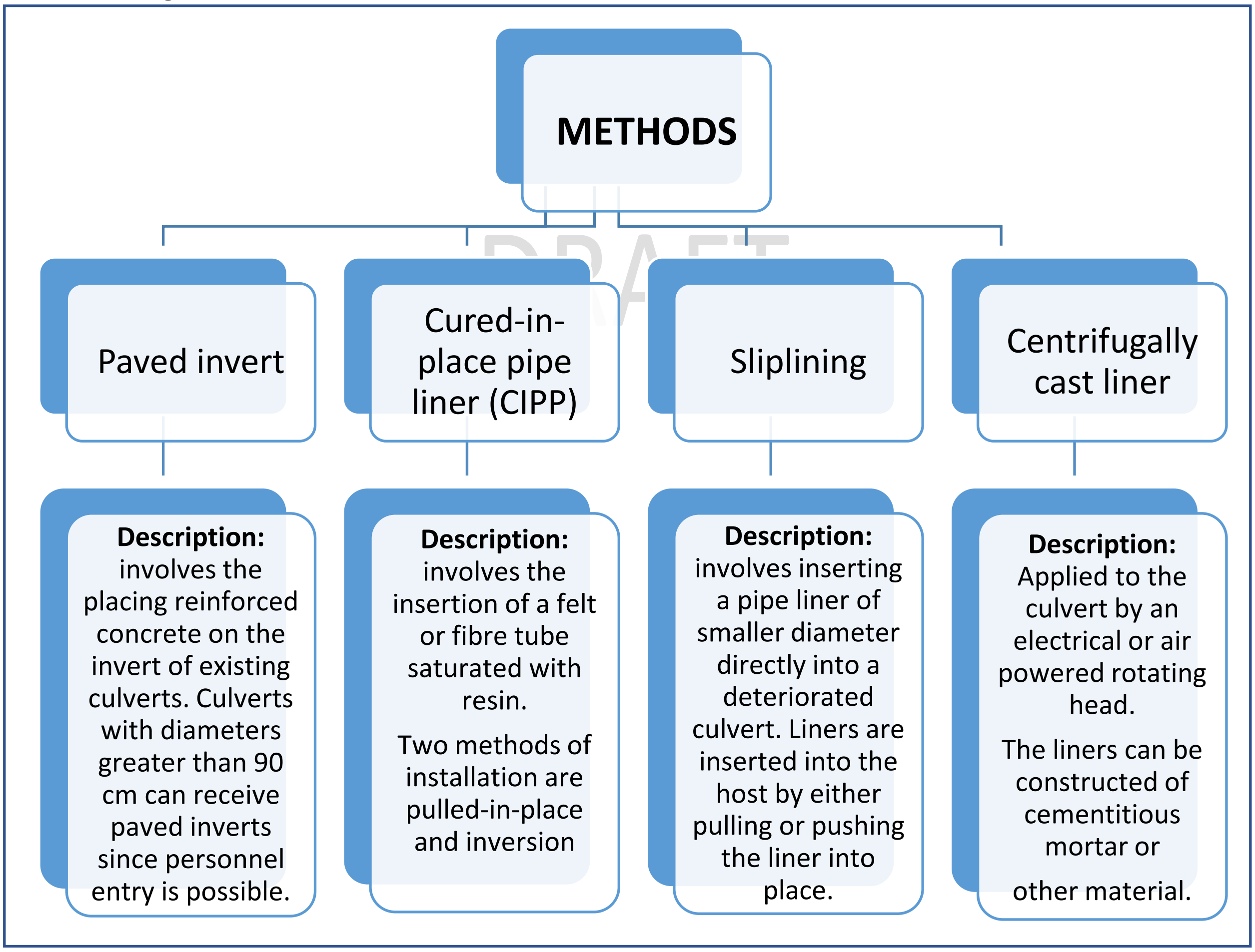

Figure 13: Methods used for the rehabilitation of culverts
Source: Bruce and Leagjeld, 2014

In addition, it is important for effective environmental management that the applicant /developer is aware of the general principles upon which sound environmental management is based and that these principles are considered in all aspects before the commencement of the activity. NEMA's general framework for environmental management principles has been summarised in SANRAL[14].

Phase 5: Monitoring, Evaluation and Reporting

Monitoring

It is required that there be routine and systematic inspection of the culverts and the flow of the stream using the established condition assessment rating to determine whether the conditions are degrading; and if the original priorities need to be modified.

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.

Scenario 2: Rehabilitation of changed and incised watercourses to facilitate natural processes.

PHASE 1: Diagnostic Phase:

Step 1: Identify the areas within the watercourse channel that are incised or impacted by erosion.

Step 2: Initiate communications with the responsible authorities (*i.e.,* local and district municipality as well as DWS Regional Office) responsible for the catchment in which the resource affected is located.

Step 3: Utilize tools such as Google Earth/ Pro /Google Earth Engine/Sentinel, ensuring the use of high spatial resolution (<10 m) satellite imagery, GIS, and remote sensing to identify the areas impacted by erosion and their extent. Soil erosion mapping can also be undertaken to ascertain the extent of the impacted areas.

Step 4: Using Remote Sensing, describe in detail the areas *(i.e.,* within the watercourse channel) impacted and the type of erosion impacts observed. Some of the examples of erosion that might be prevalent:

- Sheet or interrill erosion
- Rill erosion
- Gully erosion
- Tunnel erosion
- Stream channel/bank erosion

PHASE 2: Planning and Assessment

[14] *South African National Roads Agency SOC Limited (SANRAL). 2021. The Upgrading of National Route 1 Section 17 Between Westleigh (KM 77.8) and Heuningspruit (KM 101.6). Final Basic Assessment Report. DFFE Reference-14-12-16-3-3-1-2312*

Step 1: Conduct a ground-truthing survey to accurately identify the factors causing erosion impacts on the identified areas. Some of the common factors are as follows:

- Rainfall erosivity.
- Soil erodibility.
- Topography.
- Vegetation cover.

Step 2: Map and delineate the areas impacted and clearly show the extent of the areas impacted.

Step 3: Describe in detail the factors causing erosion and the type of erosion that is prevalent. This information is important and will inform the rehabilitation methods or techniques to be employed.

PHASE 3: Identify and define the Rehabilitation Objectives

The objectives of rehabilitation of incised or eroded river channels must be clear from onset. These objectives must be informed by the information and data collated in **Phases 1 and 2** above. In general, some of the common aims and objectives of rehabilitating incised or eroded rivers include:

- To enhance the stability of the river and improve flow of water within the river channels.
- To improve support and other life forms that belong in the habitat and enhance the biodiversity status of the general river environment.

PHASE 4: Execution

Step 1: Identify and employ the appropriate rehabilitation methods or techniques based on the site-specific **<u>extent</u>** of erosion, **<u>type</u>** of erosion and **<u>factors</u>** contributing to the impacted areas

Step 2: Employ one or a combination of the available **direct** and **indirect methods (Table 5)** and techniques available for rehabilitation:

Table 5: Direct and indirect methods and techniques for rehabilitation of erosion.

Direct Method (Addressing erosion where the intervention is slightly remote from the site of the problem)	**Indirect Method** where the problem is addressed indirectly (*i.e.,* something covers the soil to prevent it from eroding).
1. Bank stabilization using the below groyne structures to reduce flow velocities: ○ permeable groyne ○ solid groyne, ○ micro-groynes ○ Iowa vanes groyne	1. Bank Reshaping: ○ landscaping and re-vegetation
	2. Bank shaping and armouring ○ coir or geo-filter rolls
	3. Bank shaping and armouring ○ flexible concrete block mats
	4. Bank stabilization ○ riprap (rock)
	5. Bank stabilization with below longitudinal river training structures ○ logs and tree stumps ○ green gabions ○ rock gabions ○ concrete block retaining walls, ○ used-tyre retaining walls, reinforced concrete retaining walls

Step 3: The above methods/techniques must be designed and constructed according to the approved

engineering standards.

PHASE 5: Monitoring, Evaluation and Reporting

Monitoring
Undertake routine and systematic inspection of the rehabilitated areas to determine whether the flow and habitat conditions are improving or further degrading. Additional management measures must be implemented in the event the conditions do not improve.

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.

5.3 WATER QUALITY

5.3.1 Description

Water quality is a concept that refers to the condition of water using various parameters such as chemical, physical, and biological (Giri and Qiu, 2016; Camara *et al.*, 2019). These parameters indicate levels that pose no risk to humans and/or impose restrictions or limitations on the use of water, depending on the purpose of the water usage. Accordingly, there are various criteria for water quality standards such as safety for human consumption, agricultural usage, fishery, recreational, and sustainability of natural aquatic ecosystems.

5.3.2 Types of Water Quality Impacts

Water quality is influenced by several factors depicted on **Figure 14,** which include precipitation (rainfall), climate, type of soil, geology, vegetation, groundwater, flow conditions, and anthropogenic activities (Charalampous *et al*., 2015).

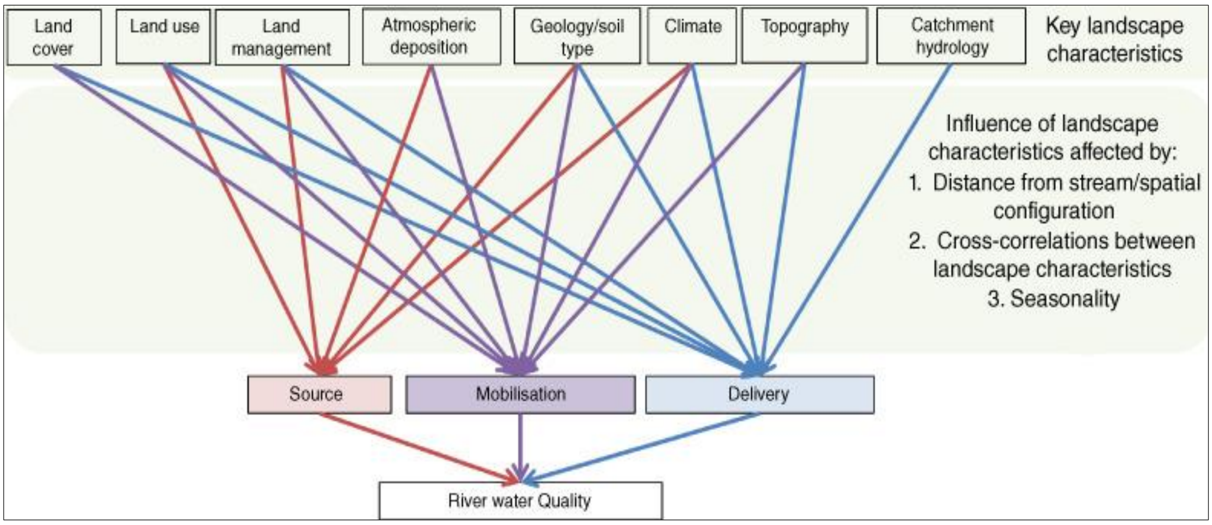

Figure 14: Key landscape characteristics affecting water quality
Source: Lintern, 2017

Water quality is affected by both **point-source** and **non-point source pollution. Point sources** of pollution are directly discharged to receiving water resources at a discrete location, such as pipes and ditches from WWTWs[15], industrial sites and confined intensive livestock operations. **Non-point source/diffuse sources** of pollution are indirectly discharged to receiving water resources, via overland and subsurface flow and atmospheric deposition to surface waters and leaching through the soil structure to groundwater during periods of rainfall and irrigation (Reese, 2020).

The biggest threat to water quality is posed by point source pollution from industries and wastewater treatment plants (Herbig and Meissner, 2019). Inadequately treated effluent from wastewater treatment plants poses a health risk to humans (Manickum and John, 2014). In South Africa, this is a very serious problem that should be emphasised more. Activities such as mining, contributing to AMD, as well as urban development also have an impact on water quality (Manders *et al.,* 2009). Furthermore, AMD causes a reduction in water resource pH, which increases the availability of dissolved metals for uptake by benthic organisms and fish (Dhir, 2018). This in turn, becomes a major pathway for their introduction into the human food chain. Non-point sources of pollution, on the other hand involve pollution that originates from runoff over a relatively large area. Diffuse pollution sources can be divided into source activities related to either land or water use, including nutrients (mainly nitrogen and phosphorus from sources like pesticides and fertilizers through agricultural runoff), sediments and toxic contaminants such as pesticide residue, metabolites, and their transformation products (Volk *et al*., 2016; Islam *et al*., 2018). Contaminants of Emerging Concern (CECs) emanating from agricultural runoff which also includes contaminants and pathogens of emerging concern; Emerging pathogens and/or CECs, including endocrine disruptors emanating from pharmaceutical industries, enter the systems from WWTWs and contribute to accumulative impacts on human and ecological health.

[15] ***Faecal sludge*** *is another common source of point-source pollution that emanates from on-site sanitation systems (i.e., ventilated, and non-ventilated improved pit latrines, conservancy tanks, septic tanks, chemical toilets, and flush bucket toilet) and introduce nutrients and harmful microbes in water resources. A scenario is developed in* ***Section 5.3.3*** *dealing with the management of faecal sludge.*

Another concern is the change in temperature due to the confluence between rivers causing water to become warm and hold less Dissolved Oxygen (DO) which is not enough to sustain the survival of aquatic species. Water bodies receive oxygen from the atmosphere and from aquatic plants. There are also several pesticide pollutants and chemicals that are of concern to river ecology in South Africa.

5.3.3 Rehabilitation Management Guidelines for Water Quality

Scenario 1: Improvement of poor water quality attributed to effluent discharge from WWTWs and Industries into Rivers.

PHASE 1: Diagnostic Phase

Step 1: Undertake a desktop assessment to identify the WWTWs & industries whose effluent may negatively impact the water quality of the rivers (*i.e.,* facilities situated as far away as 5km-10km away from a rivers).

Step 2: Initiate communications with the responsible authorities (*i.e.,* local and district municipalities as well as DWS Regional Office) responsible for the catchment in which the resource affected is located.

Step 2: Request historical water quality data and/or incident reports from relevant authorities (for water quality trends and patterns)

Step 3: Utilize tools such as Google Earth/ Pro /Google Earth Engine/Sentinel, ensuring the use of high spatial resolution (<10 m) satellite imagery, GIS, and remote sensing to pinpoint changes in land use (land-based catchment pollution that could be associated with changes in the quality of water)

Step 4: Conduct ground truthing to identify visible signs of water quality changes such as extremely foul odour, turbidity, dead fish, and loss of biodiversity in the rivers.

Step 5: In undertaking the diagnostic assessment of the facility, consideration must be given to the below factors that tend to exacerbate the poor water quality:

- The overall integrity and functioning of the WWTWs and industrial facilities;
- Challenges associated with power cuts and failures; and
- Land-based activities and the overall management of the catchment.

  Note: *Malfunctioning sewage pump stations and associated infrastructure may form part of direct pollutants to the watercourse and should be addressed as part of overall catchment management of pollution.*

PHASE 2: Planning and Assessment

Planning Phase

Step 1: Request local government officials (municipal as well as Provincial DWS/CMAs and DFFE Offices) and local NGOs and community forums responsible for assisting with identifying point sources of pollution to guide on available regulatory processes.

Step 2: Investigate other sources of pollution and poor water quality *e.g.,* non-point sources of pollution.

Assessment Phase

Step1: Undertake the following:

- Analysis of the historical data (water quality) to see the trend and reference point.
- Collect the final effluent water samples from the sources, *i.e.,* WWTW & industrial facility.
- Collect monthly water quality samples from the resource *i.e.,* River:

- 1 upstream of the WWTW and industrial facility discharge points.
- 1 downstream of the WWTW and industrial facility discharge points.

o Have samples analysed at an accredited laboratory to determine the water quality at the sources and resources, respectively.

Step 2: Undertake the following:

o Compare laboratory-generated water quality data to the expected state for the identification of areas of concern.

o Data analysis should be compared against the RQOs or Resource Water Quality Objectives (RWQOs), or Aquatic Ecosystem Water Quality Standards if RQOs/RWQOs have not yet been established for that catchment.

PHASE 3: **Identify and define the Rehabilitation Objectives**

Define clear rehabilitation objectives based on information and data gathered from **Phases 1** and **2.** Common objectives are to manage and prevent poor effluent from WWTWs and industrial facilities from discharging into water resources *i.e.,* rivers.

PHASE 4: Execution

The following steps must be followed by practitioners for the rehabilitation of water quality activities:

Step 1: Implement environmentally sustainable solutions through stakeholder engagements, communication within the water sector and between government departments sector, and between DFFE and other relevant government departments.

Step 2: Undertake the following:

o Ensure treatment of effluent from point sources prior to discharge;

o Effluent which does not meet the discharge standards should be temporarily stored for further intervention and/or treatment; and

o Monitor the effluent before discharge to ensure that it is in accordance with the DWS Special Effluent Standards.

Step 3: Undertake the following:

o Implement surface water management around the WWTWs and industrial facilities;

o Install cut-off trenches around the facilities to separate clean and dirty water and direct clean water back into natural drainage lines and the natural environment; and

o The dirty water channels should be drained to an emergency holding dam for treatment.

Step 4: Construct temporary berms along the rivers to prevent further offsite migration/discharge of effluent ending into the river.

The primary response however should be to improve the efficacy and capacity of the WWTWs, to avoid future substandard discharges.

Box 3 contains information on other known methods that should be considered for poor water quality associate with effluent discharge from WWTW.

Box 3

Complement the treatment at WWTWs running at capacity or having treatment challenges with floating treatment wetlands, constructed wetlands, microbial treatment, and algae as phytoremediation to be integrated upon feasibility investigation.

Note:

In general, the approach of DWS to water quality management is to promote the reduction of discharges of waste or water-containing waste directly into water resources. Where waste discharges are unavoidable, the impact on other users, water resources and the public are controlled by specifying the permissible levels and concentrations of the constituents of the discharge in the conditions of the authorisation.

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 responsible for remedying its effects. However, Catchment Management Agencies may, where necessary, accelerate the clean-up process by arranging for the work to be done by others and recovering any costs incurred by the responsible party. At present, all pollution incidents must be reported to the DWS so that appropriate responses can be co-ordinated, in conjunction with the National Disaster Management Centre and the relevant emergency services and disaster management centres. Ultimately this responsibility will be passed on to the catchment management agencies.

PHASE 5: Monitoring, Evaluation and Reporting

Monitoring
Step 1:

- Undertake monthly water quality monitoring in the rivers depending on the volume discharge, local municipal by-laws, and the type of permit allowed;
- Continuously assess WWTWs and industrial facilities to assist with defining the quality of the water and extend to which treatment is required (records of up to a year are desirable to characterise the state of the facilities).

Step 2:

Monitoring parameters for WWTWs:
- Nutrients (phosphorus and nitrogen), and bacteria (*E.coli* or *coliforms*).

Monitoring parameters for industries:
- Metal concentrations and distributions at least once every 3-5 years for industrial facilities;
- Metal concentrations in tissues of fish/mussels (bio-accumulation) at least once every 3-5 years.

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

Note: *The expected outcomes of monitoring and evaluation can be achieved through the use of available knowledge hubs on emerging pathogens and/or CECs emanating from pharmaceutical industries, agricultural runoff, WWTWs, etc. Pesticide residues, transformation products and endocrine disruptors in rivers should be considered for monitoring, where applicable. The outputs of monitoring should be reported to the relevant international frameworks i.e., SDGs, GBF.*

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.

Scenario 2: ***Faecal Sludge Management***

Background on Faecal and Sewage Sludge Management.

Approximately 3 billion people globally rely on on-site sanitation systems (Strande *et al.,* 2014). This number is growing exponentially owing to rapid urbanisation occurring across the globe and is expected to reach 5.5 billion people by 2030 (DWS, 2021). Almost 61% of households in South Africa have access to sewer networks, with 36% dependent on **on-site sanitation systems,** mainly septic tanks, ventilated improved pit latrines (VIPs) and 4% practising open defecation (WRC, 2020). However, 10% of households (507 732) served by on-site sanitation technologies have full pits (STATS SA, 2019) – which could lead to people resorting to open defecation.

The challenges experienced in the sanitation sector have shown that waterborne sanitation (sewerage) and wastewater treatment are not sustainable due to factors such as water shortages, technical capacity gaps, low billing and collection rates, and the lack of resources to adequately maintain these systems. The conventional sewer networks and wastewater treatment facilities cannot keep up with rapid urbanisation and population growth. As an example, in the Msunduzi Municipality (Pietermaritzburg), the incidence of serious sewage pollution (defined as more than 10 000 *E. coli* per 100 ml) detected in weekly stream and river monitoring samples is now five times more prevalent than it was 25 years ago, the average incidence having moved from 10% to over 50% (DWS, 2021).

Characteristic of faecal and sewage sludge

Faecal sludge (FS) can be defined as a mixture of human excreta, water, urine, and solid wastes (*i.e.,* toilet paper or other cleansing and hygiene materials) that are disposed of in on-site sanitation systems such as ventilated and non-ventilated improved pit latrines, conservancy tanks, septic tanks, chemical toilets, and flush bucket toilet (DWS, 2021). The management of human excreta from on-site systems, excluding package plants along the sanitation value chain includes containment, collection, transportation, treatment, safe disposal, or reuse (DWS, 2023).

Sewage sludge is defined as a product of the wastewater treatment process where the liquids and solids are separated. The solids are then treated physically and chemically to produce a semi-solid and nutrient-rich product known as biosolids (US EPA, 2020). The raw sewage goes through this treatment process, separating the solids and liquids before the cleaned effluent is discharged into water bodies such as the sea, streams, and estuaries (Pöykiö *et al.,* 2019).

Faecal Sludge differs from other sludges, which are products of the wastewater treatment process *i.e.,* **wastewater sludge**. Faecal Sludge might contain solid objects like stones, wood, plastics, baby diapers, paper, or even solid waste where pits are used as rubbish pits. Where FS is collected in industrial areas, it may contain contaminants, such as heavy metals or fats/oils (Singh *et al.,* 2017).

The WWTW processes play an important part and vary from plant to plant. Therefore, the impact of FS on a WWTW depends on:

- WWTW process and technology;
- WWTW capacity in relation to FS quantity (in some cases, it is insignificant);
- The type of FS and mode of transport; and
- Effluent quality criteria.

Two types or routes of sludge generation are illustrated in **Figure 15** below as follows:

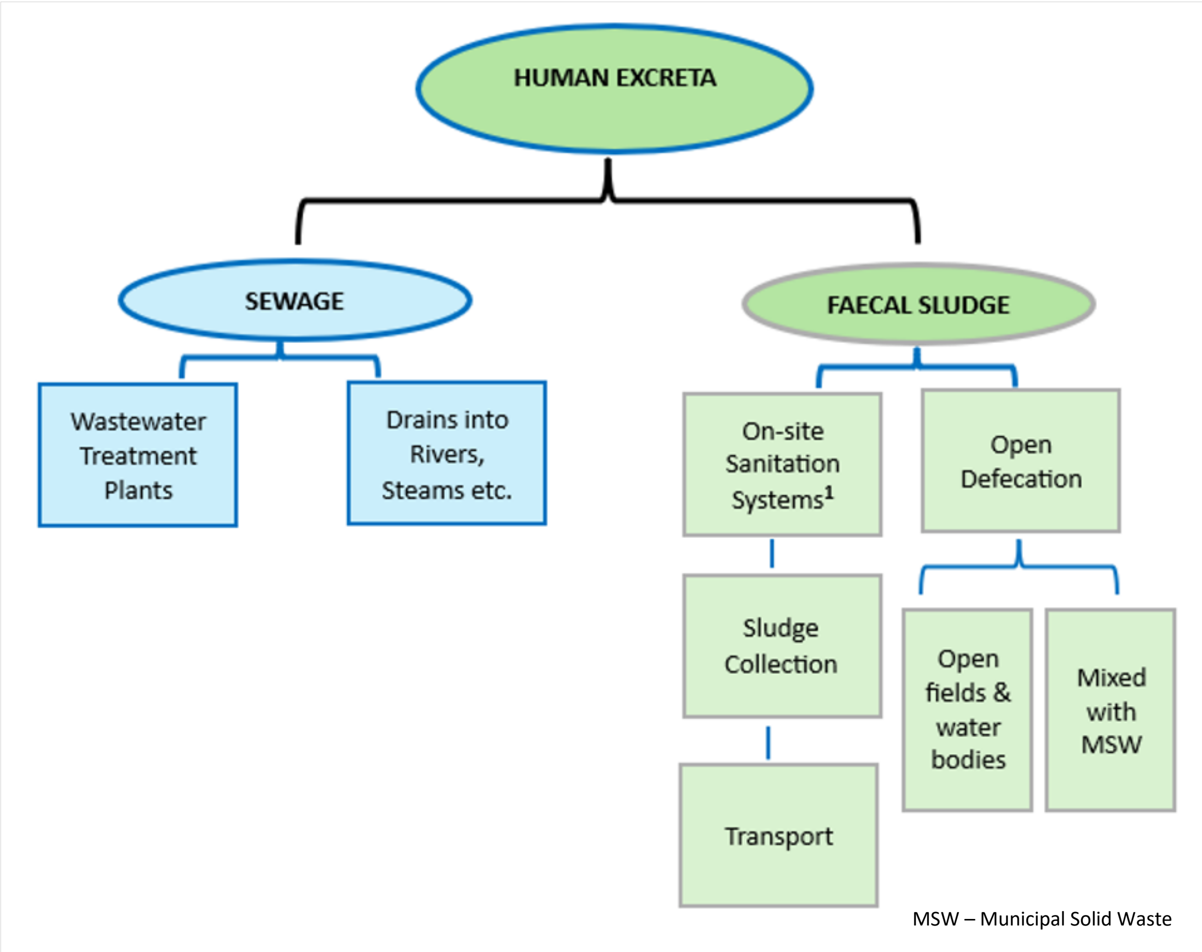

Figure 15: Routes of sludge generation
Source: modified after EAI, 2024

On-site sanitation needs to be safely managed throughout the faecal sludge service chain (**Figure 16**), which entails capturing faecal sludge from the toilet, containment, transportation, treatment, and disposal or safe reuse. In South Africa, faecal sludge management and sewer systems would complement the wastewater treatment systems that are regulated by the Department of Water and Sanitation (DWS).

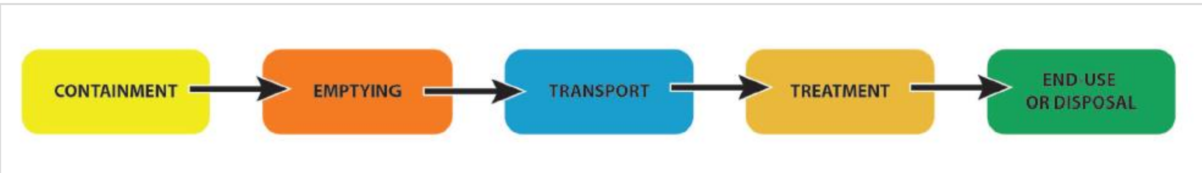

Figure 16: The Faecal Sludge Management Service Chain
Source: DWS, 2023

PHASE 1: Diagnostic Phase

Step 1: Undertake a desktop assessment to identify the WWTWs and industries whose sewage or sludge negatively impacts the water quality of water resources.

Step 2: Initiate communications with the responsible authorities (*i.e.,* local and district municipalities as well as DWS Regional Office) responsible for the catchment in which the resource affected is located.

Step 3: Request historical water quality data and/or incident reports from relevant authorities (for water quality trends and patterns).

Step 4: Utilize tools such as Google Earth/ Pro /Google Earth Engine/Sentinel, ensuring the use of high spatial resolution (<10 m) satellite imagery, GIS, and remote sensing to pinpoint changes in land use (land-based catchment pollution that could be associated with changes in the quality of water).

Step 5: In undertaking the diagnostic assessment of the facilities, consideration must be given to the below factors that tend to exacerbate the poor water quality of water resources:

- The overall integrity and functioning of the WWTWs and industrial facilities;
- Challenges associated with power cuts and failures; and
- Land-based activities and the overall management of the catchment.

  Note: *Malfunctioning sewer pump stations may form part of direct pollutants to the watercourse and should be addressed as part of overall catchment management of pollution.*

PHASE 2: Planning and Assessment

Step 1: Conduct a ground-truthing survey to accurately describe the WWTW in order to identify where the sewage impacting the water resources is emanating from. The description should include and determine the following key factors which could contribute to pollution/contamination:

- categorisation of works and operators as follows:
  - is the works categorised?
  - are all operators categorised?

    Note: *request relevant forms for categorisation of both the works and the operators in terms of the present Regulation No. R 2834, in terms of Section 26 read in conjunction with Section 12A of the National Water Act, 1956 (Act 54 of 1956) for the erection, enlargement, operation and registration of water care works, was promulgated in an attempt to ensure that operators with relevant qualifications were running the different categories of water care works.*
- method of disposal of screenings and grit, *i.e.,* burial or incineration, etc;
- location of the disposal site and/or the name of the solid waste dump;
- State of primary sedimentation tanks;
- state the number of septic tanks, the volume of each, average depth of tank(s), methods of periodical desludging, methods of disposal of the sludge removed and method of disposal of the overflow, if not intended for further processing to french drains, soakaway, etc.
- state of biological filtration systems in terms of the number of cubic meters of settled sewage per cubic meter of media per day;
- state of activated sludge systems, design information and method of operation;
- state of humus tanks or secondary sedimentation tanks;
- state of **sludge** handling in terms of the following:
  - quantity of wet sludge to be produced per day;
  - method of treatment of surplus activated sludge discharged, prior to its disposal on land or to drying beds or by other means;
  - land disposal of wet sludge to be used and state the area of land in hectares;
  - total area of any sludge drying beds;
  - the way drainage from the beds or other separators is dealt with; and
  - the way dried sludge is finally disposed of on land, *i.e.,* by incineration or burial.
- pre-treatment units ahead of the oxidation pond systems and state their capacity;

- Tertiary treatment - state basic design details, where applicable for screens, filters, reedbed systems and maturation pond systems; and
- disinfection of the final effluent - if by chlorination, give details of the method and the contact time in the pond or contact tank; if by any other method, Ultraviolet (UV) light, ozone, etc.

Step 2: Conduct a ground-truthing survey to accurately describe the **reticulation system** in order identify where the sludge impacting the water resources is emanating from. The description should include and determine the following key factors which could contribute to pollution/contamination:

- the way the area is serviced in terms of the types of sanitation systems, for example:
  - pit latrines;
  - bucket system;
  - conservancy tanks; and
  - septic tanks and french drains.
- percentage of the area which is sewered.
- type of network installed, for example:
  - standard reticulation; and
  - small bore system;
- Location of sewers, for example:
  - mid-block; and
  - standard.
- Nature of sewage:
  - domestic component - projections (no. of persons), *i.e.,* high- and low-income permanent population including holiday makers.
  - industrial component in terms of the following:
    - daily volumes/expected volume treated;
    - type of industrial waste;
    - mainly organic;
    - organic/inorganic;
    - heavy metals;
    - mixture; and
    - names of industries contributing to the volume (and locally treated), including problem constituents received from each.
- Hydraulic and organic loading of high-income, low-income, holiday makers and industrial components.

Step 3: Conduct a ground-truthing survey to accurately describe the **disposal of sludge and solid waste** to identify where factors impacting the water resources are emanating from. The description should include the following key factors which could contribute to pollution/contamination:

- **sludge** in terms of quantity, tons per day and tons per year;
- analyses of sludge
- **solid waste** in terms of quantity, tons per day and tons per year;
- analyses of solid waste (composition and percentages);
- categories of sludges according to the Guidelines: Permissible Utilisation and Disposal of Sewage Sludge, Edition 1 August 1997.
- any contracts for removal of sludges.

Step 4: Evaluate the **final waste disposal** as follows:

- Determine where the waste will be disposed of:
  - disposal on land *i.e.,* ponds/dams
  - disposal on irrigated areas;

- disposal to into groundwater, *i.e.,* recharging of aquifers;
- disposal to surface water, *i.e.,* estuaries or lagoons;
- discharge to sea, *i.e.,* surf zone, deep-sea pipelines;
- discharge to air – evaporation;
- disposal at municipal works or by private contractor;
- disposal in contained areas; and
- disposal on mined-out areas (underground).

Note: *The waste disposal practice needs to be fully evaluated taking into account various norms and standards. Before an exemption allowing a certain disposal practice can be issued, it is imperative that the practice is shown to have a minimal environmental impact and that the practice has the minimum effect on the health and interest of other water users in the environment* (DWS, 2003*).*

Step 5: Depending on the site (*i.e,* dams/ponds) and purpose for disposal, the user **should consider the factors contained in Table 5 and Appendix A.**

Note: Step 2-5 *above have been detailed as per the DWS Aide Mémoire of 2003 for Sewage Treatment Works (DWS, 2003) which is aimed at providing local authorities and owners of treatment works with information on the requirements to apply for a license in terms of section 27(1) of the National Water Act 1998 (Act No 36 of 1998) and to assist in drawing up a water quality management report in accordance with an established approach acceptable to all the regulating authorities concerned.*

PHASE 3: **Identify and define the Rehabilitation Objectives**

Define clear rehabilitation objectives based on information and data gathered from **Phases 1** and **2.** Common objectives are to manage and prevent faecal and sewage sludge from posing a threat to public health, the domestic and wider environment, and polluting groundwater.

PHASE 4: Execution

Step 1: Identify and employ the appropriate rehabilitation methods or techniques based on the site-specific **extent**, **type** and **factors** contributing to the impacted areas.

Step 2: Employ one or a combination of the below available **sewage** and **faecal sludge** techniques **(Figure 17)** as prescribed and covered in the National Faecal Sludge Management Conceptual Framework developed by DWS (2021) as well as the National Faecal Sludge Management Strategy (2023).

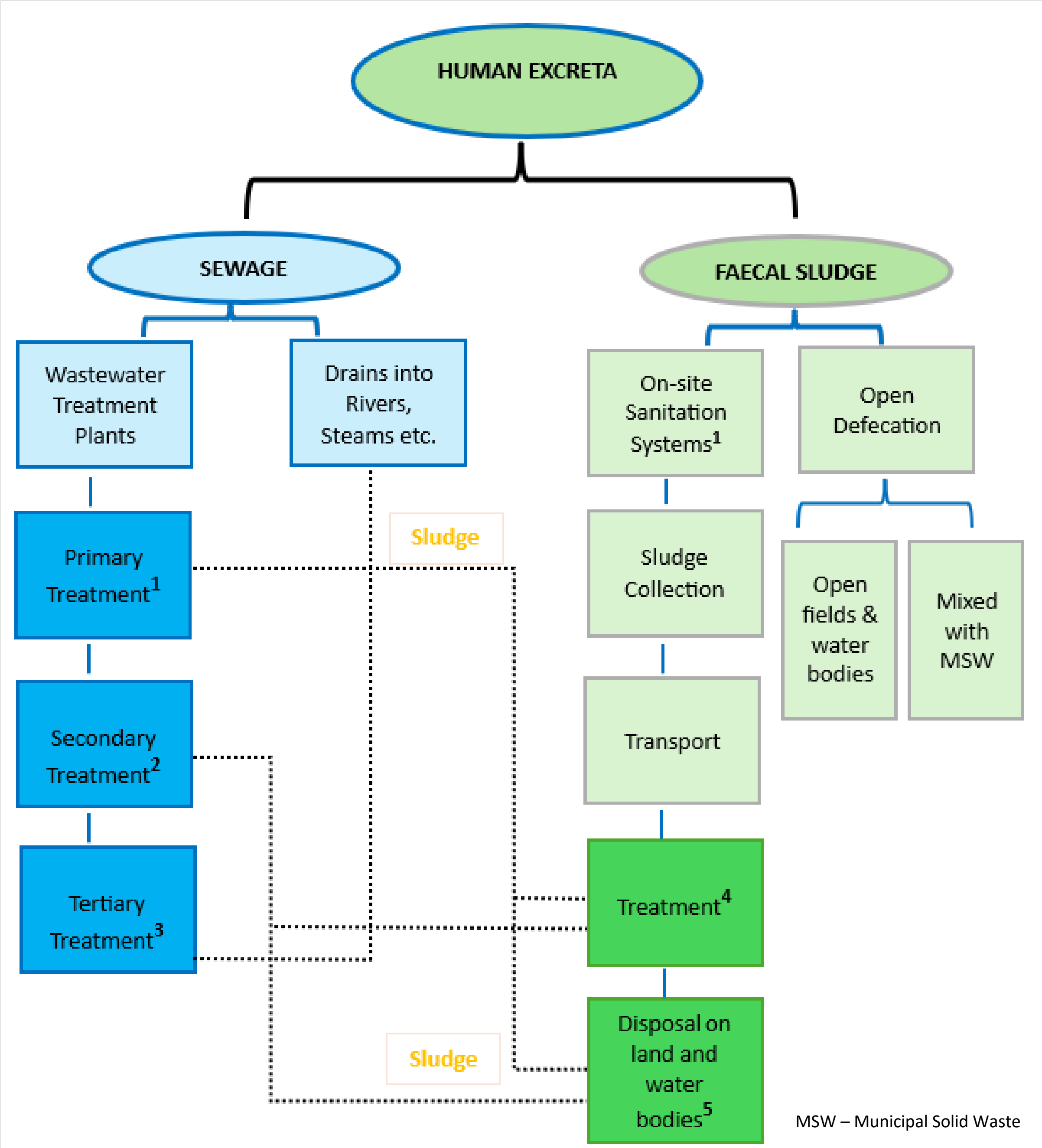

Figure 17: Sewage and faecal sludge techniques and treatment methods
Source: modified after EAI, 2024

Preliminary Treatment includes simple processes such as screening (usually by bar screens) and grit removal (constant velocity channels) to remove the gross solid pollution.

Primary Treatment[1] entails separating solids from liquids, sometimes referred to as dewatering. There are several different options for primary treatment including planted or unplanted drying beds and technologies such as the following:

- **Centrifugation:** A mechanical treatment (often used in wastewater treatment),
- **Settling-thickening tank:** A non-mechanical rectangular tank where solids settle at the bottom. Scum rises to the top, and liquid (called supernatant) is discharged through an outlet pipe,
- **Imhoff tank:** A V-shaped chamber which acts as a settling tank (sedimentation); and

- **Geobag:** a non-mechanical filtration system using geotextiles.

Secondary Treatment[2] entails treatment and removal of common pollutants, usually by a biological process which includes stabilization ponds, drying beds, and constructed wetlands, while mechanical treatment involves mechanized processes such as activated sludge, up-flow anaerobic sludge blanket (UASB) reactors, and anaerobic digesters.

Tertiary Treatment[3] or final treatment involve the treatment of the sludge that results from primary treatment usually for removal of specific pollutants, e.g. nitrogen or phosphorous, or specific industrial pollutants.

There are various types of treatment[4] for the faecal sludge that result from the primary treatment, including:

- **Co-composting:** sludge is mixed with organic waste.
- **Deep row entrenchment:** sludge is buried in deep trenches and covered with soil (can act as a fertilizer for trees).
- **Vermicomposting**: earthworms feeding on the sludge convert it to compost, which could be further enhanced by adding waste such as garden waste.
- **Anaerobic digester:** used for the digestion of organic matter in the presence of anaerobic microorganism with resultant products of slurry and biogas.
- **Solar drying:** sludge deposited in either concrete or greenhouse-type structures is dried by the sun.
- **Shallow trenches:** sludge is mixed with soil in a shallow trench.
- **Solar sludge oven:** an insulated box that reaches high temperatures to dry the sludge, which can then be used as a soil conditioner; and
- **Black soldier fly larvae:** black soldier fly larvae feed on decomposing waste, but the product is insect protein, which could be used in fishmeal. The resultant product is not suitable for agriculture with this method.

Note:

- *The decision about which type of primary treatment is appropriate depends on the available space, capacity, and physical conditions (e.g. depth of groundwater, rainfall levels, proximity of human settlement, etc) at the treatment site.*
- *In some instances, co-treatment is possible, depending on the type of technology and available space (e.g. for septic tank waste). However, co-treatment may require some adjustments, like pre-treatment, to make wastewater treatment systems suitable. It is important to note that without the extra pre-treatment, the wastewater treatment systems could be damaged.*
- *FS from VIPs should not be treated through conventional wastewater systems as it is materially different from wastewater or septic tank waste.*
- *Singh et al. (2017) have developed a decision matrix for selecting appropriate types for both primary and sludge treatment.*
- *After treatment, faecal sludge can be used beneficially in several ways, for example: as part of a compost mix, as a soil conditioner, or as fuel if made into briquettes. It is important to note that appropriate reuse options are limited by the method used for sludge treatment and by the type of sanitation system from which the faecal sludge is derived. After treatment and before use the faecal sludge product needs to be categorised to determine appropriate beneficial use.*

PHASE 5: Monitoring, Evaluation and Reporting

Monitoring

Step 1: Undertake waste quantity, quality, surface, and groundwater monitoring as detailed in **Table 6** as follows:

Table 6: Waste quantity, quality, surface, and groundwater monitoring.

<table>
<tr><th>Land disposal on ponds or dams</th><th>Land disposal in irrigation areas</th><th>Disposal to surface water</th><th>Discharge to a lagoon or estuary</th><th>Discharge to sea</th><th>Disposal to groundwater</th></tr>
<tr><td colspan="4">Waste quantity (daily or monthly volumes) and number of days discharged.</td><td>Quantity and frequency of waste discharged:
• daily
• seasonal variation</td><td>Waste volume</td></tr>
<tr><td colspan="6">Waste quality monitoring and analyses in terms of pH, conductivity, suspended solids (SS), COD, NH3, NO3, Ortho phosphate (as P), Faecal. Coliforms</td></tr>
<tr><td>Groundwater quality monitoring (macro analyses - major anions and cations) in relation to ponds or dams</td><td>Groundwater quality monitoring (macro analyses - major anions and cations) in relation to irrigated area</td><td colspan="3">• quality of minor/sub-catchment catchment before discharge into major catchment (analyses);
• quality of major catchment river upstream of minor river (analyses); and
• quality of major catchment river downstream of confluence of minor river (analyses)</td><td>Groundwater quality monitoring (macro analyses - major anions and cations)</td></tr>
</table>

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; and
- Before and after photos of rehabilitation, including a significant landmark for comparison purposes, with a brief description including location and date.

Scenario 3: Rehabilitation of operations and improvement of the quality of AMD polluted water

AMD can simply be explained as the water that is polluted from being in contact with mining activities and footprints. It is characterised by the increase in acidity (low pH), increased metal concentrations, increased sulphate concentrations (depending on what mineral is mined), and/or increased suspended solids. Below are some of the known impacts of AMD on water resources:

- **AMD decanting into rivers and streams and impacting aquatic ecosystems due to ecotoxicity.**
- Corrosion of metal equipment and appliances
- Coloured waters in streams *i.e.,* yellow = iron oxides, white = aluminium, black = manganese
- Water is unsuitable for use without treatment and only if all water quality parameters are considered.

The main sources of AMD are open-cast coal mines, exposed coal seams and gold mines. To date, some of the known affected areas are Mpumalanga (Witbank, Middelburg, etc.), Northern KwaZulu Natal (Vryheid, Paulpietersburg), and gold mining areas (East & West rand).

Keep in mind that AMD water is considered hazardous waste due to the inherent toxic properties of the chemicals and should be disposed of through the hazardous waste stream.

Scenario 1: Rehabilitation of AMD water decanting from opencast workings into rivers

PHASE 1: Diagnostic Phase

Step 1: Identify the sources of AMD, *i.e.,* AMD decanting from opencast pit or underground operations.

Step 2: Initiate communications with the responsible authorities (*i.e.,* local and district municipalities as well as DWS Regional Office) responsible for the catchment in which the resource affected is located.

Step 3: Conduct a desktop assessment to determine the conditions of the open-cast pit or underground operations

Step 4: At a desktop level and from existing information, assess the conditions of the open-cast pit or underground operations to determine the following:

- Dewatering rates (if there is such an activity taking place);
- Seepage rate into the operations;
- Recharge rate into the operations;
- Groundwater levels; and
- Lowest topographic level (where the regional piezometric head of the aquifer intersects the topographical setting – This is important because decant/seepage point(s) are normally located here.

Step 5: Collect groundwater samples from the operations 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 for water that will be dewatered from the operations.

Step 6: Collect waste rock material samples for geochemical assessment. The results of the assessment will inform whether the backfill material is suitable to be used for backfilling operations. The material to be used for backfilling must be non-acid generating.

PHASE 2: Planning and Assessment

Step 1: Rehabilitation of AMD water emanating from the operations trigger Section 21 water uses

Step 2: The person undertaking rehabilitation must determine the water uses likely to be triggered by the rehabilitation activities. Examples are:

- Section 21 (j) – dewatering of groundwater.
- Section 21 (g) – temporary storage of water pumped.
- Section 21 (f) – discharging the treated water.
- Section 21 (c) & (i) for decants in regulated areas.

- Exemption from Regulation 4(c) of GN704 for backfilling activities into the operations

Step 3: The person undertaking rehabilitation activities must determine the following:

- Geohydrological conditions of the operations terms of the geology, aquifers, inflows and outflow rates, and groundwater levels.
- Rates of inflow & outflow in the operations.
- Geochemical assessment detailing the type of waste material to be used for backfilling.

PHASE 3: Identify and define the Rehabilitation Objectives

Define clear rehabilitation objectives based on information gathered in **Phases 1 and 2.** Below are some of the common aims and objectives of the rehabilitation of opencast pit which decants into water resources:

- Pump water from the operations to reduce and maintain groundwater levels below decanting levels;
- Treat AMD water to acceptable standards and reuse; and
- Backfill the opencast pit and use the rehabilitated land for other purposes *i.e.,* agricultural purposes.

PHASE 4: Execution

Figures 18 and 19 present both passive and active methods that can be employed for rehabilitation of decanting mining operations.

Other known prevalent method for treating AMD contamination is the addition of alkaline reagents such as lime, limestone, sodium carbonate, or sodium hydroxide. This treatment aims at neutralizing acidic water and the precipitation of heavy metals.

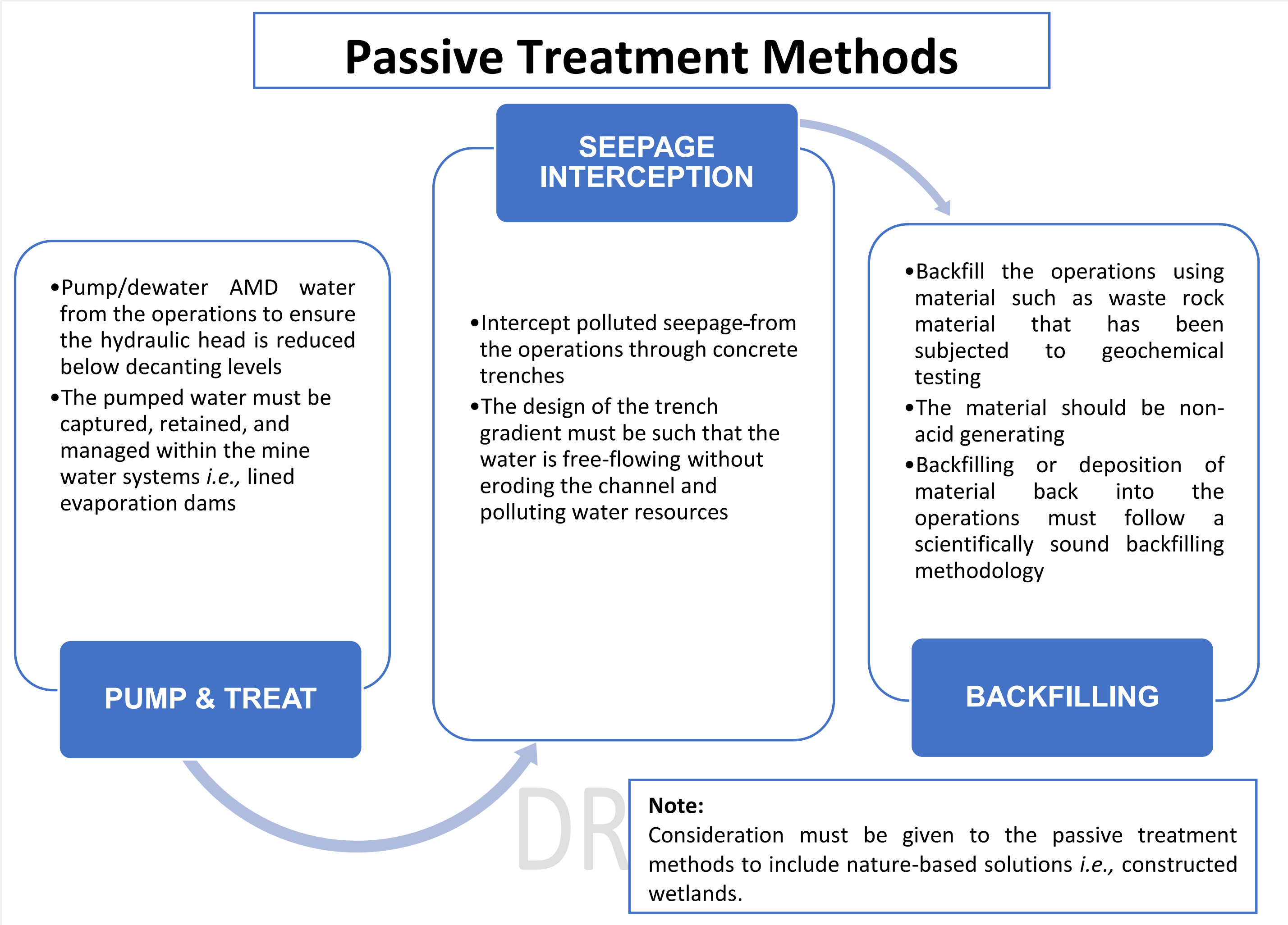

Figure 18: Passive Treatment Methods.

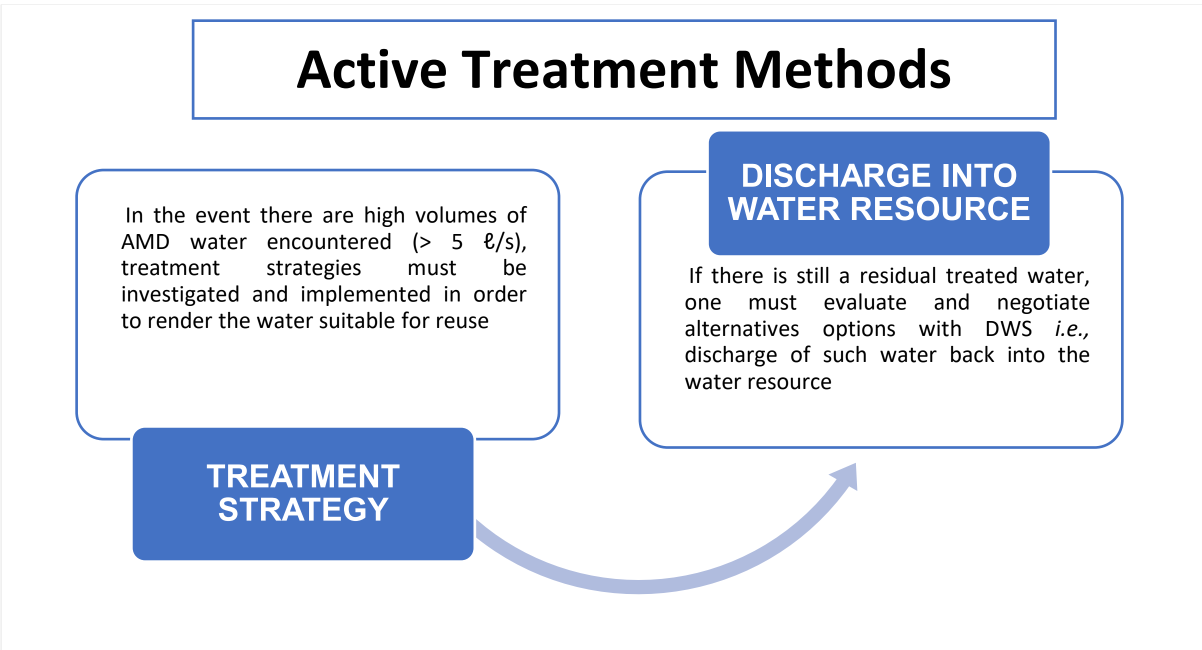

Figure 19: Active Treatment Methods.

PHASE 5: Monitoring, Evaluation and Reporting

Monitoring

- **Pump and/or dewatering** – Monitor the groundwater levels within the operations daily and report to the DWS monthly.
- **Seepage Interception** – monitor the quality of water at the trenches and downstream of the constructed wetland to assess the changes in the quality of water over time.
- **Backfilled opencast area -** develop and implement a dedicated monitoring programme to monitor the groundwater level recovery and pit water quality of the rehabilitated/backfilled area.

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.

5.3.4 Special considerations to be applied for Rehabilitation using Passive Treatment Methods

Consideration must be given to the passive treatment methods to include nature-based solutions *i.e.,* constructed wetlands.

5.4 HABITAT

5.4.1 Description

Habitat includes the physical structure of a watercourse and the associated vegetation in relation to the bed of the watercourse (NWA, 1998). Physical habitat excludes the physiochemical characteristics of the stream water, *i.e.,* water chemistry, clarity, temperature, quantity, and light intensity (Belletti *et al.,* 2017). Instead, it includes geomorphologic and biological characteristics that determine habitat structure and thus, have an impact on energy inputs. According to Kaufmann *et al.* (1999), six characteristics are the primary determinants of physical habitat structure provided by rivers, namely stream size and channel dimensions; channel gradient; channel substrate size and type; habitat complexity and cover; vegetation and structure of the riparian zone; and channel-riparian interactions.

5.4.2 Types of Habitat Impact

Table 7: Types of factors influencing the habitat.

Properties	Type of Impacts
Stream size and channel dimensions	Anthropogenic activities can change channel dimensions by altering high discharge frequency, *i.e.,* floods
Channel gradient	Anthropogenic activities affecting bedload, or factors affecting stream, can change channel gradient. Additionally, channelization can directly alter effective channel gradient

Properties	Type of Impacts
Channel substrate size and type	Anthropogenic activities that cause an increase in upland erosion which can result in an increase in sediment supply to stream channels. The increase in fine sediments decreases mean substrate size, which leads to channel destabilization, leading to channel aggradation and accelerated channel migration.
Habitat complexity and cover	Geomorphologic units (such as pool-riffle and step-pool sequences), channel sinuosity and hydraulic roughness contribute to processes that dissipate energy of water flow in stream channels. Additionally, plants and woody debris along the stream banks also contribute to energy dissipation.
Vegetation and structure in the riparian zone	Overgrazing in the riparian zone can alter vegetation type, as well as the amount of cover and forage, increase erosion and introduce more nutrients and faecal coliform microorganisms to the stream through manure. Other factors include development (*e.g.,* housing), logging and dams.
Channel-riparian interactions	Anthropogenic stream channel changes such as riprap, bank armouring structures and culverts are candidate causes. These alter flow, erosion, and deposition patterns, which result in habitat alterations.

5.4.3 Rehabilitation Management Guidelines for Habitat

Scenario 1: Rehabilitation of disturbed habitat due to disturbances caused by anthropogenic activities

PHASE 1: Diagnostic Phase

Step 1: Identify the cause of the channel disturbance/change *i.e.,* at the site, upstream of the site or within the broader catchment

Step 2: Initiate communications with the responsible authorities (*i.e.,* local and district municipalities as well as DWS Regional Office) responsible for the catchment in which the resource affected is located.

Step 3: Investigate the history and the rate of change over the years. This can be achieved through communicating with residents within the area or historical mapping.

Step 4: Obtain historical data, such as aerial photographs, to evaluate the geomorphological and vegetation issues (*e.g.,* erosion and invasive alien vegetation).

Step 5: Utilize tools such as Google Earth/ Pro /Google Earth Engine/Sentinel, ensuring the use of high spatial resolution (<10 m), satellite imagery, GIS, and remote sensing to obtain more recent images dating from the last 10 to 20 years for certain areas.

Step 6: Obtain historical flow data from DWS as an indication of long-term flow changes.

PHASE 2: Planning and Assessment

Note:

- Assessment should consider the larger-scale impacts that may affect rehabilitation measures.
- The specific scale would be dependent on the site-specific conditions.

Step 1: Note of current activities impacting riparian areas must be taken, as well as historical impacts and those that may potentially further affect the riparian zone due to river crossing construction/development activities.

Step 2: Aspects such as topography, vegetation and alluvial soils should be utilized to delineate riparian areas.

Step 3: Special attention should be paid to re-vegetation within the watercourse.

Step 4: For aquatic assessment, a visual consideration of the condition must be noted.

Step 5: Habitat integrity and suitability for aquatic macro-invertebrates and fish assemblages both up and downstream should also be assessed. Water quality should also be considered as the habitat may be rehabilitated but poor water quality will lower biodiversity or absence thereof.

PHASE 3: Identify and define the Rehabilitation Objectives

Straightforward intervention objectives must be defined and set. Common examples of aims and objectives required for ecological management are to:

- Provide immediate rehabilitation measures, such as bank stabilization and reprofiling, restoration of topographical sequences and leveling, and restoration/protection of indigenous vegetation to be implemented immediately after the construction of river crossings.
- Provide the implementation of management measures during the post-rehabilitation phases of the development to ensure that there are no ongoing impacts, *i.e.,* incision and erosion due to construction activities.
- Put measures in place for the control of alien vegetation and soil integrity.
- Ensure riparian vegetation cover within the watercourse and allow for suitable vegetation to be reinstated within riparian and terrestrial areas adjacent to the river crossing which was affected by construction activities.
- To provide suitable monitoring guidelines to ensure long-term sustainability and determine the overall rehabilitation success of the rehabilitation works.

PHASE 4: Execution

Step 1: Communication and collaboration between the water sector, DFFE, and other relevant governmental departments must be ensured.
Step 2: Apply for a WUL in terms of NWA, 1998 (Act 36 of 1998) to obtain authorization of any activities within the riparian zone.
Step 3: Similarly, obtain an environmental authorization (through carrying out a Basic Assessment and Environmental Impact Assessment) from DFFE in terms of NEMA to ensure compliance with regulations relating to the restriction of conducting activities within the riparian zone.
Step 4: Minimization of impacts from the anthropogenic construction activities
Step 5: Developed areas are reshaped and leveled to reassemble pre-construction environments as precisely as possible
Step 6: Riverbank reconstruction to tie in with existing riverbanks.
Step 7: Re-vegetation of disturbed areas
Step 8: Upon decommissioning, all construction material must be removed from riparian areas.
Step 9: Re-profiling and sloping of areas vulnerable to erosion and incision as an outcome of construction activities.

PHASE 5: Monitoring, Evaluation and Reporting

Monitoring

Upon the completion/implementation of the rehabilitation work, a suitably qualified specialist should continue monitoring habitat [channel modification, habitat cover, vegetation cover (indigenous vs. alien invasive) and encroachment] monthly for three months.

Subsequently, one monitoring site visit after six months of rehabilitation works completion is recommended. Lastly, the final sign-off of rehabilitation works should be completed after one year. Monitoring should include the following parameters:

- Determine if the reprofiled areas are compatible with the natural environment.
- Assess surface and slope stability and adequate functioning of the rehabilitation structures.
- Determination of erosion levels.
- Ground cover percentage calculation within revegetated areas, including vegetation basal cover, litter, and rock.
- Determine whether any improvement in aquatic biota communities/diversity occurred.

Evaluation

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

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.

5.4.4 Special considerations to be applied for the Rehabilitation of Habitat

Consideration must be given to the below list during the rehabilitation of the habitat:

- Scientific buffer zones (*i.e.,* 1:100-year floodline);
- Plant Species plans must be drawn up by a landscape architect or botanist and terrestrial ecologist, submitted for approval and implemented; and
- Nature-based solutions *i.e.,* constructed wetlands should be considered as part of rehabilitation options.

5.5 BIOTA

5.5.1 Description

Biota/aquatic biota is described as the community of plants and animals with a biotic integrity, which reflects the health, community structure and distribution, which is dependent on habitat (DWAF, 1999). A habitat is made of physical (abiotic) and living (biotic) factors. Abiotic factors are physical, non-living components that affect living organisms. Abiotic factors include:

- Light intensity;
- Moisture (availability of water);
- Humidity;
- Salinity;
- pH; and
- Temperature

Biotic factors are the living parts of the ecosystem with which an organism must interact. Biotic factors include:

- Predators;
- Prey;
- Food sources; and

- Parasites.

Examples of biota are as follows:

- Burchell's redfin (*Pseudobarbus burchelli*) which is a freshwater fish species in the family Cyprinidae. *P. burchelli* which are recognised as "critical endangered'' species.
- Palmiet plant (*Prionium serratum*) in the family of *Juncaceae* and play an important ecological role in stabilising the riverbed and riverbanks from erosion.

5.5.2 Types of Biota Impacts

The impacts on riparian biota are primarily a result of three changes, namely;

- Changes to the river flow pattern;
- Change in suspended sediment; and
- Damage to riparian vegetation.

According to WRC (2016a), the most common form of human-induced disturbance of sediment processes is the construction of features/barriers that alter the hydraulics and geomorphic characteristics of the river channel and floodplain, which negatively impacts the lateral and longitudinal connectivity of watercourses. These features/barriers also alter the flow velocities which cause changes in the physical habitats and, thereby, the hydraulic biotopes upon which biota depend. **Table 8** below summarizes human induced disturbances on biota.

Table 8: Summary of human-induced disturbances on biota

Human Induced Disturbances	Description
Dams and Weirs	• Dams and weirs create barriers to the migration of instream biota up and down the river • Dams and weirs have effects on physical habitat and biota immediately above the dam; and connectivity, habitat, and biota below the dam • Weirs have negative impact on the ecology of a stream when they prevent the migration of biota up and down the river. This can be mitigated by including a "fishway", a channel carrying the low flow with a lot of baffle plates to slow down the velocity of the water that biota can still migrate over the weir • Other major impact (physical habitat) is that there is scouring and armouring downstream of the structure and sedimentation upstream of the structure. This change in habitat have major impacts on the biota, both instream and riparian and impacts flora.
River diversions	• River diversions cause disconnection from natural floodplains, loss of biodiversity and loss of natural habitat diversity, and give rise to serious flooding to adjacent areas
Roads, Drifts and Bridges	• Similarly, to dams and weirs, these structures create migration barriers to biota
Bank protection structures	• Eroding, undercutting banks and/or migrating active channels are often engineered and stabilised. These stabilised banks can prevent the natural migration of the active channel, and thereby reduce physical habitat diversity and dynamics and reduces allochthonous production.
Grazing and trampling	• Excessive grazing and trampling of the riparian areas reduce vegetation and habitat complexity and is usually associated with a reduction in vegetation robustness

Human Induced Disturbances	Description
Sand and gravel mining	• Sediment removal disturbs the riverbed and banks, degrading habitat condition, especially where the sediment is being removed from the active channel and marginal zone • In the case the frequency of removal exceeds recovery rate, the zone of removal will remain a disturbed, degraded area that often supports only disturbance tolerant weedy species, with low levels of faunal diversity

5.5.3 Rehabilitation Management Guidelines for Biota

Weirs, dams, road bridges and causeways are some of the identified major existing migration barriers in rivers. The construction and in some instances, the removal/upgrading of some of these structures/features cause a reduction in the numbers and distribution of many migratory fish and invertebrate species throughout South Africa. According to WRC (2007), most indigenous species in the country carry out annual migrations within river systems, amongst others, to:

- Optimise feeding;
- Promote dispersal;
- Avoid unfavourable conditions; and
- Enhance reproductive success.

Guidelines is provided to water resource managers (using the below scenarios) to address the following impacts:

- **Scenario 1:** Impacts of barriers on biota migratory routes can often be addressed through fishways/ladders and fish lifts at old and new structures.

<u>Scenario 1: Re-establish biota migratory routes (i.e., fishways)</u>

PHASE 1: Diagnostic Phase

Step 1: Determine whether the river affected is an inland or coastal river denoting them using A and B respectively

Step 2: Initiate communications with the responsible authorities (*i.e.,* local and district municipalities as well as DWS Regional Office) responsible for the catchment in which the resource affected is located.

Step 3: At a desktop level**,** identify the river in which the biota migratory routes are affected.

Step 4: Describe the specific details of the river affected - Primary or Secondary River.

Step 5: Describe the specific reach of the river affected – Upper, Middle and Lower reaches.

Step 6: Describe the migratory region in which the affected river is located according to the following regions;

<u>Inland Migratory Regions (A):</u>

- Orange-Vaal region
- Lower and Upper Limpopo region
- Inkomati and Pongola region
- KZN inland region
- Cape inland region

<u>Coastal Migratory Regions (B):</u>

- South-East region

- South Coast region
- West Coast region

Step 7: Describe the types of migratory aquatic biota species affected by instream barriers, specifying whether they are inland or coastal species. **Table 9** provide examples of some of the common inland and coastal species[16]:

Table 9: Inland and coastal migratory aquatic biota species.

Inland Species (A)	Coastal Species (B)	Description of Inland and Coastal Species
• Potamodromous • Catadromous (including diadromous and amphidromous)	• Potamodromous • Catadromous	• **Potamodromous** - entire life cycle and migration is completed within freshwater zones for spawning, feeding, dispersion after spawning, colonisation after droughts • Diadromous - migrate between fresh water and the sea or saline waters. Within this category, there are two forms of diadromy found in South African coastal rivers. They include: ○ **Catadromous** - species which spend most of their lives in fresh water and migrate to the sea (or estuaries) as adults to breed. ○ **Amphidromous** - diadromous species, which migrate both as adults and juveniles between fresh water and the sea (and vice versa)

PHASE 2: Planning and Assessment

Step 1: Assess the ecological need for a fishway at an instream barrier.

Step 2: In the event there is no need for a fishway, consider the following alternatives and mitigation measures:

- Artificial spawning beds;
- Captive breeding; and
- Capture and transport.

Below are some of the reasons to consider other alternatives or mitigation options:

- Excessive height or poor design of the structure;
- High financial costs due to the length of fishway required; and
- Biological and/or physical constraints of migrants.

Note: *Fishways tend to be expensive and time-consuming to construct. If there is a migration barrier and a fishway is not feasible, you have to bear in mind that these mitigation measures are not a once-off. These measures are more applicable when a species has been removed from a system, such as after a spill, and you want to re-introduce them to where they occurred previously.*

Step 3: If there is a need for a fishway, quantify the ecological impact of the instream barrier on migratory species present – *i.e.,* the importance of providing a fishway at the barrier.

Step 4: Once the need and importance are identified and determined, conduct a cost-benefit analysis of an effective fishway to be designed and constructed at the instream barrier.

Step 5: Prepare a motivation and secure appropriate funding.

[16] WRC. 2007. Guidelines for the planning, design, and operation of fishways in South Africa.

PHASE 3: Identify and define the Rehabilitation Objectives

The objectives of rehabilitation of the impacts of instream barriers on biota migratory routes must be clearly defined and set. The objectives for rehabilitation must be informed by the data collated in **Phases 1 and 2** above. Some of the most common aims and objectives of rehabilitation of instream barriers are to:

- Provide migration routes to some species for spawning, feeding, dispersion after spawning, colonisation after droughts; and
- Provide migration routes between fresh water and the sea or saline waters.

PHASE 4: Execution

Step 1: Based on the information gathered, the relevant specialist, i.e., the Engineer and/or Aquatic Specialist must design a fishway.

Step 2: The fishway to be designed will depend on the site conditions. Based on the conditions, the relevant specialist, *i.e.,* the Engineer and/or Aquatic Specialist must design a – **coastal or inland fishway** – based on the below general hydraulics **(Table 10).**[17]

Table 10: General hydraulics of a fishway.

Inland Fishway (A)			
Target species and size range	**Maximum Turbulence (Watts/m³)**	**Maximum drop between pools (mm)**	**Maximum water velocity (m/s)**
Very small catadromous fish (25 – 40 mm) within 50 km of the estuary	150	75	1.2
Small fish, including catadromous species and other (> 40 mm) and weak swimmers, 50 to 120 km from the estuary	180	100	1.4
Costal Fishway (B)			
Target species and size range	**Maximum Turbulence (Watts/m³)**	**Maximum drop between pools (mm)**	**Maximum water velocity (m/s)**
Very small fish (<40 mm) and/or weak swimmers	150	100	1.4
Small to medium sized fish (40 - 100 mm) and/or moderate swimmers	180	150	1.7
Large sized fish (>100 mm) and/or strong swimmers	220	200	2.0

Step 3: The fishway designs must be informed by the following key factors for both inland and coastal species:

- Species composition;
- Types of migration;
- Season/time period species are functional;
- Swimming ability of species;

[17] WRC. 2007. Guidelines for the planning, design, and operation of fishways in South Africa.

- Swimming speed of species;
- Endurance of species;
- Physiological factors of species, *i.e.,* aerobic vs anaerobic muscles; and
- Current velocities and turbulence factors.

Step 4: The fishway design process must be supported by and include the following:
- Ecological, hydrological and engineering studies;
- Analysis of the barrier hydraulics;
- Selection of a suitable location for the proposed fishway;
- Hydraulic analysis of the selected fishway type(s); and
- Provision for maintenance of the fishway.

Step 5: Identify the appropriate fishway design suitable for the site-specific conditions (inland and coastal regions), *i.e.,* vertical slot, notched weir/or orifice, sloping baffle.

Step 6: The fishway must be constructed according to the approved engineering standards and must be informed by the selected designs, dimensions and all the results of analysis conducted in **Step 3**.

PHASE 5: Monitoring, Evaluation, and Reporting

Monitoring

Table 11 contains the key biological/ecological and physical parameters prescribed by WRC [18] , which must be monitored downstream and upstream of the fishway.

Table 11: Key biological, ecological, and physical parameters prescribed for monitoring

Source: WRC, 2007

Biological/Ecological Parameters	Physical Parameters
• Size and numbers of species that successfully pass through the biota barrier. • Size and numbers of species that attempt to use the fishway (*i.e.,* are actively migrating and enter the down-stream end of the fishway). • Size and numbers of species that actively migrate but are blocked by the barrier in question. • Proportion of species that enter the fishway.	• Water discharge rates down the biota barrier. • Internal hydraulics in the biota barrier *i.e.,* speed, turbulence, and depths. • The change of discharge down the biota barrier. • Levels of stream flow or stages of the flood hydrograph where peak migrations in the river take place. • The time of day/night/season) when migrations of the various species occur. • Water quality, *i.e.,* temperature, conductivity, pH, turbidity. • Barometric pressure, air temperature.

Note:

*The monitoring programme presented above is **generic** in nature and attempts to assess the performance of a fishway as per the scenario in question. The list of parameters in **Table 11** is by no means exhaustive and is relevant to the scenario in question. It should be noted that carefully planned monitoring programmes and more sophisticated monitoring methods are required to assess the effectiveness of fishways in South Africa, to improve their design and to optimise their management. Monitoring programmes also vary from site to site depending on the site-specific conditions of the area affected. In addition, to better understand the environmental indicators that stimulate fish migrations,*

[18] *WRC. 2007. Guidelines for the planning, design, and operation of fishways in South Africa.*

a host of environmental parameters (abiotic and biotic) need to be measured during the monitoring period, which should be performed over months rather than weeks.

It is recommended that the monitoring parameters to be developed by the users of the RMGs should be aligned to the gazetted RQOs of the area in question, as this is one of the critical RDM measures/tools for the protection of water resources. The monitoring parameters developed by the users should also form part of the River Eco-status Monitoring Programme (REMP), where applicable.

***REMP** is a programme for monitoring the ecological conditions of the river ecosystems based on the drivers and responses in the river.*

***REMP** is aimed to establish the reference condition (usually a natural or close to natural condition) of the river or reach that will be used to assess the temporal conditions of that river or reach with the consideration of both the biotic (instream and riparian biota) and abiotic (hydrology, geomorphology, and physico-chemical conditions) factors of that river.*

Indices of REMP include:

- *South African Scoring System (SASS) – for macro-invertebrates*
- *Macro-Invertebrate Response Assessment Index (MIRAI) – for macro-invertebrates*
- *Fish Response Assessment Index (FRAI) – for fish*
- *Vegetation Response Assessment Index (VEGRAI) – for riparian vegetation*

Biological Response Indices

- *Index of Habitat Integrity (IHI) – for habitat integrity*
- *Hydrology Assessment Index (HAI) – for hydrology*
- *Geomorphology Assessment Index (GAI) – for geomorphology*
- *Physico-Chemical Assessment Index (PAI) – for physico-chemical*

Driver Indices

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.

5.5.4 Special considerations to be applied for Rehabilitation of Biota

Consideration must be given to the below list during the development of the Guidelines for biota:

- Include the importance of protected species areas and consider connections between areas as corridors establishment.
- The developed lists of priority for each characteristic, such as NFEPA and Strategic Water Resources.
- Methods of fishing within river systems should be properly controlled. In addition, deserted fish nets that pose a threat to all water users should also be removed.

- Floating wetlands and scientific buffers for biodiversity and water quality enhancement. This also plays a role in pest controls on farms dams, and the betterment of conservation efforts, aesthetics, eco-tourism.

6. REMMENDATIONS AND WAY FORWARD

The River RMGs have been developed to address characteristics of watercourses, namely surface flow, interflow, groundwater flows, geomorphology, water quality, habitat, and biota, through a phased approach. In implementing these guidelines, the following are recommended to users of the guidelines:

Hydrology – surface flows and interflow:

- Rehabilitation of impacts relating to flow regime such a surface flow and interflow must also include the reinstatement of flow drivers in the landscape.
- Alien vegetation must be replaced with the appropriate indigenous vegetation to the specific areas. This is especially important when trees are removed, indigenous tree species must be brought in. Furthermore, alien plant management must be conducted in a phased approached both for eradication and revegetation. Revegetation and Re-planting Plans must be compiled and submitted to the DWS for approval.

Geomorphology:

- The identified objectives must be checked for feasibility and affordability. There must be a reasonable timeframe set to allow the river to respond to the rehabilitation actions. For instance, WRC (2004) adopted the Rutherfurd *et. al.* (2000) method of setting a timeframe: a short-term objective for the completion of the rehabilitation output and a long-term objective for evaluation of the effect of the work.
- Rehabilitation linked to rivers should always take a system-based approach and not be isolated to a section of a river reach.

Water Quality:

- Rehabilitation activities relating to impacts on water quality must consider the priority areas which are sensitive and must be protected. These priority areas that must be protected are areas such as Strategic Water Source Areas and areas that were identified as NFEPA priorities.
- Scientific buffer zones (1:100-year floodline) must be determined and implemented for water quality and biodiversity protection – when determining these buffers zones, the user must consult the Buffer Zone Guidelines (WRC, 2017).
- Scientific buffer zones should ideally be integrated into the stormwater management system to address issues relating to debris and litter.

Habitat and Biota:

Consideration must be given to the below list during the rehabilitation of the habitat and biota:

- Scientific buffer zones – when determining these buffers zones the user must consult the Buffer Zone Guidelines for Rivers, Wetlands and Estuaries compiled by WRC, 2017 - guidelines provide guidance for activities planned around and adjacent to water resources. They are to be used and applied as part of a broader suite of tools to ensure that water resource management is appropriately integrated into development planning and land use management.

- Plant Species Plans must be compiled by the relevant specialist within the field.
- Constructed wetlands must be considered and their status must not be affected by the rehabilitation activities undertaken. The passive treatment methods should include nature-based solutions *i.e., constructed wetlands*.

General:

- Rehabilitation of Rivers should consider maintaining Category A or B rivers/watercourses management units in almost pristine conditions and serve as Reference Conditions based on the available resources and budget.
- Compliance, monitoring and enforcement must be strengthened in terms of human resources and capacity for all rehabilitation work to be undertaken.
- Remote Sensing and GIS must be considered and employed instead of only relying on fixed-point photographs for monitoring aspects of rehabilitation work completed.
- Priority must be given to protected areas like national parks and nature reserves, however, rehabilitation should not only be limited to protected areas but should extend beyond those borders as well so that the river can provide goods and services throughout the river stretch.
- Gathering of data and information from the databases (*i.e.,* Green drop) within the DWS must be considered before exploring options for the monitoring and collecting data from new proposed sites. These datasets can be made available by the DWS to users upon request.
- Gathering of historical data and information from the databases to assess causes related to changes, which led to the required rehabilitation efforts.
- Collaboration between the DWS, other government departments and private institutions is recommended to find the best way possible to assist each other in implementing rehabilitation.
- Capacity building and funding must be linked to existing policy statements regarding departmental funding or charges.
- Consideration must be given to translating the guidelines to be developed into Policy.
- Although the aspects are dealt with separately in guidelines, one should keep in mind that the aspects are interrelated and, therefore a systems approach should be followed. All these aspects should be taken into account during a rehabilitation project and cannot be considered in isolation. Therefore, monitoring data providing baselines is important.
- Although the objectives define the endpoint of rehabilitation projects, an essential aspect of this is to ensure that ecosystem services are provided/or returned to a river system. The ecosystem services are a product of the interactions between the drivers and response variables.
- While it may be impossible to fully restore a river system to its original condition, efforts should focus on preserving its ecosystem functioning. This perspective should be framed within the evolving understanding of what constitutes a naturally functioning river (WRC, 2016a).

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APPENDICES

Land disposal on ponds or dams	**Land disposal on irrigation areas**	**Disposal to surface water**	**Discharge to lagoon or estuary**	**Discharge to sea** There are two types of sea discharge: surf zone & deep-sea outfalls	**Disposal to groundwater**
waste quantity (daily or monthly volumes) and number of days discharged.			***This discharge could have an impact similar to surface or sea discharge. Therefore, the information related to surface discharge is applicable here.***	quantity of waste discharged: • daily • seasonal variation	waste volume
waste quality analyses *i.e.,* pH, conductivity, suspended solids (SS), COD, NH3, NO3, Ortho phosphate (as P), *Faecal. Coli*				waste quality *analyses i.e.,* pH, conductivity, suspended solids (SS), COD, NH3, NO3, Ortho phosphate (as P), *Faecal. Coli*	
geology under-lying the dams, depth of the water table, and slope of site	• crop irrigated, drop factor and type of irrigation methods used; • irrigation/application efficiency? • monthly crop irrigation requirements; • permeability and infiltration rate of the soil profile; • slope of the irrigation area; • root depth of the soil; • underlying geology; • size of the irrigation area required; • depth of the water table for summer and winter; • quality of the groundwater (macro analyses - major anions and cations);	name of minor river catchment in terms of: • area of catchment; • mean monthly run-off; and • quality of river upstream of discharge			• depth of groundwater • yield of groundwater (1000 m / 1 km radius of disposal area) • quality of groundwater (macro analyses - major anions and cations)

Land disposal on ponds or dams	Land disposal on irrigation areas	Disposal to surface water	Discharge to lagoon or estuary	Discharge to sea There are two types of sea discharge: surf zone & deep-sea outfalls	Disposal to groundwater
	• slope of the irrigation area; an • direction of groundwater flow.				
surrounding of the disposal site *i.e.,* dams with regards to: • rivers; • boreholes *i.e.,* use yield, and quality; • springs/fountains; • natural depressions; • urban areas; • dwellings;	The surrounding of the disposal site with regards to: • rivers; • boreholes *i.e.,* use yield, and quality; • springs/fountains; • natural depressions; • urban areas; and • dwellings.	-		-	-
use of groundwater in the vicinity *i.e.,* domestic, agricultural, livestock watering, irrigation, industrial use	use of groundwater in the vicinity i.e., domestic, agricultural, livestock watering, irrigation, industrial use	established use of river for domestic, agricultural, industrial, recreational, and environmental use		**-**	potential use of groundwater for domestic, agricultural, livestock watering, irrigation, industrial use
• are the dams been sealed with plastic liners or bentonite or other clay? • are there seepage collection drains and return pumps? • are the leakage detection and monitoring systems in place?	• environmental protection methods in place such as: ○ stormwater cut-off trenches above the site; and ○ cut-off canals below the site • soil amendments are done per season to sustain soil fertility and permeability; and	• establish the applicable WQ criteria; • establish the critical components; and • name of major river catchment ** Collect same information as for minor catchment* • quality of minor catchment before discharge into major catchment (analyses)		• sea water quality criteria applicable to the discharge area; • establish the critical quality components; • calculate dilution rates required to achieve the Sea Water Quality Criteria • length of pipeline; • depth of the pipeline below the_LWOST mark	critical quality component

Land disposal on ponds or dams	Land disposal on irrigation areas	Disposal to surface water	Discharge to lagoon or estuary	Discharge to sea There are two types of sea discharge: surf zone & deep-sea outfalls	Disposal to groundwater
	• Soil evaluation (analyses)	• quality of major catchment river upstream of minor river (analyses) • quality of major catchment river downstream of confluence of minor river (analyses) • mean monthly run-off of major catchment upstream of minor river • the RWQO's for the total catchment • Calculate Waste Load Allocations (WLA's) and the effect which the discharge will have on the REQO (Receiving Environmental Quality Objectives)		(Low Water Ordinary Spring Tide); • number of diffusers at the boil; • dilution at the boil; • use of the beaches 5 km on either side of the pipeline; • categorisation of the coastline 5 km on either side of the pipeline; • disposal by evaporation which occurs within a process because of excess heat, or in cooling towers or in specially designed dams where it is promoted; • municipal or private waste purification plant (other than works being evaluated); • letters of acceptance of the waste by the owner of the works (attach a copy of the agreement for the delivery and acceptance of the waste); • purification plant compliance record;	

Land disposal on ponds or dams	**Land disposal on irrigation areas**	**Disposal to surface water**	**Discharge to lagoon or estuary**	**Discharge to sea** There are two types of sea discharge: surf zone & deep-sea outfalls	**Disposal to groundwater**
				• quality acceptance limits in operation, *e.g.* Drainage by-laws (attach a copy); • any critical components in the raw waste (identify); and • effect of acceptance of the raw	