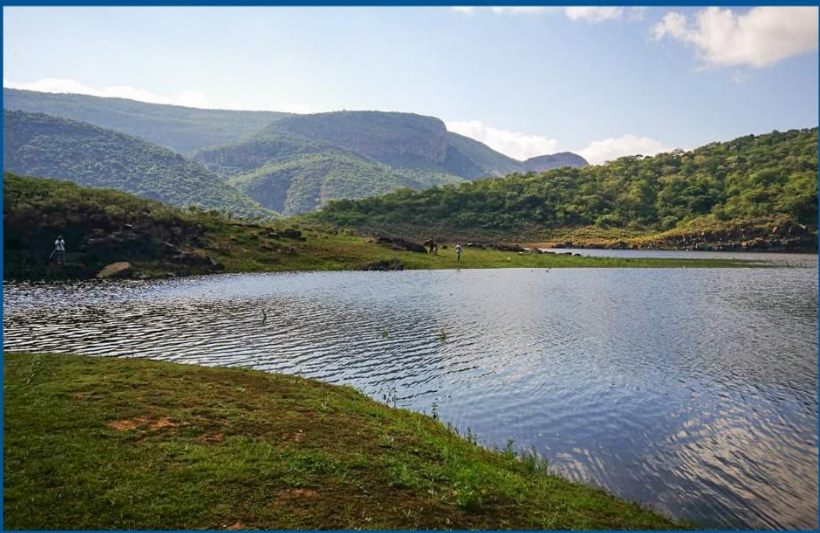
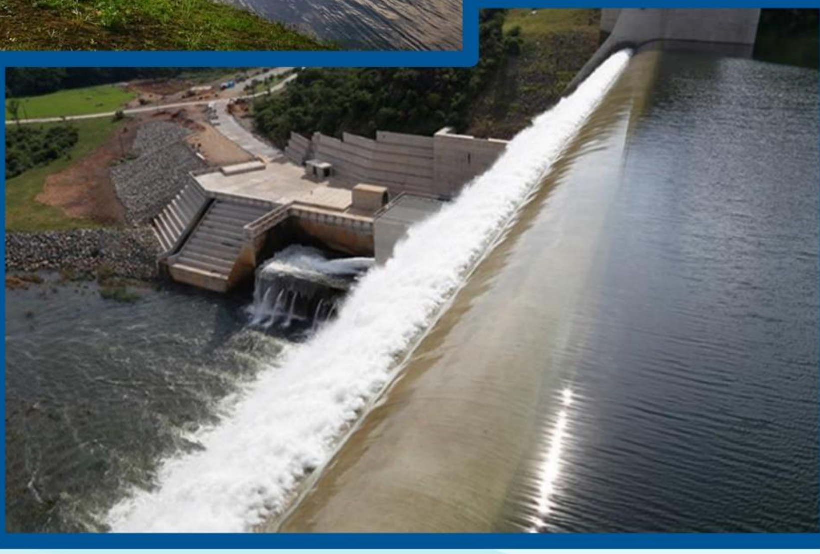
REHABILITATION MANAGEMENT GUIDELINES FOR WATER RESOURCES

VOLUME 4: LAKES & DAMS





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Sanitation is Dignity

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LIST OF ACRONYMS

AMD	Acid Mine Drainage
BOD	Biochemical Oxygen Demand
CARA	Conservation of Agricultural Resources Act
CD: WEM	Chief Directorate: Water Ecosystems Management
CMAs	Catchment Management Agencies
COD	Chemical Oxygen Demand
DALRRD	Department of Agriculture, Land Reform and Rural Development
DCOGTA	Department of Cooperative Governance and Traditional Affairs
DFFE	Department of Forestry, Fisheries and Environment
DSEP	Dam Safety Evaluation Programme
DSRP	Dam Safety Rehabilitation Programme
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
ECA	Environment Conservation Act
EIA	Environmental Impact Assessment
EMSIP	Eutrophication Management Strategy into Practice
EMSSA	Eutrophication Management Strategy for South Africa
EWRs	Ecological Water Requirements
FRAI	Fish Response Assessment Index
GAI	Geomorphology Assessment Index
GBF	Global Biodiversity Framework
GIS	Geographic Information System
HAI	Hydrology Assessment Index
HDRP	Hartbeespoort Dam Integrated Biological Remediation Programme
HSRS	Hydrosuction Sediment Removal Systems
IAPs	Invasive Alien Plants
ICOLD	International Commission on Large Dam
IHI	Index of Habitat Integrity
IWQM	Integrated Water Quality Management
IWRM	Integrated Water Resource Management
MIRAI	Macro-invertebrate Response Assessment Index
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
MWM	Mine Water Policy
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
NFA	National Forest Act
NFEPAs	National Freshwater Ecosystem Priority Areas
NHRA	National Heritage Resources Act
NPA	National Parks Act
NWA	National Water Act
NWRS	National Water Resource Strategy
NW&SMP	National Water and Sanitation Master Plan
PCOs	Pest Control Operators
PAI	Physico-Chemical Assessment Index
POM	Particulate Organic Matter
RMGs	Rehabilitation Management Guidelines
RQOs	Resource Quality Objectives
RDM	Resource Directed Measures
RWQOs	Resource Water Quality Objectives

SACOLD	South African National Committee on Large Dams
SANBI	South African National Biodiversity Institute
SASS	South African Scoring System
SAV	Submersed Aquatic Vegetation
SESs	Social-Ecological System
SDCs	Sources Directed Controls
SDS	Sourced Directed Studies
SDGs	Sustainable Development Goals
SWSAs	Strategic Water Source Areas
VEGRAI	Vegetation Response Assessment Index
WML	Waste Management License
WRC	Water Research Commission
WULA	Water Use License Application
WUL	Water Use License
WWTWs	Wastewater Treatment Works

GLOSSARY OF TERMS

A dam, in terms of physical appearance, refers to the structural barrier that is constructed across a river or a valley ensure that water is prevented from flowing.

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.

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.

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.

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).

Baczyme is a biological solution for sewage waste, septic tanks, and pit toilets. The product contains organic bacteria that decomposes sewage waste into two main components, water, and carbon-dioxide.

Small dam – wall height lower than 12m; **Big dam** – wall height more than 30m

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.

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.

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.

Spillway - the designed "overflow" section of the dam is called the spillway.

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.

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.

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.

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

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. ***Note:*** *There are two types of chlorophyll:*

- *Suspended chlorophyll which is related to algal cells in the water column; and*
- *Benthic chlorophyll with is related to the literal zone of the dam (e.g. filamentous algae).*

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.

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

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.

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.

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

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.

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

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

A **reservoir** on the other hand is a large waterbody that forms behind a dam to form an artificial lake.

Resource Water Quality Objective (RWQOs) 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.

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

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

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.

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

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.

National Freshwater Ecosystem Priority Areas (NFEPAs) are strategic spatial priority areas or national network of freshwater ecosystem priority areas, including rivers, wetlands and estuaries required to meet conservation requirements for South Africa’s freshwater ecosystems and supporting sustainable use of water resources.

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EXECUTIVE SUMMARY

South African lakes and dams are predominantly impacted by eutrophication, salinisation, sedimentation/siltation, and acidification. In 2017, the Department of Water and Sanitation (DWS) developed the Integrated Water Quality Management (IWQM) Policies and Strategies, which identified the above-mentioned impacts as priority water quality issues that require intervention as a matter of urgency for lakes and dams.

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

The project aims to address the lack of Rehabilitation Management Guidelines (RMGs) for Lakes and Dams for ecological functioning which includes measures/interventions/best management practices relating to the rehabilitation of dams for hydrological and ecological connectivity which is currently not documented in the literature. It is for this reason that the DWS is developing Lakes and Dams RMG to address characteristics of watercourses, namely hydrology, geomorphology, water quality, habitat, and biota through following a phased approach, namely; diagnostic, planning, and assessment, setting of the rehabilitation objectives, execution, and monitoring phases. The following are key aspects covered to address the shortcoming for each characteristic of the watercourse:

- Description of the specific characteristics of the watercourse;
- Types of impacts for each characteristic of the 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 the watercourse; and
- Step-by-step guidelines on rehabilitation measures/interventions for executing rehabilitation - planning, design, implementation, and monitoring.

Human-induced disturbances such as constructed weirs within rivers/dams change the hydrology, physico-chemistry, and connectivity of river ecosystems. Abstraction of water from the dam for irrigation purposes and other uses results in the decline of water levels which has a direct impact on ecological category, habitat, and biota of the riverine systems. Climate change also causes shifts in vegetation cover that may lead to increased erosion rates, which can be expected to increase the rates of sedimentation in reservoirs. Rehabilitation Management Guidelines for hydrology have been developed with a focus on re-design and maintenance of improperly designed weirs to restore/improve flow characteristics conditions of associated instream dams.

Agriculture is a major source/cause of increased erosion. Most cultivated agricultural soil remains with insufficiently developed vegetation for long periods. Intensive agricultural practices *(i.e.,* overgrazing) with loss of soil cover, erosion by cultivation of steep slopes and fertiliser application dominate the physiography of the catchment, increasing erosion and leaching processes which affect the water quality in dams. Human-induced activities and unsustainable land management practices such as agricultural farming practices and sand mining contribute to erosion, sediment transport, and deposition of sediments throughout the river basin. In terms of geomorphology, the RMGs have been developed with a focus on the rehabilitation of disturbed vegetation (upstream and downstream of dams) to promote flood attenuation and soil stabilisation.

Eutrophication driven by effluent discharge from Wastewater Treatment Works (WWTWs) affects water quality and poses a health risk to humans and negatively impacts ecosystems and species. Acid mine drainage (AMD) is another impact causing enduring environmental and water quality problems. Salinisation, which is the build-up of salts in a river system, poses a threat to the ecological integrity of a lake or dam and interferes with the desirable uses of the water. Rehabilitation Management Guidelines have been developed to address effluent from WWTWs.

Sediment trapping by dams result in the accumulation of sediment in dams which affects the ecosystem's structure and function. It alters aquatic ecology, affecting species composition and ultimately both recreational and subsistence fishing. It also reduces the storage capacity of the dams to an extent that dams lose their functionality. Rehabilitation Management Guidelines have been developed for habitat with a focus on rehabilitation for sedimentation for the ecological functioning of the aquatic ecosystem and improvement of dam storage capacity.

The presence of existing instream barriers (*i.e.,* weirs and dams) to migratory species in rivers 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 migrate annually within river/wetland systems to optimise feeding, promote dispersal, avoid unfavourable conditions, and enhance reproductive success. Rehabilitation Management Guidelines have been developed for biota with specific reference to re-establishing species migratory routes.

1. INTRODUCTION

1.1 BACKGROUND

In South Africa, dams and lakes are reported to be degraded by eutrophication, salinisation, sedimentation/siltation, and acidification (IWQM, 2017). In 2017, the Department of Water and Sanitation (DWS) developed the Integrated Water Quality Management (IWQM) Policies and Strategies, which identified the above-mentioned impacts as priority water quality issues that require intervention as a matter of urgency for dams and lakes.

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

In the Situation Assessment Phase of the project, it was found that the majority of the studies and practices conducted on the rehabilitation of lakes and dams in South Africa are mainly structural and geotechnical related. This presents a challenge to the current guidelines since the focus is on the rehabilitation of water resources for ecological functioning.

The DWS plays a major role in regulating the use of our water resources and ensuring the safe operation of dams in the country. This is achieved through two programmes namely, the Dam Safety Evaluation Programme (DSEP) and the Dam Safety Rehabilitation Programme (DSRP). The DSEP include conducting 5 yearly dam safety evaluation on the dams owned by the department. The DSRP is informed by the recommendation from the 5 yearly dam safety evaluation. The DSRP implement the recommendations from the DSEP by rehabilitating dams to comply with the dam safety regulations. These programmes ensure that the dam safety guidelines by the South African National Committee on Large Dams (SANCOLD) and International Commission on Large Dams (ICOLD) are adhered to. Although programmes and initiatives have been developed and implemented, below is a list of gaps identified from the review conducted:

- Lack of Rehabilitation Guidelines for lakes and dams for ecological functioning.
- Lack of rehabilitation measures/interventions/best management practices relating to rehabilitation of dams for hydrological and ecological connectivity, decommissioning of dams (*i.e.,* demolishing of dams and weirs) for ecological functioning and gain.
- There is no rehabilitation programme to address all characteristics of watercourse for dams like surface flow, interflow, groundwater flow, geomorphology, habitat, and biota.

Based on the gaps and shortcomings identified, it is evident that there are Dam Safety Guidelines in place, but they only address engineering-related rehabilitation. It is against this backdrop that the development of Rehabilitation Guidelines for Lakes and Dams was initiated (*e.g.,* re-design and maintenance of improperly designed weirs to restore/improve flow characteristics conditions of associated instream dams).

1.2 DEFINITIONS OF LAKES AND DAMS

There are two types of lakes, namely, natural lakes and artificial lakes (reservoirs and dams). These resources play an important role in water supply, biodiversity, habitat, and flood control, and they are also important culturally and aesthetically. Water supply is one of the factors necessary for economic development and it plays an important role in the development of society. The water source (*i.e.,* contribution of groundwater vs surface water) is one of the key differences between these waterbodies. Natural lakes are generally subdivided based on hydrology, whereas artificial lakes are often categorised based on their size and their primary reason for being constructed (Hayes, *et. al.* 2017). **Figure 1** provides key differences between lakes and reservoirs.

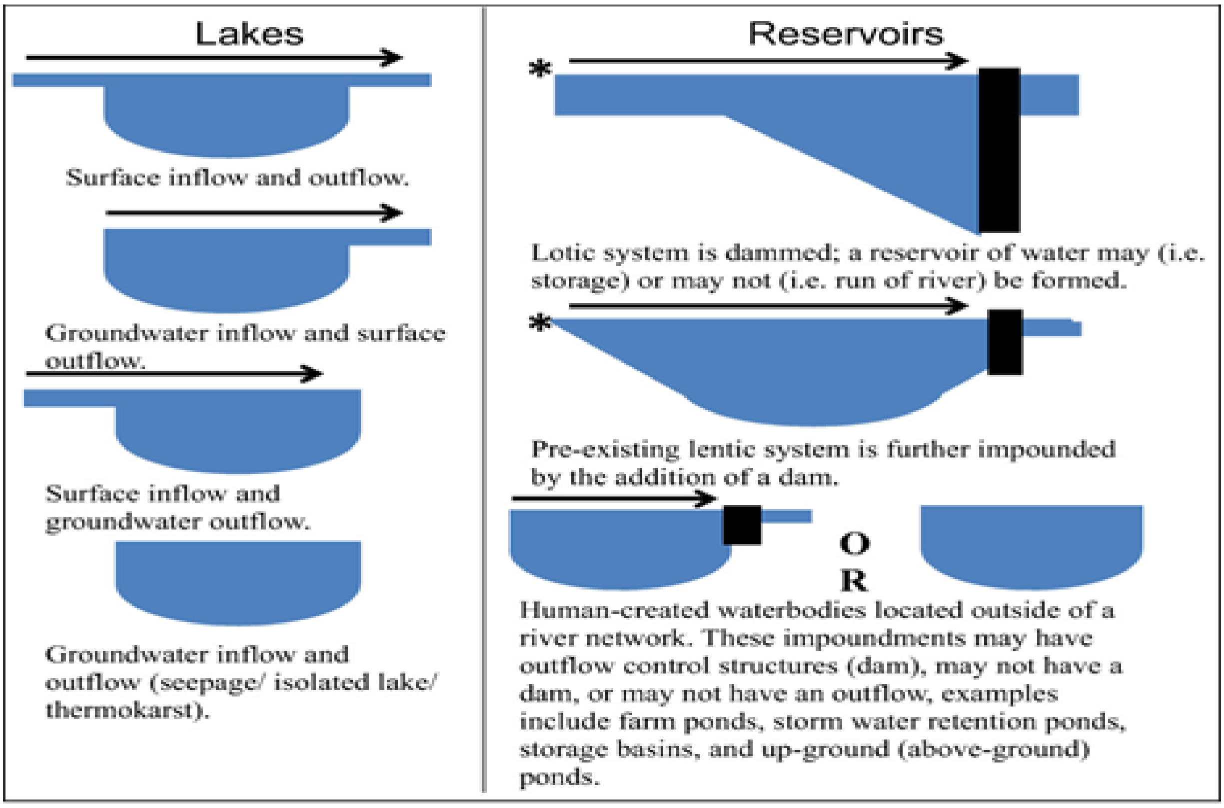

Figure 1: Key differences between lakes and reservoirs
Source: Hayes *et. al.,* 2017

A dam (**Figure 2**, represented by blue and orange broken lines)**,** in terms of physical appearance, refers to the structural barrier that is constructed across a river or a valley ensure that water is prevented from flowing. When the impounded water exceeds the full supply level of a dam, the water will then be conveyed downstream in a controlled manner by means of a spillway[1] (**Figure 2** and **3,** represented by orange broken lines), with other releases from a dam often done by means of an outlet pipe. A dam is used mainly for storage of water for supply and electricity generation. It is useful for control or attenuation of floods, and it may often serve as a tourist attraction. A dam, if not appropriately designed and constructed, can prevent the migration of fish species upstream and downstream of a river. **A reservoir** (**Figure 2**, represented by blue solid lines) on the other hand is a large waterbody that forms behind a dam to form an artificial lake. A reservoir is used to supply water for consumption and agricultural purposes and is often used as a recreation site (fishing, boat activities). A reservoir, once created by the construction of a dam *i.e.,* a small dam with wall height lower than 12m or big dam with a wall height more than 30m, requires people/communities residing within the reservoir basin (typically below the 1 in 100-year flood level) to be relocated to another area as it presents a risk of inundation.

[1] *The designed "overflow" section of the dam is called the spillway.*

The familiar term for artificial lakes in South Africa is dams. Therefore, for this project "Rehabilitation Management Guidelines" and convenience, artificial lakes will be referred to as dams. It must also be noted that natural lakes and artificial lakes will be grouped in one guideline document which is **Rehabilitation Management Guidelines for Lakes and Dams** in terms of their interactions with characteristics of watercourses, namely, hydrology, geomorphology, water quality, habitat, and biota**.**

Figure 2: Midmar Dam situated in Kwazulu-Natal Provincial
Source: DWS Hydrological Services website, 2024

Figure 3: A spillway on the Metsi-Matsho Dam in the Free State Province
Source: DWS Hydrological Services website, 2024

1.3 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 watercourse is contained in the definition above as well as in* ***Section 3****.1 and* ***3.2*** *of the report.*

1.4 PURPOSE FOR DEVELOPMENT OF THE REHABILITATION MANAGEMENT GUIDELINES FOR LAKES AND DAMS

The primary objectives of the guidelines are to:

- Develop Rehabilitation Management Guidelines for Lakes and Dams in terms of their interactions with characteristics of watercourses, namely, hydrology, geomorphology, water quality, habitat, and biota; and
- Integrate, align, and harmonise lakes and dams rehabilitation work across various disciplines and institutions.

1.5 GUIDING PRINCIPLES AND APPROACH FOR DEVELOPMENT OF THE GUIDELINES

The current Rehabilitation Management Guidelines will be developed for characteristics of watercourses, namely; hydrology, geomorphology, water quality, habitat, and biota.

The following are aspects to be covered under each characteristic of the watercourse:

- Description of the specific characteristics of the watercourse;
- 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

The need for rehabilitation arises due to degradation attributed amongst others to "natural" (lake aging) or "cultural" (as a result of human impacts) factors. 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 the status quo;

- Determining the original unimpacted state to serve as baseline or reference conditions 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 major abiotic drivers of the ecosystem;
- 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;
- Monitoring should be an essential component of rehabilitation.

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 Lakes and Dams Rehabilitation Management Guidelines being developed aim to guide the water users on step-by-step rehabilitation measures/interventions to be followed for executing rehabilitation with specific attention to and consideration of planning, design, implementation, and monitoring for the identified impacts. **Table 1** below presents the approach to be followed for the development of the RMGs for Lakes and Dams guidelines.

Table 1: Approach to be followed for development of Rehabilitation Guidelines for lakes and dams including the associated characteristics of watercourses.

Stakeholder Engagement

Phase	Description
PHASE 1: Diagnostic Phase	• The characteristics will be diagnosed to identify the cause/source of impact; and determine the level of modification and rehabilitation measures will be recommended to reinstate the conditions of the drivers. • Describe the characteristics, if possible, of the target system before the occurrence of the impact. This will assist in determining clear Rehabilitation Objectives. • Determine the conditions and the type, size, extent of impacts and vegetation cover/ species on characteristics of watercourses.
PHASE 2: Planning and 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 the resources ecosystem.
PHASE 5: Monitoring, Evaluation (M & E) and Reporting	• Monitor the results of the techniques and methods employed for rehabilitation to determine whether objectives are being achieved and whether there are any additional interventions required. • Evaluate the effectiveness of interventions against the achievement of rehabilitation objectives and outcomes. • Determine maintenance objectives. • Compilation of Rehabilitation Report *i.e.,* record implementation on a database for reporting intervention type and extent.

Note:

- *The studies and remedial actions should be undertaken by suitably trained and qualified professionals/specialists i.e., Hydrologist, Ecologist, Botanist, Aquatic Scientist / Limnologist/ Ichthyologist, Water Engineer etc.*
- *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. In addition, the expected outcomes of monitoring and evaluation can be achieved through the use of available knowledge hubs. The outputs of monitoring should be reported to the relevant international frameworks i.e., SDGs, GBF.*

1.6 INTENDED USERS OF THE GUIDELINES

The RMGs for Lakes and Dams 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 issues and aspects. The guidelines are intended for all Government Departments (National, Provincial and Local), Catchment

Management Agencies (CMAs), sectoral institutions (*i.e.,* higher education institutions), civil society members, non-governmental entities, private sector (agriculture, industries, mining) and all interested and affected parties involved in the water sector. The guidelines are developed at a national scale for implementation at a catchment level.

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 Lakes and Dams rehabilitation.
- **Section 3** describes the characteristics of watercourses and their linkage to water resources.
- **Section 4** provides the overarching water resource impacts and degradation impacts associated with characteristics of watercourses.
- **Section 5** provides step-by-step Technical Rehabilitation Guidelines for characteristics of watercourses.
- **Section 6** provides recommendations and a way forward.

2. LEGAL FRAMEWORK

2.1 OVERARCHING LEGAL FRAMEWORK

The DWS as the mandated authority over water resources has undertaken to review, revise and update its policies, strategies, guidelines, and systems to align with the laws of the new Democracy and the Constitution of the country. Hence, the development of *Rehabilitation Management Guidelines for Lakes and Dams.*

Table 2 provides pieces of legislation that relates to lakes and dams management. It must be noted that there is no single legislative system specifically for lake management, however, they have been catered for in various legislations (acts) which have been enforced by a wide range of authorities with differing objectives and approaches. These authorities include but are not limited to the DWS, Department of Forestry, Fisheries, and the Environment (DFFE), South African National Biodiversity Institute (SANBI), SANParks Board and provincial nature conservation departments.

Table 2: Authorities responsible for lakes and dams management and objectives of relevant acts.

Act	Description
Constitution of the Republic of South Africa, 1996	The Bill of Rights contained in Chapter 2 of the Constitution applies to all law and binds the legislator, the executive, the judiciary, and all organs of the state. Section 24 makes provision to the right of an environment that is not harmful to their health or well-being; and have the 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 sustainable development and use of natural resources while promoting justifiable economic

Act	Description
	and social development. Whereas Section 27(1)(c) makes specific provision to access of sufficient water.
The Lake Areas Development Act, 1975 (Act 39 of 1979)	The Minister of Environment Affairs may, by notice in the Government Gazette, declare any land comprising or adjoining a tidal lagoon, a tidal river or any part thereof, or any other land comprising or adjoining a natural lake or river or any part thereof which is within the immediate vicinity of a tidal lagoon or a tidal river, to be a Lake Area. This Act may serve to protect the natural habitats in and around lakes.
National Water Act (NWA), 1998 (Act 36 of 1998)	The NWA provides the legal framework for the effective and sustainable management of our water resources. The Act aims to protect, use, develop, conserve, manage and control water resources as a whole, promoting the integrated management of water resources with the participation of all stakeholders. **Chapter 3** specifically provides for the protection of water resources. The aim of protecting water resources is to ensure that water is available for current and future use. This is achieved by leaving enough water of a certain quality in the water resources to maintain the overall ecological functioning of the rivers, lakes and dams, wetlands, groundwater, and estuaries. Protection of the water resource is therefore about the quantity and quality (overall health) of the nation's water resources. Some water resources are already overused and polluted, the available water is already taken, and the surrounding environment is in a poor state. Hence, there is a need for rehabilitation and protection of water resources.
Environment Conservation Act (ECA), 1989 (Act 73 of 1989)	Provides for the protection and controlled utilisation of the environment and the determination of policy to protect, use sustainably, and rehabilitate the environment
National Environmental Management (NEMA) Act, 1998 (Act 107 of 1998)	NEMA provides for co-operative environmental governance by establishing principles for decision making on matters that are affecting the environment and providing for certain aspects of the administration and enforcement of other environmental management laws. Environmental law encompasses the following three distinct but interrelated areas of general concern (DWS, 2021): • Land-use planning and development; • Resource conservation and utilisation; and • Waste management and pollution control. The provisions and regulations of Government Notice NR. 543 to R. 547, dated 18 June 2010, promulgated in terms of NEMA regarding control over activities that may have a detrimental effect on the environment must be complied with. Normally it will be required that an Environmental Impact Assessment (EIA) be carried out before any works *i.e., rehabilitation, restoration, enlargement, or repair,* of an existing dam will be authorised. Written authorisation must be obtained from the relevant provincial government department before the commencement.
National Environmental Management: Biodiversity Act (NEM: BA), 2004 (Act 10 of 2004)	Aims to provide for the management and conservation of South Africa's biological diversity, the protection of both ecosystems and species in need of protection and the sustainable use of indigenous biological resources. In terms of its relevance to protecting lakes, the Act gives effect to relevant international agreements which South Africa is a party of (*i.e.,* the Ramsar Convention on Wetlands and the Convention on Biodiversity), as well providing for co-operative governance, which is important when there are a number of agencies at different tiers of government responsible for the management of ecosystems (O'Sulliva and Reynolds, 2005).
National Parks	South African National Parks is responsible for inclusive nature conservation and to advance

Act	Description
Act (NPA), 1976 (Act 57 of 1976)	nature conservation policies in line with the National Development Framework for Sustainable Development and the National Development Plan; and the objective of the NPA is to establish national parks for the preservation and study of wild animal, marine and plant life and objects of geological, archaeological, historical, ethnological, oceanographic, educational and other scientific interest and objects relating to the life, events or history of the park, which is retained in its natural state for the benefit of visitors.
National Forest Act (NFA), 1998 (Act 84 of 1998)	The purpose of the Act is to promote the sustainable management and development of forests for benefits of all and it provide special measures for the protection of certain forests and trees. The act provides for legal protection of all South African natural forests. The 26 National Forests type of South Africa has been declared under Section 7(2) of NFA (include Mangrove forests, Swamp Forests and Lowveld Riverine Forests). Changes in the structure and functioning of ecosystems could cause the impact and functioning of forest ecosystems and biodiversity.

Note: *The DWS GA 509 of August 2016 was revised and replaced with GA 4167 of December 2023. The GA makes provision for rehabilitation work in general that will enhance the 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 watercourses; and if any of those activities in terms of rehabilitation constitute those water uses, they need to get authorized accordingly.*
- *The RMGs provide guidance to 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 AND STRATEGIES

Various policies, strategies and guidelines inform Lakes and Dams Rehabilitation Management in South Africa. **Table 3** below provides a summary of the most prominent policies and strategies that give direction to the rehabilitation of Lakes and Dams in South Africa and highlights of their important aspects for alignment with the rehabilitation of lakes and dams.

Table 3: Alignment of policies and strategies with the rehabilitation of lakes and dams

Policies and Strategies	Alignment with the Rehabilitation of Lakes & Dams
National Water Resource Strategy (NWRS)	The NWRS is a statutory strategy, required in terms of the NWA, is binding on all authorities and institutions implementing the Act and provides the framework for integrated water resource management for the country as a whole, and within which water resources will be managed at the regional or catchment level.
National Water and Sanitation Master Plan (NW&SMP)	NW&SMP constitutes the roll-out mechanism for NWRS implementation and specifies, inter alia, priority budget items,

Policies and Strategies	Alignment with the Rehabilitation of Lakes & Dams
	scheduled up to 2030 and beyond, for the entire water sector (DWS, 2021).
Draft Rehabilitation Policy	Laid a foundation for DWS to implement, regulate and facilitate Environmental Rehabilitation within its mandate as custodian of water resources. One of the objectives of this initiative was to perform environmental rehabilitation that is associated with water resources development impacts to acceptable international standards.
Integrated Water Quality Management Strategy (IWQM), 2017	The IWQM Strategy sets out strategic actions which are required to be undertaken to realise the vision and goals for water quality in South Africa. It articulates the broader process of IWQM and provides the prioritised strategic actions that need to take place in relation to the management of water quality in a holistic manner such as coming up with strategies and guidelines to manage water resources and priority water quality issues such as eutrophication, salinisation, sedimentation/siltation, and acidification that require intervention as a matter of urgency.
Eutrophication Management Strategy for South Africa (EMSSA)	The EMSSA gives direction with the respect to the management of eutrophication, specifically, the control of anthropogenic sources of excessive nutrient enrichment from a strategic country-perspective. EMSSA vouches for the rehabilitation and restoration of ecological infrastructure, rehabilitation of hard infrastructure as well as adequate maintenance of water resources and services infrastructure as some of the responses to drivers of the degradation of water resources. Further, it promotes the rehabilitation and restoration of affected water resources, including the implementation of bio-remediation initiatives, such as the Harties Metsi-a Me/ Hartbeespoort Dam Biological Remediation Project, in affected water resources which should be supported to attain more innovative and progressive solutions to address issues such as eutrophication problems.
Mine Water Policy (MWM)	The DWS formulated the policy on the management of mine water due to legacy impacts of mining in South Africa, together with the socio-economic stimulus triggered by current and potential mining mega-developments in Mpumalanga, Limpopo, Free State, North-West and the Northern Cape provinces. The Policy is aimed to respond to cross cutting mine water management issues in abandoned and ownerless mines, mines that are currently active, and in proposed mining operations. The MWM Policy of 2022 is supported by principles of the IWQM Policy which itself seeks to amalgamate and describe an integrated, inclusive, and adaptive approach to IWQM; amplifies the principles of sustainable development; addressing gaps in policy and legislation; and invoking of the "polluter-pays" principle framework. The Policy further sets out the vision, goal, values, underlying principles, and policy responses for managing the overall quality of our water resources.

In addition to the strategies and policies listed in **Table 3**, the below is a list of other related policies strategies, principles, and concepts:

- The implementation of Resource Directed Measures (RDM), particularly the Reserve, Water Resources Class, Resource Quality Objectives (RQOs) and Source Directed Controls (SDCs) is founded on principles of improving water resources quality and reducing deterioration where applicable.

- The implementation of Catchment Management Strategies as informed by the National Water Policy to provide the framework for managing water resources within the water management area.
- Policy principles and guidelines for control of development 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.

Other 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 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.
- 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.
- 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.
- 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).

3. CHARACTERISTICS OF WATERCOURSES

3.1. INTRODUCTION TO CHARACTERISTICS OF WATERCOURSES

A comprehensive process of water resources rehabilitation requires attention to be given across the board to characteristics of watercourses, namely, hydrology, geomorphology, water quality, habitat, and biota.

For all the above-mentioned characteristics, rehabilitation of watercourses is limited, and a practical case is that some dams are not catered for ecological releases. Generally, rehabilitation concerning shaping, re-vegetation, and alien and invasive species (AIS) (including other related invasive species *i.e., Potamogeton, Lagarosiphon, and Stuckenia*) eradication is limited under the NWA. Rehabilitation interventions and practices that focus on and include water quality issues such as pollution from WWTWs and from non-point sources are also limited. There are multiple concerns on the issues of rehabilitation and the main factors are mines, WWTWs as well as poor compliance and implementation of legislation in terms of buffers to watercourses. Therefore, the need for the development of rehabilitation guidelines with a focus on the characteristics of watercourses is essential.

To this end, to develop such guidelines, it is important to consider factors (drivers and responses) that underpin water ecosystem health and functionality. **Figure 4** 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, and the habitat (vegetation) and biota (fauna) are the responses but are interlinked.

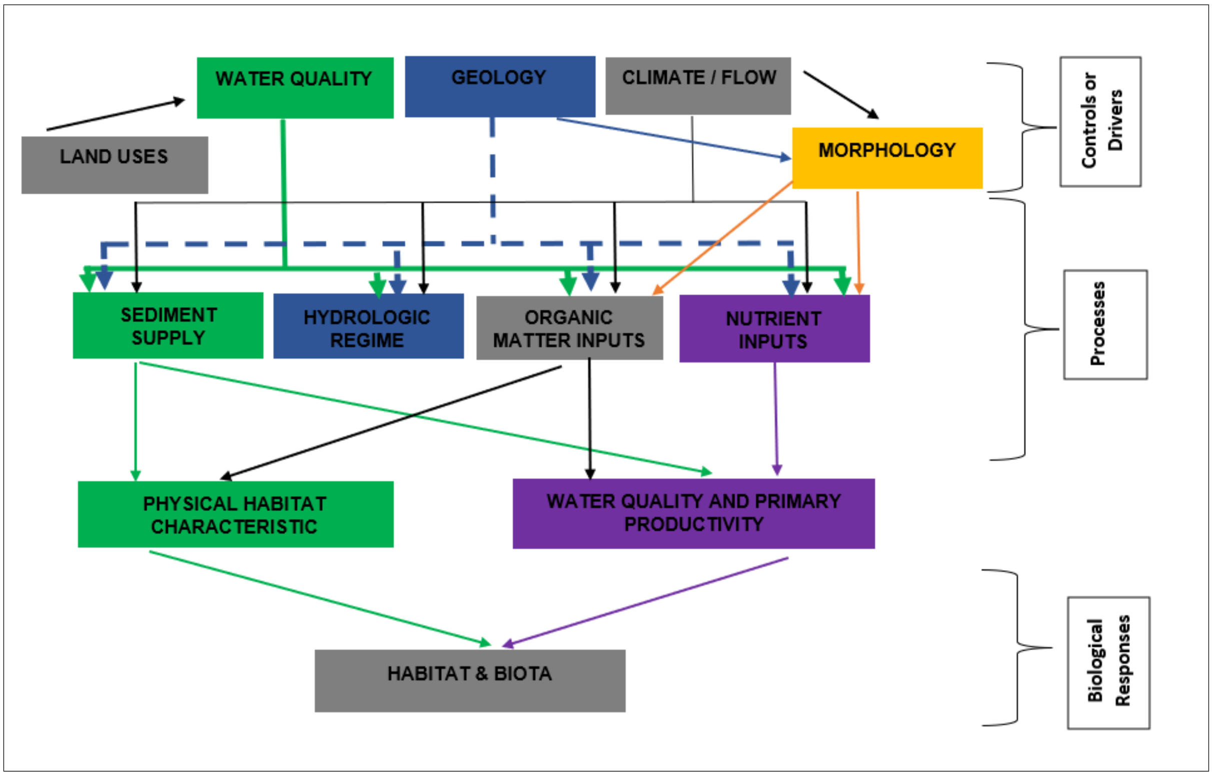

Figure 4: The Ecological Water Requirements of the Reserve including drivers and responses
Source: Beechie and Bolton, 1999

3.2. LINK BETWEEN WATER RESOURCES AND CHARACTERISTICS OF WATERCOURSES

The rehabilitation of water resources is directly linked to the rehabilitation 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, water quality, geomorphology, habitat, and biota. The other reason is that dams share the same characteristics as 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 or measures, dams need operating rules while rivers need Ecological Flow requirements/ Ecological Water Requirements. **Figure 5** below illustrates the link between water resources and the characteristics of watercourses.

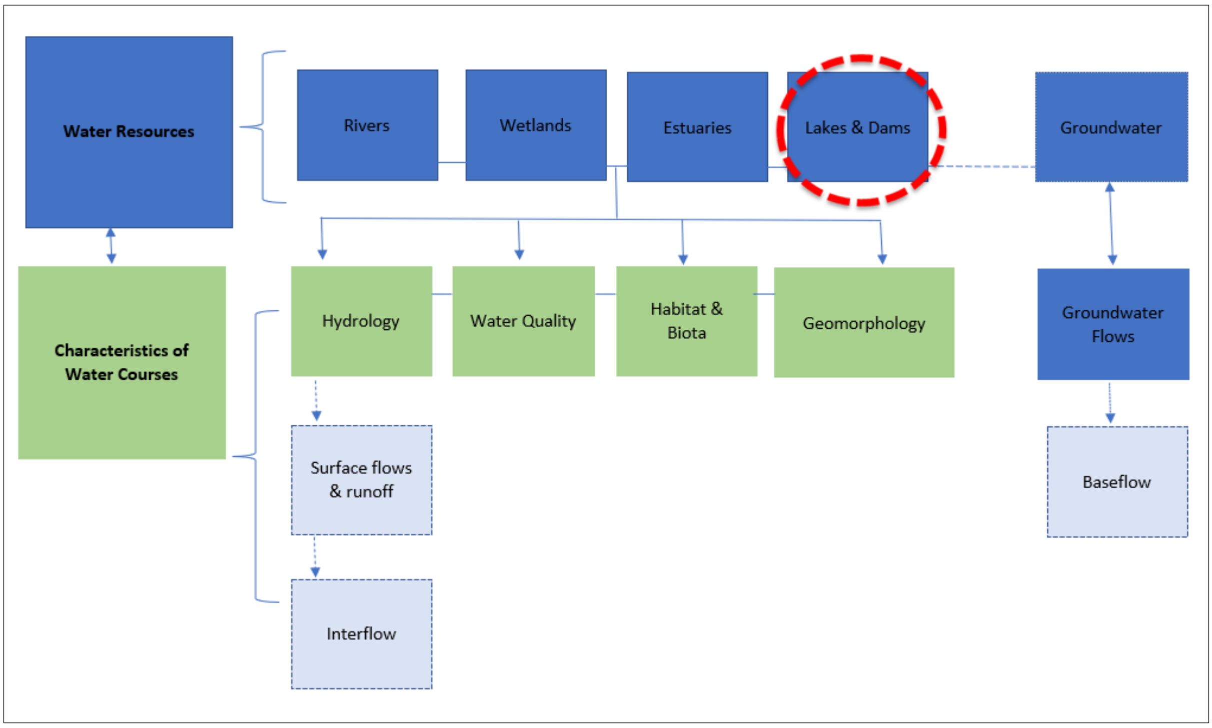

Figure 5: Diagram depicting the link between water resources and characteristics of watercourses.

4. IMPACTS CAUSING DEGRADATION OF LAKES AND DAMS

Artificial reservoirs (*i.e.,* dams) experience degradation and loss of storage (*i.e.,* become shallower) capacity at a faster rate than lakes. This problem applies particularly to small retention reservoirs, localised areas dominated by anthropogenic and agricultural activities. The phenomenon is due to natural conditions of water catchment areas and the supply of external organic and mineral matter, as well as their low resistance. The degree of natural resistance to the impact of the water catchment area depends on the depth of the reservoir, its capacity ratio, and the length of the coastline (Bartoszek and Koszelnik, 2015).

In South Africa dams and water reservoirs have been reportedly impaired by sedimentation, mineralisation/salinisation, nutrient enrichment (at an excessive rate leads to eutrophication) and acid mine drainage (AMD). These impacts are either related to natural or anthropogenic activities as depicted in **Figure 6**. In addition, the key pressures on South Africa's freshwater lakes are reported to be changes to the hydrological regime, water pollution, habitat modification, invasive species, and climate change (SANBI, 2019). Further information on the impacts is covered in detail under **Section 5** of the guidelines.

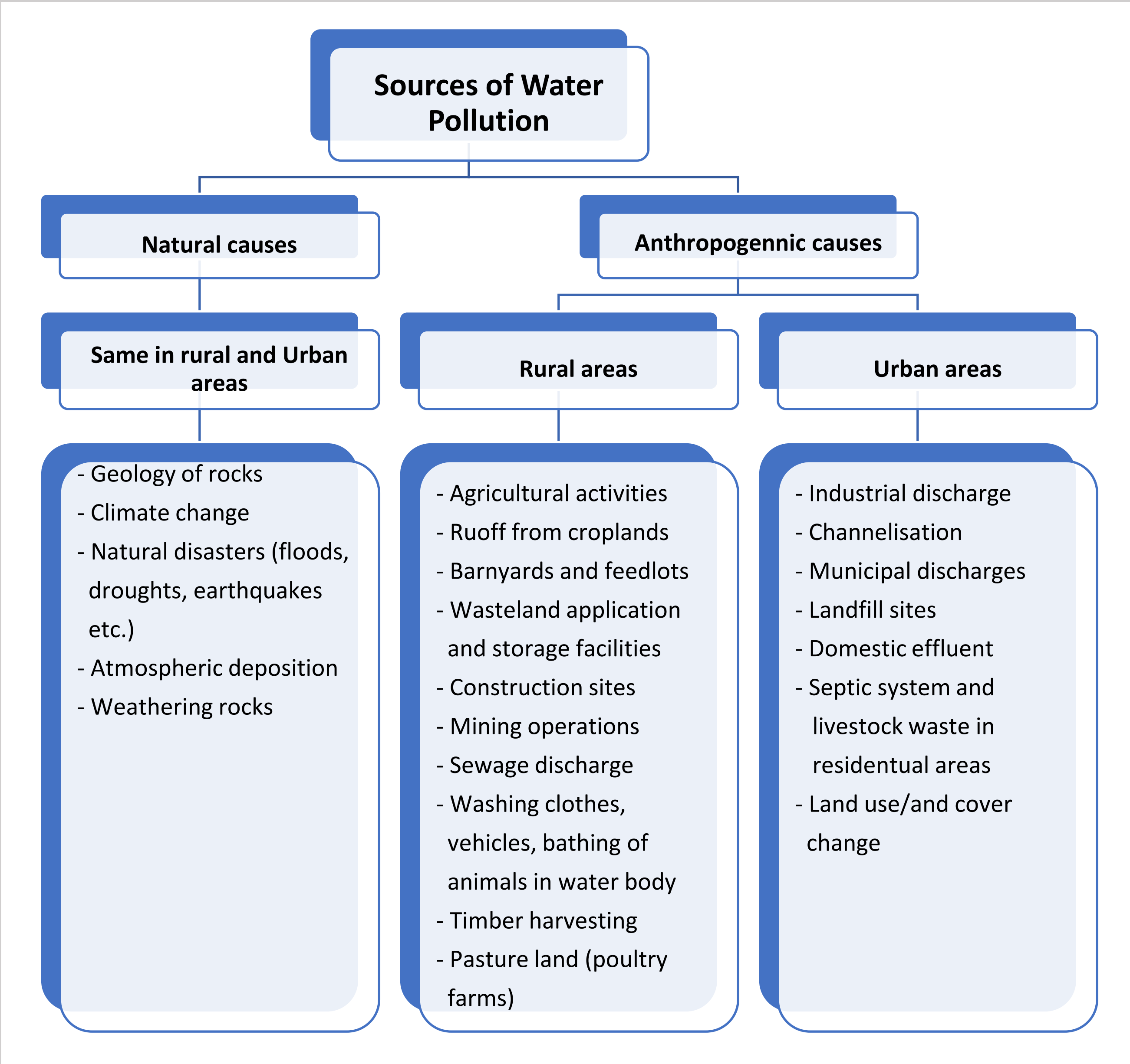

Figure 6: Natural and anthropogenic impacts on lakes and dams
Source: modified after Khatri and Tyagi, 2014

In addition to the natural and anthropogenic sources of pollution presented in **Figure 6,** below is a summary of the water quality impacts prevalent in lakes and dams:

- Eutrophication – excessive nutrients (nitrogen and phosphorus) loading in water through point and non-point sources is an ecological concern and affects water quality in surface water bodies. In addition, human and aesthetic impacts include odour and taste problems, morbidity and mortality due to potential toxic cyanobacteria biotoxins;
- Algal blooms – algae growth in canals block irrigation systems;
- Organic pollution – pesticides and herbicides used in agricultural activities cause reduction of dissolved oxygen and negatively impacts aquatic organisms and fish;
- Turbidity – high levels of turbidity reduce aquatic light levels and affects the rate of photosynthesis in aquatic organisms;
- Low oxygen levels – reduced oxygen levels have a negative impact on the life of aquatic organisms and fish; and

- Ecological impacts – nutrient loads from domestic wastewater treatment plants, fertilisers from agricultural lands and urban areas cause change in aquatic life *i.e.,* alteration of fish population and reduction of biodiversity.

5. GUIDELINES FOR CHARACTERISTICS OF WATERCOURSES

5.1. HYDROLOGY

5.1.1. Description

Rivers are characterised by connectivity in three dimensions, namely, longitudinal (*i.e.,* upstream-downstream), lateral (*i.e.,* channel to floodplain and side channel), and vertical (surface-groundwater) (Kondolf, 2006). Dams affect the longitudinal continuity of river systems directly, and, through changes in flow regime and induced changes in channel form, can also reduce lateral connectivity (Kondolf and Yi, 2022). Moreover, these changes can also reduce vertical connectivity.

5.1.2. Types of Impacts

5.1.2.1. Constructed weirs.

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. **Figure 7** below illustrates a typical example of a weir structure (Station ID: C2H007; Place: Vaal at Orkney) located within the Vaal Water Management Area (WMA 5).

Figure 7: A weir structure located within the Vaal WMA
Source: DWS Hydrological Services website, 2024

A weir is used to prevent and attenuate flooding, measure water flow, and hold water. A weir will typically disrupt life-cycles, reduce gene pools, and create conditions where fish become more susceptible to disease and predation, and hence it can have a detrimental effect on the local ecology of a river system. A weir can artificially reduce the upstream water velocity, which can lead to an increase in siltation.

Although many benefits of weirs are reported, their incorrect design, construction, or placement may result in profound effects on riverine ecosystems.

Weirs are reported to impact river ecosystems negatively by changing the geomorphology, hydrology, physico-chemistry, and connectivity of river ecosystems (Doyle *et al*., 2005; Csiki and Rhoads, 2010) as detailed below:

- **Hydrological effects** - weirs raise water levels upstream to the height of the weir crest or higher. As a consequence of the increased river levels and loss of gradient caused by weir impoundment, velocities upstream are reduced (Stanley *et al*. 2002; Pohlon *et al.* 2007; Mueller *et. al.,* 2011). This decrease in river velocity can extend several kilometers upstream of a weir, depending on the bed gradient.
- **Physicochemical effects** - dependent on the type of weir impoundment, the physico-chemical characteristics of a river are also altered. Weir ponds tend to cause the accumulation of particulate organic matter (POM), which in turn leads to a higher biochemical oxygen demand (BOD) (Pohlon *et al*., 2007).
- **River connectivity effects** - weirs pose a barrier to fish movement and have been found to delay or prevent upstream migration of aquatic species.
- **Biotic effects** - weirs directly affect life in rivers by breaking up the river connectivity and altering the riverine environment. Evidence for this effect has been collected for many groups of organisms such as benthic algal communities, zooplankton fauna, macro invertebrates, and aquatic vegetation.

5.1.2.2. Dam/Lakes Induced Impacts on Connectivity and Flow; and Loss in hydrological connectivity.

Dam/Lakes-induced changes in river flow regimes vary widely, depending on the natural hydrology of the river, and the purpose, size, geometry, and operation of the dam and reservoir (Kondolf and Yi, 2022). The changes in the flow regimes induce changes in river ecology in multiple ways. River flow and sediment load create physical habitats, such as bars, riffles, pools, and floodplains. Changes in flow regimes can result in changes to these features (Ashraf *et al.,* 2022). Artificially modifying the seasonal flow regime can disrupt ecological responses, habitat, biota (various life stages of organisms, such as reproduction, juvenile growth, and migration), and adult migration because aquatic species have evolved to adapt to natural seasonal patterns of flow.

Flow alteration (by construction of dams, weirs, abstractions, diversions etc.) is one of the key impacts by humans on freshwater ecosystems. Anthropogenic activities can significantly alter the flow and may lead to biological impairment. Flow alteration refers to the modification of flow characteristics, or natural conditions which may lead to changes of biotic community composition. 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 altered depends on the river hydrological change (Rolls and Bond, 2017).

5.1.2.3. *Water abstraction*

Abstraction of water from rivers and dams for irrigation purposes and other uses results in the decline of water levels, affects ecological releases and reduces assimilative capacity of the resource and impacts water quality; all of which have a direct impact on ecology, habitat (destruction of riverine forests /woodland), and biota (*i.e.,* animal and plant species) of the riverine systems.

5.1.2.4. *Climate Change*

Climate change causes flooding and desertification resulting in the shift of vegetation cover that may lead to increased erosion rates, which can be expected to increase the rates of sedimentation in reservoirs (Nearing *et al.,* 2004). Even larger changes are documented from land-use changes in river basins draining to dams, with road construction, mining, and land-clearing for agricultural expansion or alien vegetation clearing in the upper catchments being among human actions with the greatest impact on flow and sediment loads reaching dams.

5.1.3. Rehabilitation Management Guidelines for Hydrology

Scenario 1: Re-design and maintenance of improperly designed weirs to restore/improve flow characteristic/conditions of associated instream dam/lake.

Note: *For purpose of this scenario, the assumption is that the functioning of the weir has been disrupted due to flood events that deposit debris and scour the foundation of the weir; rehabilitation activities must be undertaken to restore its functioning.*

Typical examples *of* ***expertise*** *required to undertake rehabilitation for Hydrology component: Hydrologist, Aquatic Scientist / Limnologist, Ichthyologist, Water Engineer etc.*

PHASE 1: Diagnostic Phase

Step 1: Identify the weir in question within the river/stream that is affected.

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: At a desktop level, use mapping various tools such as Google Earth Pro/Engine, aerial or satellite images, Geographical Information System (GIS), and/or Remote Sensing methods to obtain baseline information. It should be noted that the use of the above tools will not necessarily result in all information required on the affected weir. Therefore, the type of weir affected should be verified and validated in terms of type and extent during the site visit to be undertaken in the planning and assessment phase. Some examples of the different types of weirs include:

- Sharp crested weir, Broad crested weir (or broad-crested weir), Crump weir, Needle dam, Proportional weir, Combination weir, MF weir, V-notch weir, Rectangular weir, Cipolletti (trapezoidal) weir, and Labyrinth weir.
- **Figures 8-10** illustrate some of the above-mentioned weirs.

Figure 8: Example of a compound sharp-crested weir in the Vaal River downstream of Vaal Dam

Source: Wessels and Rooseboom, 2009

Figure 9: Example of a horizontal compound Crump weir without dividing walls in the Vaal River catchment (Mpumalanga)

Source: Wessels and Rooseboom, 2009

Figure 10: Example of a V-shape Crump weir in the Mooi River near Potchefstroom (North-West Province)
Source: Wessels and Rooseboom, 2009

PHASE 2: Planning and Assessment

Step 1: Undertake a site visit to collect pertinent information and data regarding the weir in question. The information and data may include but are not limited to the following:
- Site location and description of the locality within which the weir is located;
- Biodiversity features associated with the weir;
- Designs and dimensions;
- Weir hydraulics;
- Construction material used for the weir *i.e.,* rock-filled gabions, reinforced concrete, mass concrete.

Step 2: Based on information collated in **Step 1,** determine the main factors affecting the functioning of the weir. Examples of impacts are as follows:
- Flooding events;
- Deposit of debris;
- Scouring of foundation of weir;
- Erosion and siltation clogging the weir;
- Degradation, and ageing of the weir; and
- Structural impacts.

PHASE 3: Identify and define the Rehabilitation Objectives

The objectives of the rehabilitation of weirs must be clearly defined and set. The objectives must be informed by the data collated in **Phase 1** and **2** above. Some of the most common aims and objectives of rehabilitation of weirs are to:

- Mitigate the increased runoff and prevent flooding events;
- Provide a passageway, *i.e.,* a fishway for migratory fish;
- Operate dam to natural flow and temperature regimes;
- Ensure Ecological Water Releases; and

- Correct structural problems *i.e.,* deterioration of concrete, failure of spillways, cavitation of outlet pipes[2].

PHASE 4: Execution

There are several rehabilitation methods/techniques available for the control and management of affected weirs due to flood events. The technique applicable for this above-discussed scenario is rehabilitation with a steel-reinforced concrete weir and piped outlet works. The weir would have to be re-designed with new dimensions (*i.e.,* height, length, and width) to ensure the ability to withstand future flooding events. The new pipeline would be constructed such that it would feed water from the weir.

Other examples of available methods/techniques include:

- Modification of the structure (weir) to increase the spillway capacity to allow passage of floodwater to satisfy dam safety;
- Spillways are intended to safely pass the floodwaters without allowing the dam to overtop and without damaging downstream properties through flooding or erosion. An example is the principal spillway which represents the main outlet of the reservoir. It can take several forms and can either be a single-phase or a multi-phase structure. The main functions of the principal spillway are as follows:
  - To safely pass the design storm flows;
  - To maintain the desired water level within the reservoir.
- Installation of deflectors at appropriate angles in the channel to regulate the velocity of the water during flood events;
- Installation of permanent riprap fill for stabilisations of the walls downstream of the weir.
- Addition of cobbles downstream of the weir;
- Installing a safety and debris boom upstream as part of the weir;
- Structural Grouting - stabilisation of the foundation of the weir with grout;
- Grinding and refinishing weir surfaces with erosion-resistant coating;
- Energy Dissipation Basin - replace the eroded energy dissipation basin with a new multi-purpose design to dissipate flow energy, support fish passage, and reduce operations and maintenance.

Figure 11 below presents a summary of the rehabilitation methods/techniques discussed in **Phase 4** above.

[2] *Depending on size of dam or weir, the rehabilitation of the cavitation the outlet pipe may need to be undertaken in accordance with the DWS Dam Safety Regulations*

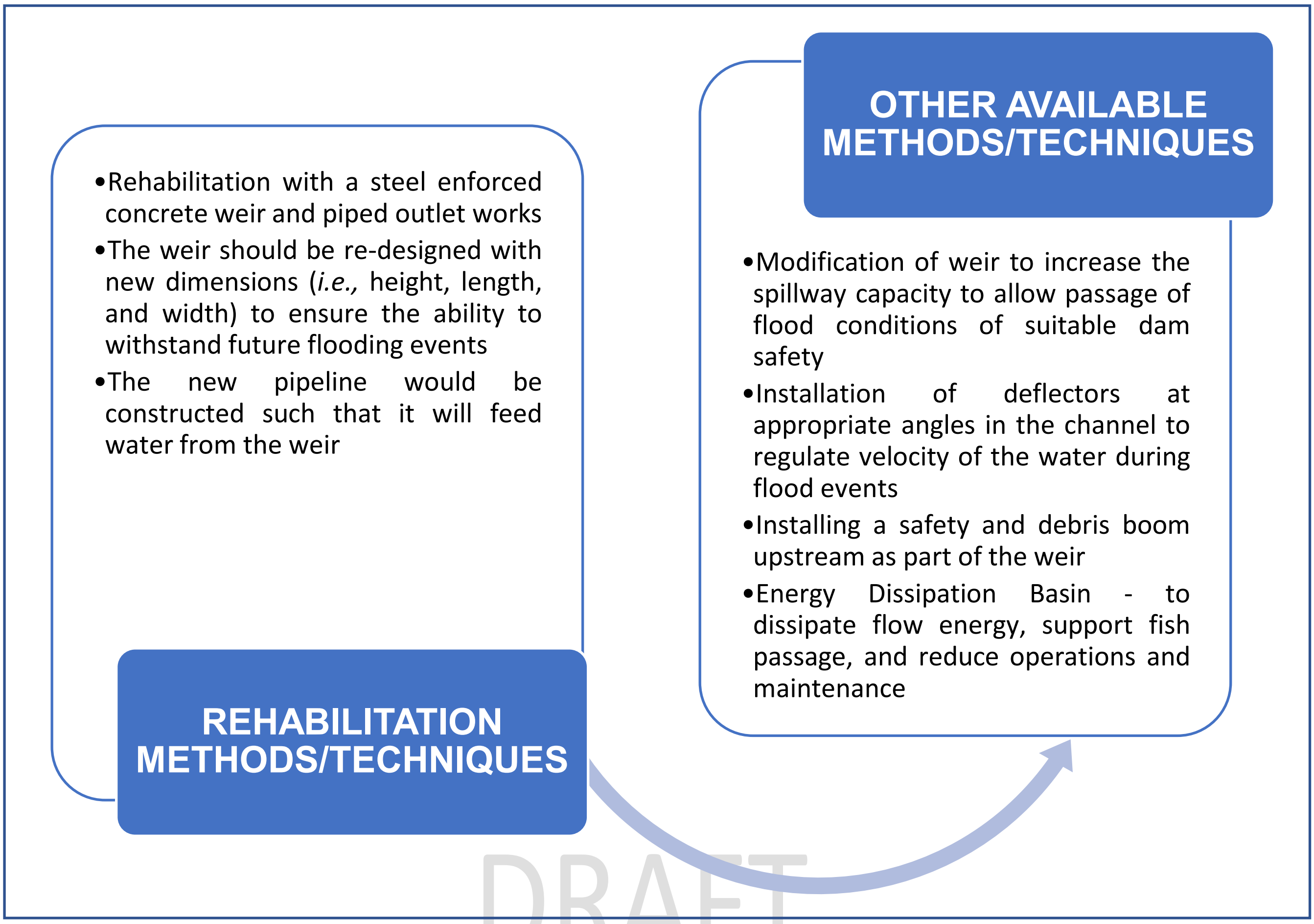

Figure 11: Rehabilitation methods/techniques available for control and management of affected weir due to floods events.

Note:

- *Structures such as dams, weirs and fishways were historically built without considering the migratory species functions.*
- *It has become a worldwide phenomenon to demolish structures that form barriers for the improvement of environmental ecology, flow of water, sustainability, and landscape.*
- *The removal of non-functioning structures acting as barriers to the flow of water, should be considered to form part and parcel of the available rehabilitation interventions based on the site-specific conditions.*
- *The **demolition of weirs** should be only considered in cases where there **are environmental problems experienced**. In addition, historic dams and weirs do not cater for fishways and ecological flow releases; therefore, where there are impacts that **cannot** be **mitigated,** then one should consider the demolition of such structures.*

PHASE 5: Monitoring, Evaluation and Reporting

<u>**Monitoring and Maintenance**</u>

<u>Monitoring</u>

- Weirs require regular maintenance and monitoring to remain in good working condition and to ensure these structures work in harmony with the environment;

- The rehabilitated weir must be monitored quarterly, before the rainy season and directly after a heavy rainfall event to ensure the crest of the weir is in good condition and free of obstructions. Furthermore, ensure that the weir remains in a safe working condition through continuous monitoring during the implementation phase *i.e.,* avoid slumping, cracking, or obvious changes to the crest of the wall;
- Determine maintenance objectives.

Maintenance

- Maintenance activities include clearing debris from the crest, removing silt, from upstream of the weir, providing safety booms, and carrying out repairs to the structure are also critical;
- Future maintenance of the river reaches upstream and downstream of the weir should also be considered in the implementation phase;
- Activities such as clearing vegetation, cutting back overhanging trees, removal of silt and repairs to erosion protection may form part of the channel maintenance regime in the vicinity of the weir.

Note: *Weirs that incorporate a fish pass, regulating gates, and/or flow/level monitoring equipment are likely to require more maintenance than a standard weir structure. The specific requirements of any particular installation must be considered in the design process, and the design tailored to facilitate safe maintenance activities.*

Evaluation

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

Reporting

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

- A map of disturbed and rehabilitated areas. The below are the types of maps that can be produced:
  - An electronic georeferenced image of the rehabilitation with clearly marked areas of intervention; and
  - A polygon and point shapefile detailing all intervention types and extents done. It should be noted that this option has proven to yield the best results.
    Note: *Intervention extents should be quantifiable for reporting extent per area or ecosystem types, at a national and global scale.*
- Before and after photos of rehabilitation including a significant landmark for comparison purposes, with a brief description including location, and date.

5.2. GEOMORPHOLOGY

5.2.1. Description

Geomorphology is a science focused on understanding Earth's surface processes and landscape (such as river channels, estuaries, wetlands, mountains, and valleys) 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).

5.2.2. Types of Impacts

5.2.2.1. Human-induced sedimentation

Agriculture is a major source of increased erosion. Most cultivated agricultural soil remains with insufficiently developed vegetation for long periods. Intensive agricultural practices *(i.e.,* overgrazing) with loss of soil cover, erosion by cultivation of steep slopes, and fertiliser application dominate the physiography of the catchment, increasing erosion and leaching processes that affect dams. The sources of erosion include road construction, and any other building activities, which leave the soil barren for prolonged periods (Straškraba and Tundisi, 1999).

5.2.2.2. Poor Land Use and Management including inappropriate interventions.

Human-induced activities and unsustainable land management practices such as agricultural farming practices and sand mining contribute to erosion, sediment transport, and deposition of sediments throughout the river basin. Another contributing factor to erosion is excessive grazing which causes alteration of the natural vegetation cover, reduces vegetation and habitat complexity. These changes lead to sedimentation on the receiving waterways predominantly evident in rural areas. Indirect effects of grazing include trampling and creation of localised erosion gullies, while severely trampled riparian areas may be more vulnerable to erosion. Other activities and practices include urban development, road construction, construction the of dams that block the transport of sediment downstream and agricultural activities which impacts flow and sediment loads reaching dams (Kondolf, 2014).

5.2.2.3. Alien Invasive Species (i.e., Vegetation and fish)

Indigenous vegetation and biota species enhance ecosystem functioning and the provisioning of ecosystem goods and services (Rodriguez, 2006). The spread of invasive alien species (plants and fish), however, can limit the functioning of ecosystems (Pejchar and Mooney 2009). In South Africa, aquatic species (*i.e.,* weeds) frequently invade freshwater systems, forming dense monocultures that outcompete and replace indigenous vegetation, thus reducing biodiversity within indigenous species and altering ecosystem functioning (Chamier *et al.,* 2012). Furthermore, invasive alien plants have impacts on interflow and/or stream flow which leads to stream flow reduction. Alien invasive impacts are also notable on the ecological function of aquatic ecosystem including ecosystem habitat and biota.

Note: *Several dams in South Africa are infested by indigenous invasive vegetation species such as Stuckenia, Potamogeton Lagarosiphon and others including reed monocultures which leads to increased water loss, increased sedimentation, and poses a safety risk.*

5.2.2.4. Changes to beds and banks of watercourses; and sediment deprived water downstream of dams.

Large dams have a negative effect on the physical properties of the river such as the bed and banks. The alteration of a river's flow and sediment transport downstream of a dam often causes the greatest sustained environmental impacts. For instance, when a watercourse is devoid of water and there is low flow downstream then its sediment load increases, it tends to recollect it by eroding the downstream riverbed and banks (Kondolf, 2008).

Rivers transport sediment from eroding uplands to depositional areas near sea level. If the continuity of sediment transport is interrupted by dams or removal of sediment from the channel by gravel mining, the flow may become sediment-starved (hungry water) and prone to erode the channel bed and banks, producing channel incision (downcutting), coarsening of bed material, and loss of spawning gravels (as smaller gravels are transported without replacement from upstream) (Kondolf, 1997).

5.2.2.5. Desilting impacts

Dredging and desilting are methods that are used to remove an accumulation of silt material, such as fine gravels or soils that have been washed into rivers from surrounding land in the catchment. These methods tend to damage or destroy fish spawning grounds and make riverbanks unstable. Silt is ultimately deposited into dams and becomes suspended in the water, lowering oxygen levels, and potentially releasing harmful chemicals that may be present. This, in turn, impacts on wildlife, and water quality downstream.

5.2.3. Rehabilitation Management Guidelines for Geomorphology

Scenario 1: Rehabilitation of disturbed vegetation (upstream and downstream of a dam) to promote flood attenuation and soil stabilisation.

***Typical examples** of **expertise** required to undertake rehabilitation for Geomorphology component: Hydrologist, Ecologist, Botanist, Aquatic Scientist / Limnologist, Water Engineer etc.*

PHASE 1: Diagnostic Phase

Step 1: Undertake a desktop study using tools such as Google Earth Pro/Engine, satellite images, GIS, and/or Remote Sensing to identify the areas in the vicinity of the lake/dam in question that has experienced modification of vegetation cover.

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: Using the desktop study results from **Step 1**, undertake an assessment to identify the potential impacts, causes, and effects of disturbed vegetation. Impacts on vegetation may in most cases be attributed to the following:

- Excessive grazing by cattle, goats, sheep, and wild animals;
- Trampling activities;
- AIS infestation;
- Excessive proliferation of indigenous vegetation;
- Dumping activities which result in modification of landscape;
- Sewage leakages and polluted mine water;
- Development activities in close proximity to the dam; and
- Erosion resulting in soil destabilisation.

Step 4: Describe the biome and vegetation types within which the dam is situated *i.e.,* catchment level. This information is critical for making recommendations on the re-vegetation plan inclusive of suitable indigenous vegetation.

PHASE 2: Planning and Assessment

Step 1: Conduct a field/site visit to accurately ascertain area(s) within the dam affected by vegetation modification. The survey results must include the following:

- Identification of areas affected by vegetation modification and degradation;
- The causes and effects of vegetation modification and degradation
- The type(s) of vegetation prevalent on site;
- The extent of the affected areas with the details relating to estimated hectares.

Step 2: The below activities should be undertaken conjunctively with the site visit to supplement

and ensure reliable information about the affected site.
- Collection and collation of data with regards to the site from existing literature by using available tools such as Google Earth Pro/Engine, satellite images, GIS, and/or Remote Sensing;
- Review of historical status (reference conditions);
- Review of vegetation maps;
- Review of threatened ecosystems;
- Review of Conservation Management Plan;
- Review of historical aerial imagery trends to provide clues on the vegetation patterns around the dam and disturbances over time.
  Note: *not all historical aerial images of South Africa are uploaded to Google Earth Pro, but many are available* from the Department *of Agriculture, Land Reform and Rural development (DALRRD), and can be georeferenced.*

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

Step 4: Mapping must be undertaken by comparing geo-referenced field survey data to the visual inspection of available and suitable imagery.

Step 5: Undertake a vegetation sensitivity assessment to identify the following features of ecological importance:
- Ecosystem or threatened vegetation unit;
- Habitat or potential habitat to plant species of conservation concern; and
- Ecologically sensitive features such as SWSAs, NFEPAs and riparian areas.

PHASE 3: Identify and define the Rehabilitation Objectives

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

- Revegetate all disturbed areas with suitable indigenous and local plant species;
- Shape to original or better topography;
- Achieve stabilisation of the disturbed area and minimise erosion;
- Minimise the visual impact of disturbed areas; and
- Ensure that disturbed areas are rehabilitated to a condition similar to that found before ~~to~~ disturbance.

PHASE 4: Execution

Vegetation modification and degradation attributed to erosion and other related activities detailed in **Phase 1, Step 2**, are the main impacts identified in this scenario. **Figure 12** below represents available rehabilitation methods/techniques for disturbed vegetation.

REHABILITATION METHODS/TECHNIQUES

- Brush mattresses are recommended to restore riparian vegetation habitat, biota and enhance conditions for colonisation of indigenous plants
- This method reduces soil erosion and intercepts sediment flowing down the stream
- Once vegetation reaches a certain height, it can improve biota by shading the stream, lowering water temperatures, and offering protection from predators

OTHER AVAILABLE INTERVENTIONS

Revegetation plan/strategy is another option that should be implemented with some of the below considerations:

- Soil preparation prior to revegetation
- Use of indigenous seeds and plants
- Revegetation must be based on the specific conditions of the site
- Seeds must be thoroughly mixed before applying
- The seeds must be applied according to the required rates
- Application rates can be increased in areas that are unfavourable or steep, but no more than double the recommendations

Figure 12: Rehabilitation methods/techniques for disturbed vegetation.

<u>Note</u>: Rehabilitation methods/techniques must be supported by a Plant Species Plan developed by the relevant specialist i.e., an Ecologist or Botanist.

PHASE 5: Monitoring, Evaluation and Reporting

Monitoring of rehabilitated and revegetated areas must be undertaken on an annual basis to ensure that the intervention methods employed are adequate and effective. Additional measures must be implemented in the event the monitoring results show no substantial changes *i.e.,* double the application rates of seeds in areas where there are no signs of vegetation growth.

<u>Evaluation</u>

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

<u>Reporting</u>

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

- A map of disturbed and rehabilitated areas. The below are the types of maps that can be produced:

- An electronic georeferenced image of the rehabilitation with clearly marked areas of intervention; and
- A polygon and point shapefile detailing all intervention types and extents done. It should be noted that this option has proven to yield the best results.
  Note: *Intervention extents should be quantifiable for reporting extent per area or ecosystem types, at a national and global scale.*

- 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. These parameters indicate levels that pose no risk to human bodies and/or impose restrictions or limitations on the use of water, depending on the purpose of the water usage, while also damaging ecological functioning. 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. In South Africa, dams are reportedly impacted by sedimentation, mineralisation/salinisation, eutrophication, and AMD.

Numerous factors such as biochemical oxygen demand (BOD), Chemical Oxygen Demand (COD), plant nutrients (phosphorus and nitrogen), temperature, pH, electrical conductivity, nitrogen, potassium, dissolved oxygen, dissolved solids, turbidity, and colour can be utilised to evaluate water quality for dams and lakes (Bhateria and Jain, 2016).

5.3.1.1. Types of Impacts

5.3.1.2. Discharges from Wastewater Treatment Works, Industries, and Mines

Rapid urbanisation and population growth exert water demand pressure. In addition, poor operation, and lack of maintenance of WWTWs, industries and mines are considered key drivers of water resource quality decline. This is a major concern that affects water quality and increases treatment costs for water users, which has direct implications for the economy including aquatic ecosystem functioning and subsequent goods and services derived from it. Treatment costs and the quality of domestic water are highly correlated with raw water in dams (Mnyango *et. al.,* 2022; Lencha, 2021; Abdel-Fattah *et. al.,* 2020; COGTA, 2008).

5.3.1.3. Poor water quality attributed to ageing infrastructure.

Water quality problems commonly occur during dam ageing, and their respective causes are reported by Straškraba and Tundisi (1999) as follows:

- **Increased concentrations of organic matter** - leached from the soil decomposition of drowned vegetation;
- **High nutrient concentrations leached from disturbed soil** - decomposition of organic matter;
- **Excessive growth of algae and macrophytes** - increased nutrient concentrations from internal and external sources;
- **Low oxygen concentrations** - oxygen is consumed during the decomposition of dissolved and particulate organic matter that enters via the inflow and is released from disturbed soil and decaying vegetation. Autochthonous organic matter increases with increased plant growth; and

- **Increased colour** - indicates the concentration of resistant organic matter. Colour changes occur very slowly.

5.3.1.4. Eutrophication

Eutrophication is defined as nutrient enrichment of waters, which results in the stimulation of an array of symptomatic changes, amongst which increased production of algae and aquatic macrophytes, deterioration of water quality, and others found to be undesirable and to interfere with water users (OCED, 1989). The drivers, sources and impacts of eutrophication are as follows:

Drivers

- Wide-spread discharge of raw or inadequately treated municipal sewage. Raw sewage overflows from urban run-off are also a source of pollution. Diffuse runoff and drainage from fertilised cultivated land.

Root causes

- **Natural causes** - nutrient leaching from local geology and soils and vegetation; and
- **Unnatural causes** - atmospheric emissions of ammonia (NH_3) and nitrogen dioxide (NO_2) resulting in increased loads of NH_3 and NO_2 in precipitation; increased nutrient loads in discharges from WWTWs (both phosphorus and nitrogen species); increased nutrient loads in agriculture, alien vegetation, and urban runoff; excessive nutrient loads in industrial wastewater.

Impacts

- **Ecological impacts** - disturbance to biodiversity;
- **Human and aesthetic impacts** - odour and taste problems, morbidity, and mortality due to potential toxic cyanobacteria biotoxins;
- **Recreational impacts** - decreased recreational use, and decreased access to water ways;
- **Socio-economic impacts** - increased stock losses, corrective action costs, and loss of property value; and
- **Agriculture** - algae can block irrigation systems. Macroscopic and fragments of algae block irrigation canal systems causing water loss and damage to infrastructure. (Du Plessis and Davidson, 1990).
- **Algae growth in canals** - canals are man-made, concrete-lined channels **(see Figure 13)** of water that direct water to dams. Some dams are “off-channel dams”, which means they are not situated in the path of a river and water must be diverted from several nearby rivers through a network of canals to fill the dams. Many canals are plagued by aquatic weeds, such as filamentous algae and aquatic macrophytes. Aquatic weeds cause a host of operational problems in water canals, such as reducing hydraulic capacity and flow speed in affected canals – some to such a degree that the supplied water cannot reach the terminal point of the canal system. Aquatic weeds can replace significant volumes of the capacity of a canal which results in overflows that may contribute to losses out of the system, as well as crop losses due to under-supply of water to irrigators.

5.3.1.5. Salinisation

Salinisation is the build-up of salts in a river system to such a level that it poses a threat to the ecological integrity of a dam or lake and interferes with the desirable uses of the water. The drivers, sources, and impacts of salinisation are as follows:

Drivers

- Diffuse drainage and wash-off of rainfall-mobilised natural *in-situ* salts and soils;
- Diffuse source sub-surface irrigation return flows; and
- Mine water drainage and atmospheric deposits.

Root causes

- Poor farming practices, such as inappropriate dry-land tillage;
- Inappropriate dry-land crops;
- Over-irrigation;
- Inappropriate irrigation technology;
- Lack of intercepting drainage and related evaporation pond infrastructure; and
- Inappropriate irrigation water conveyance practices.

Impacts

- Salinisation changes the chemical composition of freshwater resources such as lakes and dams degrading the quality of water supply to the domestic and agricultural sectors, contributing to loss of biodiversity, taxonomic replacement by halotolerant species (Vengosh, 2003), and creating severe health problems.

5.3.1.6. Acidification

The process whereby water and soil become acidic is characterised by an increase in acidity (low pH), increased metal concentrations, increased sulphate concentrations, and/or increased suspended solids. The drivers, sources, and impacts of acidification are as follows:

Drivers

- Mining source;
- Industrial sources and emissions;
- Contaminated seepage, leaching, runoff, and spills; and
- Wash-off and leaching of widespread acidic atmospheric deposits.

Root causes

- Lakes become acidic when the input of hydrogen ions exceeds the amount of bases produced in the catchment, by the weathering of rocks, or in the lake itself, through the reduction of acid anions, such as sulphate and nitrate;
- Metal contamination and related issues;
- Acidic atmospheric deposits; and
- Historical and recent lack of precautionary planning, regulation, and enforcement by the relevant authorities, and ring-fenced rehabilitation financing for the necessary rehabilitation by the relevant mining companies.

Impacts

- Changes in the structure and functioning of ecosystems;
- Increased pollution from sulfate and nitric acids;
- Damage to forests; and
- Chemical, physical, and biological changes lead to the extinction of aquatic organisms.

5.3.1.7. *Temperature changes*

The construction of dams can change the water temperature in a basin. Changes in water temperature may negatively impact the river ecosystems, and as the number of dams increases, this negative impact may accumulate. Abnormal temperature fluctuations affect sensitive species (*i.e.,* Cape *Galaxias zebratus*, Breede River redfin *Pseudobarbus burchelli*, Berg River redfin *Pseudobarbus burgi*, Clanwilliam redfin *Pseudobarbus calidus* and fiery redfin *Pseudobarbus phlegethon*) and can lead to algal blooms and decreased oxygen levels.

5.3.2. Rehabilitation Management Guidelines for Water Quality

Scenario 1: Improvement of degraded water quality in the instream dam due to eutrophication caused by effluent discharged from Wastewater Treatment Works (WWTWs) and Industries

***Typical examples** of **expertise** required to undertake rehabilitation for Water Quality component**:** Hydrologist, Aquatic Scientist / Limnologist, Water Engineer etc.*

PHASE 1: Diagnostic Phase

Step 1: Carry-out a feasibility study first to diagnose problems (*i.e.,* eutrophication in the lake or dam) and causes (effluent discharge from WWTWs and industries) per specific resource. Understanding the characteristics of lakes and dams (resources) is a critical step to take before choosing and applying an appropriate rehabilitation approach.

Step 2: Undertake a desktop assessment to identify the WWTWs and industries (sources) negatively impacting the water quality of the lake or dam. Focus on facilities situated in 1: 100-year floodline of a lake or Dam, and check if there are any other point sources in the vicinity.

Step 3: 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 4: Utilise tools *i.e.,* Google Earth Pro/Engine, satellite images, GIS, and/or Remote Sensing images to identify changes in land use (land-based) catchment pollution that could be associated with changes in the quality. If possible, check the status of the resource before and after the facility was constructed and compare the changes.

Step 5: Conduct a ground survey to identify visible signs of water quality changes in the resource such as:

- Extremely foul odour;
- Scum formation - scum on the surface of the water will give an indication of organic pollution;
- Dead fish;
- Leached plants (loss of biodiversity); and
- Visible clumps of sewage in the lake or dam and feeding river streams and other wetlands.

Step 6: 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 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

Planning Phase

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

Step 2: Investigate other sources of pollution and water quality *e.g.,* non-point sources of pollution *i.e.,* in the upper and lower reaches of the Dam or Lake.

Assessment Phase

Step 1: Undertake the following:

- Analysis of the historical data (water quality) to see the trend and reference point.
- Collect the actual final effluent water samples from the sources *i.e.,* WWTW and industrial facility.
- Collect monthly water quality samples from the resource *i.e.,* lake and dam:
  - 1 upstream of the WWTW and industrial facility discharge points.
  - 1 downstream of the WWTW and industrial facility discharge points.
- Have samples analysed at an accredited laboratory to determine the water quality at the sources and resource, respectively.

Step 2: Eutrophication variables that should also be analysed in the sample include but are not limited to chlorophyll-a, total phosphorus concentrations, electrical conductivity, total nitrogen, total suspended solids, pH, temperature (*i.e.,* ambient and water temperature), and dissolved oxygen.

Step 3: Compare laboratory-generated water quality data to the expected state for the identification of areas of concern. Data analysis should be compared against the RQOs/ RWQOs, or water quality standards if RQOs/ RWQOs have not yet been established for that catchment.

Step 4: Analysis of available data should determine the trophic status of the lake or dam, the WWTW as well as an overall water quality status (upstream and downstream) in terms of salinity, temperature, dissolved oxygen, suspended solids, turbidity, inorganic nutrients (phosphates, nitrates, silicates, nitrites ammonium, and *faecal coliforms* against the applicable water quality guidelines per different uses.

PHASE 3: Identify and define the Rehabilitation Objectives

The objective(s) of rehabilitation must be informed by the vision and goal, data collected during the assessment phase as well as historical data, if available. This process must include conditions and prioritised actions informed by problems (*i.e.,* eutrophication in the lake or dam) and causes (effluent discharge from WWTWs and other pollution point-sources *i.e.,* industrial facilities) identified in the feasibility study.

Each prioritised action may have its distinct objective which is set based on any of these categories: Ecological, Infrastructure, social, or recreational.

The identified objectives must be checked if they are feasible and affordable, and there must be a reasonable timeframe [(short-term (0-3 years)] or long-term (>5 years) set to allow a lake or dam to respond to the rehabilitation actions.

PHASE 4: Execution

Techniques/methods available for rehabilitation of the resource *i.e.,* lake or dam:

Short-term solutions to minimise impacts on the lakes and dams include **diversion of final effluent** from the problematic **WWTW**. **Diversion** is attained by diverting[3] the polluted water (effluent) away from the feeding stream/river by insulation.

The more common approach in South African conditions is the **construction of artificial wetlands** which can effectively remove pollutants associated with municipal (including domestic), agricultural, mining, and industrial wastewater as well as stormwater.

The WWTW facility and environmental manager, DWS regional office, and DFFE need to collaborate in terms of authorisation processes, and also appoint relevant specialists to undertake the work since rehabilitation is a specialised field.

In terms of nutrient enrichment solutions, the DWS has developed the Eutrophication Management Strategy for South Africa (EMSSA)[4] which guides different strategies to manage eutrophication in the country from Core Strategies (at a National level) to Operational Strategies (at a Localised level) and Supporting Strategies (cross-cutting). DWS further developed the Eutrophication Management Strategy into Practice (EMSIP) report which provides direction on the responsible authorities for each strategic action. This will assist in identifying the relevant authority to approach for further assistance. Both EMSSA and EMSIP are accessible on this website: https://www.dws.gov.za/RDM/SDCCO.aspx

- Other rehabilitation management tools available include:
- *Bio-manipulation* is the deliberate alteration of an ecosystem by adding or removing species, especially predators. Bio-manipulation is well-known as a management tool for eutrophic systems. Chlorophyll-a and plant nutrients concentrations should be analysed and serve as an indicator of eutrophic status. An example is hyacinth harvesting – removal of hyacinth to be used to produce compost and fertiliser that can improve soil and nourish plants.

Techniques/methods available for rehabilitation of the source *i.e.,* WWTW:

- Use of baczyme[5] and other similar biological reagents;
- Use of effective Microorganisms (EM) technology. These microbes (EM) consume the organic mass of the wastewater and utilize the nutrients from sewerage for their growth, thereby enhancing the water quality;
- Contain and temporarily store the effluent discharged at the source for possible treatment before to discharge;
- Implement surface water management measures around the problematic WWTW. This can be achieved through (but not limited) to installation cut off trenches around the WWTW to divert surface runoff to drain back into the natural drainage lines and the natural environment; and
- Construct temporary berms along the dam/lake/river to prevent further offsite migration/discharge of effluent ending into the dam/lake/river.

[3] *The polluted water could be diverted, contained, and temporarily be stored in a holding treatment dam for possible treatment before re-use or discharge.*

[4] *DWS. 2022. Eutrophication Management Strategy for South Africa. Edition 2, Project Report Number 4.2, Sources Directed Studies Report Number RDM/EMP&S/00/IHS/SDS/0520. Pretoria, South Africa [Internet]. Pretoria. Available from: https://www.dws.gov.za/RDM/SDCCO.aspx*

[5] *Baczyme is a biological solution for sewage waste, septic tanks, and pit toilets. The product contains organic bacteria that decomposes sewage waste into two main components, water, and carbon-dioxide.*

Note:

In general, the approach of DWS to water quality management is to promote the reduction of discharges of waste or water containing waste 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 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 from 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, with the relevant emergency services and disaster management centres. Ultimately this responsibility will be passed to the catchment management agencies.

PHASE 5: Monitoring, Evaluation and Reporting

Monitoring

Continuous monitoring of WWTW effluent and changes in the lake or dam (*i.e.,* habitat, odour, and colour) to help determine the water quality and the extent to which treatment is necessary. Monitoring should take place inside the dam close to the wall as well as upstream and downstream of the dam as part of catchment monitoring activities.

In addition, remote sensing can be used to monitor changes on the surface of the lake or dam, which might also be used as an early warning tool and to check if there are other possible polluters in the vicinity other than a WWTW.

Note: *A suitably qualified specialist i.e., Limnologist, should establish the variables needed be monitored.*

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. The below are the types of maps that can be produced:
  - An electronic georeferenced image of the rehabilitation with clearly marked areas of intervention; and
  - A polygon and point shapefile detailing all intervention types and extents done. It should be noted that this option has proven to yield the best results.
    Note: *Intervention extents should be quantifiable for reporting extent per area or ecosystem types, at a national and global scale.*
- Before and after photos of rehabilitation including a significant landmark for comparison purposes, with a brief description including location, and date.

- Water quality results and data (*in-situ* and laboratory analysis) evaluating/comparing historical data with new data.

5.4. HABITAT

5.4.1. Description

Habitat encompasses all the physical, chemical, and biological characteristics that impact or sustain the organisms in an ecosystem. Physical habitat excludes the physiochemical characteristics of the stream water, 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. As an example, the largest natural freshwater lake in South Africa (*i.e.,* Lake Sibaya), separated from the ocean by forested dunes; includes areas of swamp forest and wet grassland. A large variety of endangered or endemic species of reptiles, fish, birds, mammals, and plants occur. The lake is important for numerous species of breeding birds and supports the second largest population of hippopotamus. The lake supports a diverse zooplankton fauna, 15 species of aquatic and 43 species of terrestrial molluscs, as well as flora and other fauna unique to South Africa (DWS, 2015).

5.4.2. Types of Habitat Impact

5.4.2.1. Sediment Trapping by dams.

In a natural river basin, sediment is transported through river basins from rapid erosion caused by human activities at headwaters downstream to the river. Dams disrupt the natural continuity of sediment transport through a river basin because they trap sand that moves along the channel bed. Dam sediment trapping can have severe consequences for the downstream river. As dams trap and begin to accumulate sediment, the trapped sediment begins to interfere with the ecological functioning of the system (Blum and Roberts 2009). The trapped sediment can begin to interfere with the functioning of the dam, long before the water storage capacity itself is seriously compromised (Randle *et al.,* 2021). Other consequences of sedimentation in dams are reported as follows:

- **Storage capacity loss** - the most direct consequence of sedimentation in dams is the corresponding decrease in capacity. Sediment deposition in the dams reduces and eventually eliminates usable storage capacity, rendering the dam unusable for water supply or flood control. In addition, sedimentation leads to encroachment of dam basins by reeds. This has a snowball effect on the system *i.e.,* the more sediment, the more reeds, and the more sediment as the reed beds lower flow velocity with associated increase in sedimentation.
- **Intakes and outlets** - Sediments can block or clog intakes and low-level outlets at dams, and clog or otherwise damage gates not designed for sediment passage.
- **Ecology** - accumulation of sediment in dams affects the ecosystem structure and function. The below are examples of how ecosystem functioning could potentially be affected:
    - Excessive sediments can bury and suffocate fish eggs and bury the gravel nests they rest in;
    - Suspended sediment in high concentrations can shift plants, invertebrates, and insects in the stream bed;
    - Suspended sediment can affect the food web adversely in the dam - low light penetration can reduce algae biomass as primary producer and can interfere with predator and prey interaction.
    - Food source *i.e.,* fish can be affected; and

- Substrate is generated for submersed aquatic vegetation (SAV) to proliferate. This can lead to a problematic infestation of SAV resulting in further impact on the operation of a dam.

In addition to the above, changes in sediment loading and sediment accumulation can dramatically alter reservoir ecology, affecting species composition and both recreational and subsistence fishing.

- **Energy loss** - Loss of storage eliminates the potential to capture high flows for subsequent energy generation and flood attenuation.
- **Navigation** - Both commercial and recreational navigation can be severely impaired by sediment accumulation. Recreational access can be impaired as sediment accumulates at marinas and boat ramps and provide substrate for nuisance vegetation growth.

5.4.2.2. Habitat modification, degradation, and loss

In addition, the key pressures on South Africa's freshwater lakes are reported to be changes to the hydrological regime, water pollution, **habitat modification,** invasive species, and climate change. The key drivers of habitat loss are land clearing for croplands, human settlements, plantation forestry, mining, and infrastructure development. These activities have led to the loss of 21% of South Africa's natural terrestrial ecosystem extent. Habitat loss is also usually associated with habitat fragmentation, which further impacts ecological functioning and viability of species, particularly in the context of climate change and biological invasions (SANBI, 2019).

5.4.3. Rehabilitation Management Guidelines for Habitat

***Scenario 1:* Rehabilitation and management of sedimentation for ecological function of the-aquatic ecosystem and improvement of dam storage capacity**

Note: *Instream dam construction on rivers intercepts sediments and causes reduced sediment supply/discharge into rivers and the sea i.e., estuaries. In addition, because of dams, the sediment supply to rivers and/or estuary and its adjacent coast is reduced.*

The above aspects are interrelated and therefore a systems approach is followed in the development of the scenario for management of sedimentation in dams, rivers, and/or estuaries. All these aspects are taken into account during a rehabilitation project and should not be considered in isolation.

Estuary and watercourse are separately defined in the NWA. These definitions imply that estuaries are not seen as watercourses. Therefore Section 21 (c) and (i) activities will not be regulated in estuaries unless there is a freshwater link i.e, estuaries with salt marshes form part of the tidal zone, but there may be a strong freshwater inflow on the other side. Therefore, any activity from the 500 m of the freshwater zone would trigger Section 21 (c) and (i) activities.

***Typical examples** of **expertise** required to undertake rehabilitation for Habitat component**:** Ecologist, Botanist, Hydrologist, Aquatic Scientist / Limnologist, Water Engineer etc.*

PHASE 1: Diagnostic Phase

Step 1: Identify the dam in question within the river channel that is affected by sedimentation.
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: At a desktop level, Utilise tools *i.e.,* Google Earth Pro/Engine, satellite images, GIS, and/or Remote Sensing images to gain insight and evaluation of the sediment deposition patterns in a reservoir.

Step 4: Using the tools mentioned in **Step 2,** identify the possible source(s) of sedimentation by examining the following three main aspects:

- Characteristics of the source (*i.e.,* the catchment);
- Characteristics of the sediment transfer into the dam (*i.e.,* the transportation mode);
- Characteristics of the dam.

Step 5: Describe the specific details of the dam affected in terms of the below-given characteristics. This information is important to guide the recommendation of the types of interventions that must be considered through a site-specific approach.

- Land use in the catchment;
- Sediment loads, siltation rates, and sediment retention time;
- Economic, ecological, and cultural importance;
- Current storage volume vs sediment load; and
- Flood peaks and volumes.

PHASE 2: Planning and Assessment

Step 1: Undertake a site inspection to collate pertinent information and data regarding the dam in question. The information and data to be collected may include but are not limited to the following:

- Catchment hydrology inclusive of mean annual runoff (MAR), mean annual precipitation (MAP), and catchment yield;
- Land use to determine the type of management practices *i.e.,* communal land will differ from the types of management practices on commercial agriculture land;
- Sediment characteristics (such as particle size grading, hazardous nature);
- Sediment management design features (sediment flush gates, bypass channels, sediment traps) and the functionality of these, if there are any in place and
- Erosion risk.

Step 2: Determine the type of dam in question (*i.e.,* small, or big)[6]. The dam type will dictate the techniques to be employed for rehabilitation. Less significant dams on small catchments could be assessed using simpler tools, however large dams with high economic importance should be examined in much greater detail with more exact estimates of sediment impacts.

Step 3: Determine the main source(s) of sedimentation *i.e.,* erosion, land use impacts, climate change, alien vegetation, and environmental degradation.

Step 4: Based on comprehensive information and data acquired in **Step 1-3** above, determine the main source(s) of sedimentation (*i.e.,* erosion) and recommend the most feasible intervention. Below are examples of some broad categories of available sedimentation management strategies:

- Reduce sediment yield from the catchment;
- Route sediments around or through the storage pool to minimise depositions; and
- Remove deposited sediment.

[6] *Small dam – wall height lower than 12m; Big dam – wall height more than 30m*

PHASE 3: Identify and define the Rehabilitation Objectives

The objectives of the rehabilitation of dams must be clearly defined and set. The objectives for rehabilitation must be informed by the data collated in **Phase 1** and **2** above. Some of the most common aims and objectives of rehabilitation of sedimentation of dams are to:

- Reduce sediment yield to dams by erosion control in the upstream river basin;
- Provide a passageway *i.e.,* a fishway for migratory fish;
- Restore sediment continuity, move sediment around or through the dam via sediment bypass, sluicing, and flushing;
- Install an upstream sediment trap which can be periodically cleaned, if applicable; and
- Operate dam and associated structures such as weirs, canals etc. to natural flow and temperature regimes. **Figure 13 A** and **B** below illustrates a typical examples of different canal structures.

Note:

- ***Figure 13 A*** *- Station ID: N2H010; Place: Left Canal from Dam located within the Mzimvubu-Tsitsikamma WMA 7.*
- ***Figure 13 B –*** *Station ID: X1H034; Place**:** Left Canal from Vygeboom Dam, located within the Inkomati-Usuthu WMA 3.*

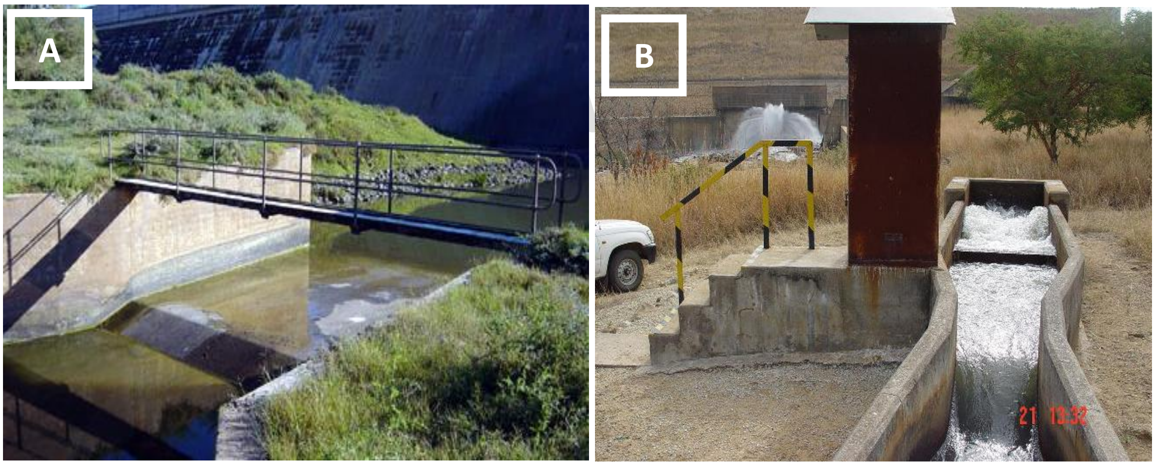

Figure 13: Examples of a canal structures.
Source: DWS Hydrological Services website, 2024

PHASE 4: Execution

Rehabilitation methods/techniques available for control and management of sedimentation are divided into three broad main categories of strategies[7], namely reduce sediment yield from the catchment; route sediments around; and remove deposited sediment. A combination of these approaches may be implemented.

<u>**Reduce sediment yield**</u>

- Sediment delivery to a reservoir can be reduced by techniques such as soil conservation measures (erosion control, reforestation, or revegetation), and upstream sediment trapping.

[7] *Water Research Commission (WRC). 2006. Reservoirs and their management: a review of the literature since 1990*

Route sediments

- *Seasonal drawdown* - the reservoir is partially or completely emptied during the flood season at a predetermined time each year. This serves to increase flow velocity with a corresponding decrease in retention time and sediment trapping;
- *Sluicing* - this is an operational technique aimed at reducing the trap efficiency of the reservoir by releasing most of the sediment load with the flow through the dam before the sediment particles settle. This is usually accomplished by operating the reservoir at a lower level during the flood season to maintain sufficient sediment transport capacity through the reservoir;
- *Sediment by-pass* - when topographic conditions are favourable, a large capacity channel or tunnel can be constructed to bypass sediment-laden flow around an instream storage reservoir. Nagle Dam in South Africa uses this method;
- *Offstream reservoir* - since inflow can be controlled at the diversion point, an off-stream reservoir can be prevented from receiving sediment-laden water in various ways. An advantage is that downstream transport of bed material can be maintained;
- *Venting of turbid density currents* - turbidity currents can be vented from reservoirs by opening a low-level outlet at the dam. In some reservoirs, it has been possible to release more than half the total sediment load in an individual flood by venting the turbidity current. Successful venting depends on properly located low-level outlets that are opened in time to release the current, using a discharge rate that matches the turbidity current flow.

Removal of sediments

- *Hydraulic flushing - f*low velocities in a reservoir are increased to such an extent that deposited sediments are remobilised and transported through bottom outlets. Unlike sediment routing which attempts to prevent deposition during flood events, flushing uses drawdown and emptying to scour and release sediment after it has been deposited;
- *Hydraulic dredging and dry excavation* - uses a mechanical pump to supply the energy to remove deposited sediment. To retain capacity, dredging must continue for as long as the reservoir is to remain in service. A suitable disposal site for sediment is required;
- *Hydrosuction sediment removal systems (HSRS)* - this system holds promise as a method of removing deposited or incoming sediments from reservoirs using the energy represented by the difference between water levels upstream and downstream from the dam. There are two types of hydrosuction sediment removal:
  - Hydrosuction dredging in which deposited sediment is dredged and transported to either a downstream receiving stream or to a holding treatment basin;
  - Hydrosuction bypassing in which incoming sediment is transported without deposition, past the dam to the downstream receiving stream.
- *Construct a sediment trap – Sediment traps can be constructed to limit the sediment load to a waterbody. The design must accommodate easy cleaning.*

There are other available adaptive management strategies such as redistributing sediment; increasing storage, increasing efficiency, modifying infrastructure, adjusting to reduce benefits, and repurposing or decommissioning.

PHASE 5: Monitoring, Evaluation and Reporting

Monitoring should entail:

- Monitoring of rehabilitated dams must be undertaken on an annual basis to ensure that intervention-methods employed are adequate and effective;
- Water quality monitoring downstream of the dams due to disturbed sediments. Monitoring parameters and frequency are as follows:
  - Suspended sediment concentration – Monthly

  - Sediment Quality – Annually
  - Riparian Vegetation/Habitat – Annually
- Additional measures must be implemented in the event the monitoring results show no substantial changes *i.e.,* if erosion persists after revegetation, other erosion control measures must be considered.

Evaluation

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

Note: *Monitoring and evaluation should be conducted by a suitably qualified specialist i.e., Aquatic Scientist / Limnologist.*

Reporting

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

- A map of disturbed and rehabilitated areas. The below are the types of maps that can be produced:
  - An electronic georeferenced image of the rehabilitation with clearly marked areas of intervention; and
  - A polygon and point shapefile detailing all intervention types and extents done. It should be noted that this option has proven to yield the best results.
    Note: *Intervention extents should be quantifiable for reporting extent per area or ecosystem types, at a national and global scale.*
- 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:

- Plant species plans must be drawn up by the relevant specialist *i.e.,* Ecologist, Botanist, and Aquatic Scientist / Limnologist for approval and implementation; and
- Constructed wetlands and nature-based solutions should be included as part of rehabilitation measures.

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 Impacts

5.5.2.1. Impediment impacts on migratory biota species.

One key ecological impact of dams is blocking the passage-way for migratory fish. While dams block fish migration in rivers globally *e.g.,* the Clanwilliam sandfish - *Labeo Seeberi* that seek to swim upstream from the sea where they spend their adult life to their natal freshwater streams to spawn but are blocked by dams (Lucas *et al.,* 2008). However, many fish species in other river systems also depend on migration, often long-distance, to reach spawning grounds, and when they cannot reach their spawning areas, the fish runs can become extinct. Likewise, populations of catadromous fish, notably eels, which reproduce in the ocean, but spend their adult lives in freshwater until they redescend seaward to spawn, have been impacted by dams that interfere with their longitudinal movements.

5.5.2.2. Impacts of alien species (animal and plant species)

The construction of dams, reservoirs, and the accompanying hydrological manipulation has been instrumental in increasing the susceptibility of river systems in South Africa to invasions by introduced fish (De Moor 1996; Gehrke and Harris, 2001), as well as range extensions to native species *e.g.,* the movement of *Clarias* from the Orange River to the Fish River.

5.5.2.3. Loss of ecological connectivity for other biota like fish, hippo, crocodile, crustaceans

Dams and weirs have effects on physical habitat and biota immediately above the dam; and connectivity, habitat, and biota below the dam. Weirs have a negative impact on the ecology of a stream when they prevent the migration of biota up and down the river (WRC, 2016). This can be mitigated by including a "fish ladder," a channel carrying the low flow with a lot of baffle plates to slow down the velocity of the water so that biota can still migrate over the weir. **Figure 14** illustrates an example of a fish ladder (Station ID: C2H061; Place: Vaal at Klipplaatdrift) located within the Middle Vaal WMA. **Figure 15** is the Google Earth image produced using the coordinates of Station ID: C2H061 to illustrate an aerial view of the fish ladder.

Note: *A fish ladder can, however, also increase the vulnerability of migrating fish as they are more exposed to piscivores.*

Figure 14: A typical example of a fish ladder
Source: DWS Hydrological Services website, 2024

Figure 15: Google Earth image depicting fish ladder.

5.5.3. Rehabilitation Management Guidelines for Biota

Scenario 1: ***Re-establish biota migratory routes*** *(i.e., fishways)*

Typical examples *of* ***expertise*** *required to undertake rehabilitation for Biota component****:*** *Hydrologist, Aquatic Scientist / Limnologist, Ichthyologist, Water Engineer etc.*

PHASE 1: Diagnostic Phase

Step 1: At a desktop level**,** determine and identify the instream dam in which the migratory are affected.
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: Describe the specific catchment details of the river affected within which the instream dam is located – Primary or Secondary catchment.
Step 4: Describe the specific reach of the river affected within which the instream dam is located – Upper, Middle, and Lower reaches.
Step 5: Identify the relevant fish species occurring in the system from historical data and *in-situ* monitoring.

PHASE 2: Planning and Assessment

Step 1: Assess the ecological need for a fishway at an instream barrier.
Step 2: If the assessment result proves that there is no need for a fishway consider the following alternatives and mitigation measures:
- Artificial spawning beds;
- Captive breeding; and
- Capture and transport.

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.

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 **Phase 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.,* Engineer and/or Aquatic Specialist (Ichthyologist) must design a fishway.
Step 2: The fishway to be designed will depend on the site conditions. Based on the conditions, the the relevant specialist *i.e.,* the Engineer and/or Aquatic Specialist must design the fishway general hydraulics[8]
Step 3: The fishway designs must be informed by the following key factors:
- Species composition;
- Types of migration;
- Season/time period species are functional;
- Swimming ability of species;

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

- Swimming speed of species ("burst speed");
- 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 undertaken by various suitably qualified specialists;
- 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.

Step 6: The fishway must be constructed according to the approved 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

Table 6 contains the key biological/ecological and physical parameters prescribed by WRC [9] which must be monitored downstream, upstream, and in the dam/lake.

Table 4: 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. • Diatoms *(i.e.,* bioindicators for the assessment of water quality)	• 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 6** is by no means exhaustive and is relevant for 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, 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

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

measures/tools for protection of water resources. The monitoring parameters developed by the users should also form part of 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 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:

Biological Response Indices:

- *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*

Driver 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 water quality*

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. The below are the types of maps that can be produced:
  - An electronic georeferenced image of the rehabilitation with clearly marked areas of intervention; and
  - A polygon and point shapefile detailing all intervention types and extents done. It should be noted that this option has proven to yield the best results.
    ***Note:** Intervention extents should be quantifiable for reporting extent per area or ecosystem types, at a national and global scale.*
- 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 the Rehabilitation of Biota

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

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

6. RECOMMENDATIONS AND WAY FORWARD

The lakes and dams RMGs have been developed to address characteristics of watercourses, namely hydrology, geomorphology, water quality, habitat, and biota through a phased approach. In implementing these guidelines, below is a summary of recommendations to users:

- Plant species plans must be compiled by the relevant specialist within the field *i.e.,* Ecologist, Botanist, and Aquatic Scientist / Limnologist.
- **Alien vegetation** must be replaced with the appropriate indigenous vegetation. 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 approach both for eradication and revegetation. Revegetation and re-planting plans must be compiled and submitted to the relevant authorities *i.e.,* DWS and DFFE for approval.
- **Invasive indigenous vegetation** should be managed by suitable trained Aquatic Scientist / Limnologist who are registered as professional PCO's (Pest Control Operators) with the Department of Agriculture (Registrar: Act No: 36 of 1947).
- **Scientific Buffer zones** – when determining these buffers zones the user must consult the Buffer Zone Guidelines (Buffer Zone Guidelines for Rivers, compiled by WRC, 2017) - guidelines to guide activities planned around and adjacent to rivers. 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.
- **Constructed wetlands** must be considered as a rehabilitation option for all characteristics of watercourses and their status must not be affected by the rehabilitation activities undertaken.
- The protection and conservation of wetlands upstream of Lakes and Dams is recommended since wetlands are known to act as natural filters for polluted water.
- The identified objectives must be checked for feasibility and affordability. There must be a reasonable timeframe set to allow the river/dam to respond to the rehabilitation actions. For instance, WRC (2004) adopted 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 the evaluation of the effect of the work.
- Ensure that carrying capacity and livestock grazing programme are determined and implemented.
- Implement nature-friendly fencing and optimise the positioning of fencing for better connectivity up and downstream of dams.
- Fishway designs must be made as natural as possible to ensure no access for people or predators to predate and poach. Monitoring of fishways is recommended and old fishways must be upgraded to natural systems.
- Rehabilitation funding models should be developed and be linked to existing policy statements.
- Consideration must be given to translating the guidelines to be developed into Policy.
- Consideration must be given to adopting international best practices for demolition or destruction of dams and weirs as rehabilitation measures where impacts are too great and not mitigatable.
- The users of the guidelines should consider gathering of historical data and information from the databases to make informed decisions *i.e.,* assess causes related to changes, which led to the required rehabilitation efforts. Once rehabilitation interventions are implemented, the information should be archived in the relevant databases in order to be accessed by users in the future.

- 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 interventions.
- Rehabilitation of waterways should consider including nature-based solutions and green infrastructure as far as possible and should be catchment based rather than site specific.

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